The Tea Research Institute of Sri Lanka

PROCEEDINGS

OF THE

228th EXPERIMENTS AND EXTENSION FORUM

THEME: "ADAPTATION STRATEGIES FOR CLIMATE CHANGE AND CARBON FRIENDLY TEA CULTIVATION"

31ST JANUARY 2014

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The Tea Research Institute of Sri Lanka
Talawakelle

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KEY NOTE ADDRESS

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1. RAIN FALL DISTRIBUTION IN 2013

1.1 Annual Rainfall in 2013

The annual rainfall for the year 2013 showed significant differences when compared with the average rainfall value over the last 10 years. For example, Talawakelle, Kandy and Deniyaya areas have received significantly higher annual rain fall (29%, 33% and 6% respectively) whereas in Ratnapura and Galle area, rainfall has reduced by 4% and 9% respectively (Figure 1).

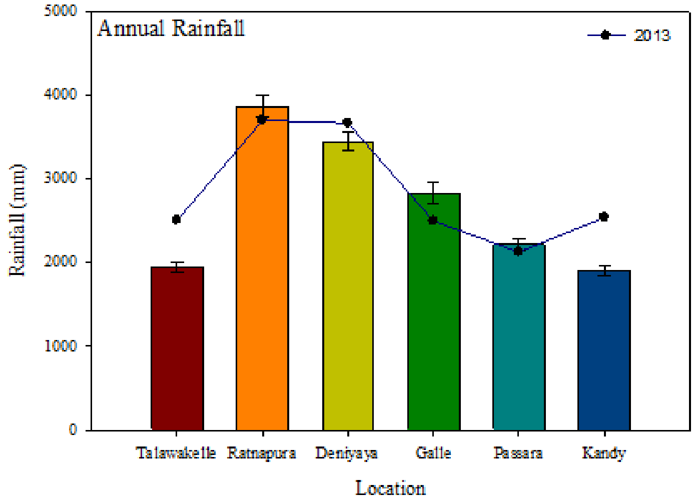

Figure 1 Rain fall distribution in 2013

1.2 Monthly Rainfall Variation

Monthly rainfall variation pattern showed that in January, Kandy, Passra, Galle, Deniyaya and Talawakelle areas had received higher rainfall. However in Ratnapura area January rainfall was reduced by 8%. Significant feature of the monthly rainfall variation was increase in monthly rainfall during May-July period in Talawakelle as shown in Figure 2.

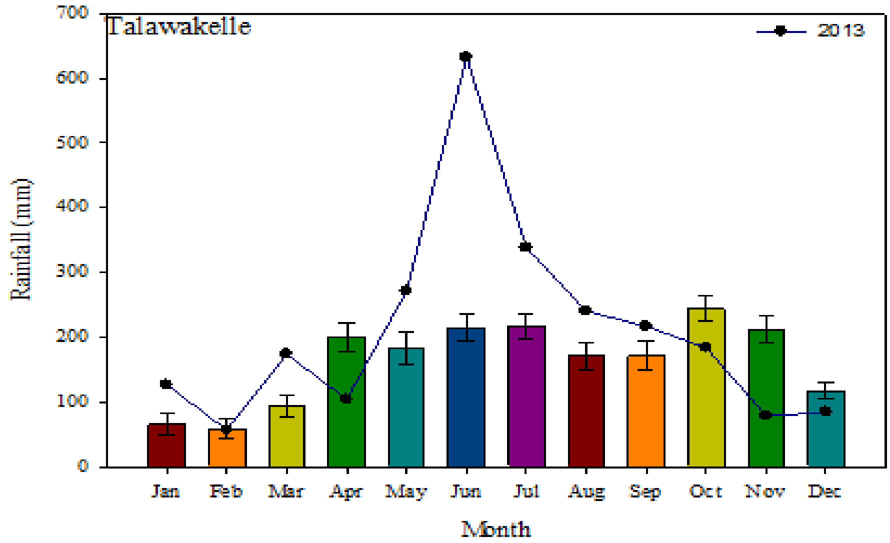

Figure 2 Monthly rainfall variation – Talawakelle

2. CLIMATE CHANGE SCENARIOS IN TEA GROWING COUNTRIES

Tea Research Foundation of Kenya conducted a study using climatic data over the last 50 years and they found increase in temperature, decrease in rainfall (4.82mm/year), large soil water deficit in January –March period, increase in propensity of hail, drought and frost. Based on the study they predicted increase in temperature by 2.5^{0}C, reduction in ground water table and restriction of tea growing areas in Kenya to above 2000-2300 amsl.

Studies conducted by Tea Research Association, Tocklai, India using climatic data over 100 years showed increase in temperature by 2^{0}C , uneven rainfall, flash floods, water logging, soil erosion, yield drop and increase in pest and diseases over the last 100 years.

Results of the studies conducted in China, Japan and Taiwan also supported the observations made by Kenya and India.

3. WORKING GROUP ON CLIMATE CHANGE OF FAO – INTERGOVERNMENTAL GROUP ON TEA

At the inter sessional meeting of the Intergovernmental Group on Tea (2011), The group recommended setting up of a Working Group on Climate Change to study the impact of climate change on tea. India was elected as the chair and Kenya and Sri Lanka were elected as Co-chairs.

Terms of Reference of the working group are given below.

1. To collect and collate all available research data on climate change in member states.

2. To determine the impact of climate change on the tea economy.

3. To identify /suggest mitigation and adaptation strategies.

4. To develop appropriate long term technologies for mitigation/adaptation.

4. R & D WORK ON CLIMATE CHANGE AT TRI

The studies on climate change and its impact on tea cultivation in Sri Lanka were commenced in year 2002 under a project titled "Assessment of the impact and adaptation to Climate Change in the Tea and Coconut Plantations in Sri Lanka" with the collaboration of SLAAS, DOM, CRI & NRMC.

4.1 Findings of the Study

The results of the study revealed that optimum rainfall required for tea varied from 223 - 417mm/month in different tea growing regions and reduction of monthly rainfall by 100mm could reduce productivity by 29-81 kg/ha/month. Optimum yields were recorded at temperatures around 22^{o}C under this study.

A crop model was developed to predict tea yield under future climatic scenarios and the model predicts that tea yields are likely to increase at high elevations (WU) while yields at mid and low elevations are likely to reduce. Most importantly WL, WM & IU regions were identified as the highly vulnerable areas.

4.2 Recommendations/ Adaptation Measures

Based on the findings of the study adaptation measures through crop improvement, soil improvement and improvement of aerial environment (shade) were proposed and these recommendations were communicated to tea growers through seminars/workshops.

Importance of establishment and maintence of shade trees to address adverse climatic patterns were also highlighted following the findings of the disgnostic survey conducted by TRI in 2008 (Figure 3).

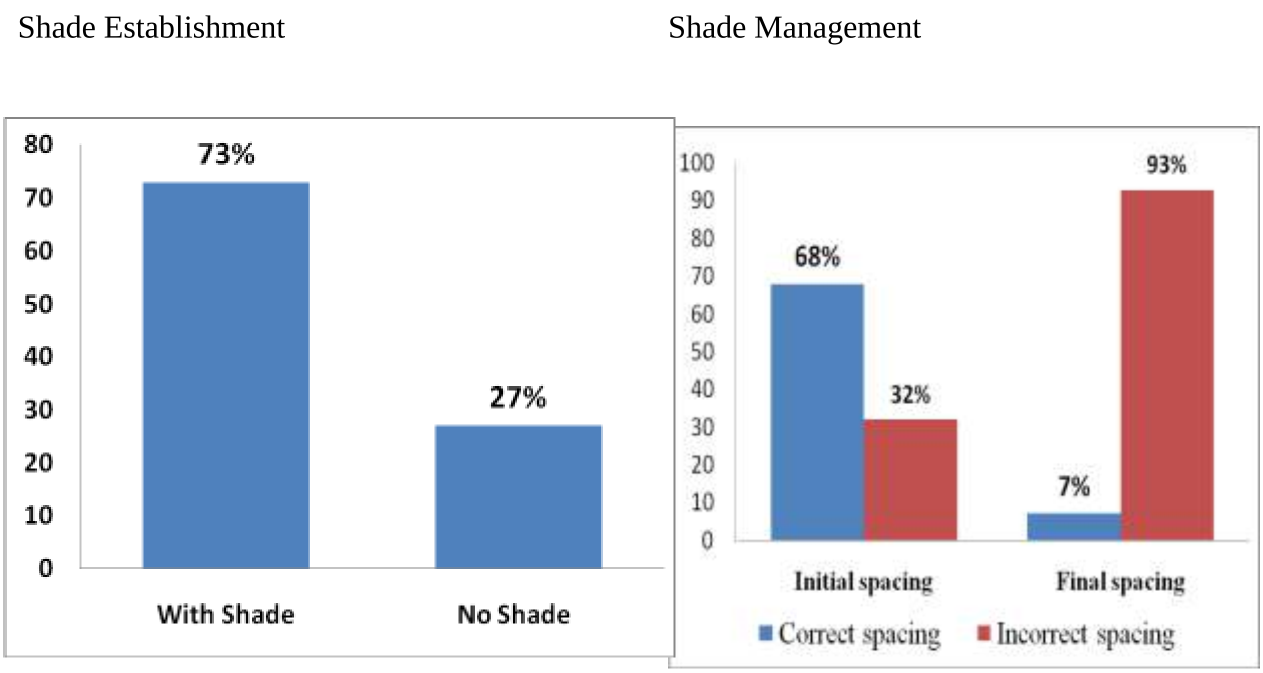

Figure 3 The level of adaption of shade management

5. CARBON BALANCE IN TEA PLANTATIONS

A study to determine carbon balance in the Sri Lankan tea industry was conducted in collaborative with University of Peradeniya. Factors considered to determine the carbon balance are given in Figure 4.

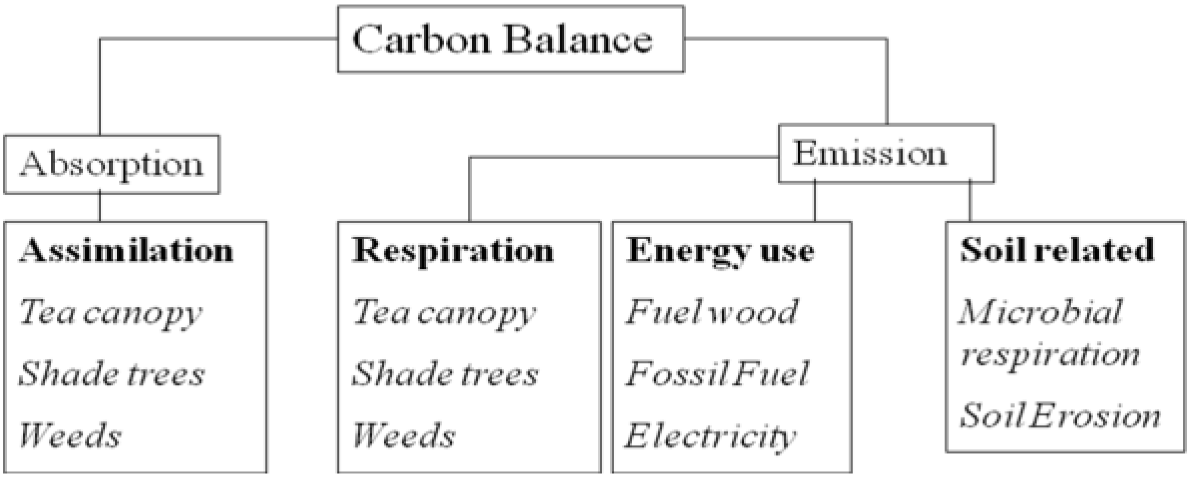

Figure 4 Factors considered in the determination of carbon balance

Findings revealed that Sri Lankan tea industry is a net carbon absorber and thereby contributes to mitigation of long term climate change Figure 5.

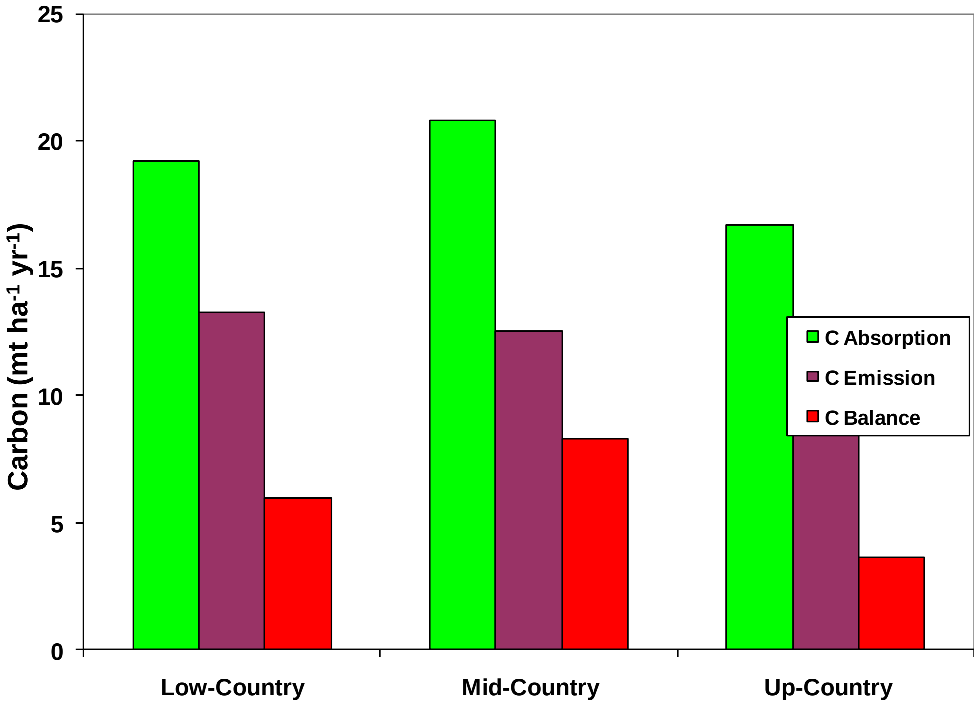

Figure 5 Annual Carbon Balance (per ha)

In a study conducted by TRI, carbon sequestration potential of seedling /VP tea plants and shade trees in different elevations were quantified. A model (Sheffield Dynamic Global Vegetation Model) is fine tuned and relationships were developed to predict future tea yield variation in response to global climatic change.

6. ADAPTATION FOR CLIMATE CHANGE

6.1 Development of Drought Tolerance/Resistance Cultivars

TRI has already recommended 64 cultivars for commercial planting and out of that 45 cultivars are found to be drought tolerance i.e. DG 39, DG 7, DN, S 106, CY 9, KP 204, CH 13, TRI 2025, 2027, 4042, 4052.

Selection of cultivars with high yield incorporated with high quality, P&D resistance and specially drought tolerance were given very high consideration in the development of TRI 5000 series. Rapid and more reliable techniques were developed to identify drought tolerant accessions using recently developed Drought Susceptibility Index (DSI). This facilitates precise screening of large amount of plant materials within a shorter period of time.

6.2 Development of Drought Tolerant/Resistant Seed Stocks

TRI has developed "Improved seeds" (Bi and Poly Clonal Seeds) as alternative planting materials to withstand drought conditions while maintaining appreciable productivity levels. These improved seeds were evaluated in marginal tea growing areas and very promising results were obtained.

6.3 Increasing Availability of Seeds

In order to increase the availability of the improved seeds TRI maintain existing gardens at Reucastle & Rambukkand Estates (Bi- clonal) and Salawa, Halpe, Kiriporuwa, Sapumalkanda & Rambukkanda (Poly- clonal).

TRI rejuvenated old seed gardens at Peenkanda, Welimada and El- Tab and established new seed gardens at TRI Kottawa and Hanatana. Initiatives have already been taken to establish new seed gardens at Waltrim, Ury &and Dessford estates.

6.4 Development of Graft Combinations

TRI has developed graft combinations suitable to withstand drought and grafted plants are being field tested. The combinations include TRI 2023 on CY 9, TRI 2026 on DN, TRI 4046 on DN and TRI 4052 on DN.

6.5 Identification of Metabolites for Facilitating Screening / Identification of Drought Tolerant Cultivars

TRI has initiated a project to identify metabolites related to drought tolerance (i.e. amino acids – Proline) with the financial assistance from National Research Council. Successful completion of the project will lead to early screening of large amount of plant materials with drought tolerance within a shorter period of time.

7. UPDATE ON MRL ISSUE

The present MRLs given for tea by EU, Japan, USA and China are given in Table 1.

Table 1 MRLs given for tea by EU, Japan, USA and China

a.i.	EU	Japan	USA	China
Bitertanol	0.10	0.10		
Copper Hydroxide	40	Exempted		
Copper oxide	40	Exempted		
Copper Oxychloride	40	Exempted		
Hexaconazole	0.05	0.05		
Propiconazole	0.10	0.10		
Tebuconazole	0.05	50		
2,4-D	0.10	0.01		
Diuron	0.10	1.0		
Glufosinate Ammonium	0.10	0.30		0.5
Glyphosate	2	1.0	1.0	1.0
MCPA	0.10	-		
Oxyfluorfen	0.05	0.01		
Paraquat	0.05	0.30		
Carbofuran	0.05	0.20		
Chlorfluazuron	0.01	10		
Diazinon	0.02	0.10		
Dazomet	0.02	0.10		
Imidachloprid	0.05	10		0.5
Fipronil	0.005	0.002		
Metam Sodium	0.02	0.10		
Sulphur	Exempted	Exempted		

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CLIMATIC VARIATIONS IN TEA GROWING REGIONS AND VULNERABILITY OF TEA PLANTATIONS TO CLIMATE CHANGE

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ABSTRACT

Tea cultivations in Sri Lanka are found in 25 Ago-ecological regions (AER). The rainfall, temperature and soil conditions which largely influence productivity of tea lands differ among these regions. Additionally, the changes of environmental factors due to global warming (climate change) are reported to pose many challenges to agriculture where tea is no exception. Therefore, an attempt was made to analyse long term rainfall and temperature data in tea growing AERs with a view to establish their temporal variations and trends over the period from 1961-2010 and identify AERs that are potentially vulnerable to climate change impacts. In this analysis, rainfall for a given AER was estimated by developing monthly rainfall surfaces through interpolation of data recorded in all meteorological stations in Sri Lanka. Further, some soil properties in main tea growing regions affecting growth and yield of tea were also considered in developing vulnerability indices.

Trend analysis showed that the variability and quantity of rainfall have significantly changed in some of the tea growing regions and the temperature increase over the 50 year period was estimated to be about 0.5-2 ^{o}C. The variability of North East monsoon rainfall (NEM; from December-February) was found to be higher than that of the other monsoons. Vulnerability analysis performed using rainfall variations, temperature increase and soil conditions have shown that tea lands in WL1a, WL1b and WL2a in low elevation and WM2a, WM2b, WM3a, IM2b, IM3a and IM3c in mid elevation are highly vulnerable to climate change impacts. Further, tea lands in WM1a, WM1b, WM3b, IM1a and IM2a in mid elevation and IU3a, IU3d and IU3e in high elevation are also vulnerable to climate change.

Keywords: climate change, rainfall, soil, Sri Lanka, tea, temperature, vulnerability

1. INTRODUCTION

Presently, there are approximately, 205,000 ha of tea in 14 administrative districts in Sri Lanka. There are nearly 400,000 smallholders engaged in tea cultivation and about 75% of them are growing tea in low country districts. Additionally, large number of estate workers and their families are resident in large tea estates. The industry supports a population of around 2.5 million, more than a tenth of the total population. Tea exports to more than 140 countries earned 1.4 billion USD in 2012 as foreign exchange. Sustainability of the industry is vital not only due to its socio-economic importance, but also in the environmental aspects as majority of tea lands are on steep terrains and in watersheds feeding river system of the country that are vulnerable to erosion and soil degradation in the event of poor management and abandonment of cultivated lands.

Climate change due to accumulation of Green House Gases (GHG) in the atmosphere is reported to bring many challenges to agriculture. The rising CO_2 levels and temperature and variation of rainfall are the main causes impacting land productivity under climate change. Tea being a rain-fed plantation crop grown at different elevation in Sri Lanka is reported to be vulnerable to the climate change. Additionally soil conditions also play a great role on crop productivity under varying climatic conditions. For instance, drought effects are more pronounced in the regions with poor soil conditions. The climatic and soil conditions greatly vary among different tea growing regions and in addition, they tend to vary with time. When the socio-economic importance of the tea industry in Sri Lanka is considered, it is very important to identify tea growing regions that are vulnerable to climate change and propose suitable adaptation measures. Hence, an attempt was made to identify tea growing Agro-ecological regions (AER) vulnerable to climate change based on trend analysis of long-term temperature and rainfall data (1961-2010) and some important soil conditions influencing crop productivity.

2. DATA COLLECTION AND ANALYSIS

The temperature and rainfall data representing 25 AERs over the period of 1961-2010 were obtained from the Department of Meteorology, Sri Lanka. In order to get the representative rainfall figure for a given AER, rainfall surfaces were developed for the whole country by linear interpolation of all recorded rainfall data as per the internationally accepted procedures. However, terrain effect of each AER was not considered in this interpolation. As temperature data was not available for each AER and the variation of temperature is largely due to changes in elevation, maximum and minimum temperatures of selected locations representing high, mid and low elevations of wet and intermediate zone were used in this analysis.

In order to establish clear trends and understanding the recent changes in comparison with those in the past, the 50 year period was divided into two *viz.* 1961-1990 (base period) and 1991-2010 (recent past 2 decades). Monthly rainfall and temperature data was summarized for the distinct 4 seasons *viz*. North-east Monsoon-NEM (December-February), 1st inter monsoon (March & April), South-west monsoon-SWM (May-September and 2nd inter monsoon (October – November). As the degree of vulnerability of tea plantations vary with the interaction of climatic and soil factors, vulnerability indices were established for each AER based on rainfall, temperature and soil properties.

The total rainfall during NEM and 1st inter monsoon (December-April) in the wet zone (W) regions and 1st inter monsoon and SWM (March-September) in the intermediate zone (I) are critical for growth of tea as they represent distinct dry months (moisture stress). Further, AERs with <2000mm of total annual rainfall, <100mm of monthly rainfall during critical periods, low rainfall (critical period) recorded in the recent two decades, a significant negative trend of rainfall over the 50 year period and a significant increase in rainfall variability (during critical periods) in the recent two decades were considered vulnerable for climate change impacts. Temperature indices were based on the optimum temperature for growth of tea. Accordingly, low elevation where the present mean temperatures are above 22^{o}C was considered highly vulnerable while mid elevation where the present temperatures are around 22^{o}C was considered vulnerable to global warming.

When the available data and soil requirements of the tea plant are considered, tea soils with a depth of less than 90cm were considered vulnerable for climate change while those with a gravel % of 15-30% was considered vulnerable and those with more than 30% as highly vulnerable due poor water holding capacity. The soils with more than 40% sand and those with a bulk density of more than 1.1 g/cm^3 were considered vulnerable. With regard to soil organic carbon level, soils with more than 4% carbon content was considered not vulnerable, 2-4% as vulnerable and less than 2% as highly vulnerable. Some records of soil properties used for this analysis are given in Table.1.

Table 1 Some soil properties of tea lands in main tea growing AERs (source: Amarathunga, M K S L D, 2000)

Soil properties	WL	WM	WU	IM	IU
Depth-cm	79.5	83.5	95.0	80.8	84.0
Gravel %	39.5	40.5	13.5	35.4	28.2
Sand %	51.3	62.6	40.0	53.6	48.6
Bulk Density	1.2	1.2	1.08	1.18	0.86
OC %	1.37	2.30	4.40	2.17	2.60

3. RESULTS

3.1 Trend Analysis of Rainfall in Tea Growing Regions

Variation of mean annual rainfall of tea growing regions for the 50 year period (1961-2010) has been given in Figure 1. Analysis of data shows that WM3b, IU3a, IU3d, IU3e and IM3a regions receive very low rainfall (<2000mm/yr) and hence, are vulnerable to adverse impacts of climate change.

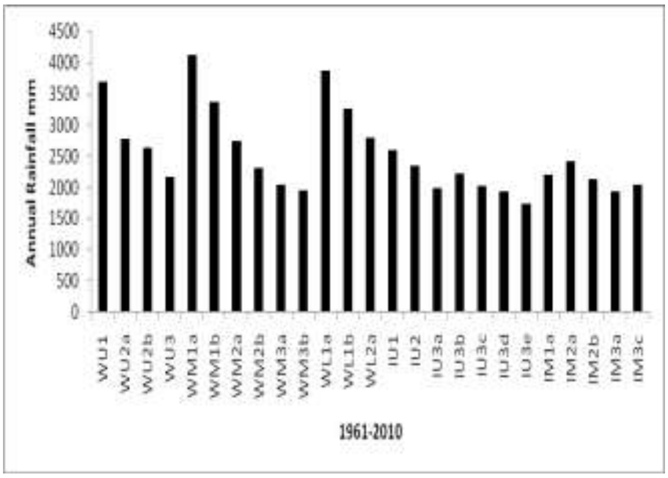

Figure 1 Mean annual rainfall of tea growing AERs for the 50 year period (1961-2010)

Monthly rainfall of 4 distinct seasons (monsoon periods) is given in the Table 2. Accordingly, WM2b and WM3a (wet zone) receive less than 100mm/month (critical rainfall for tea) of rainfall during the NEM period. Mean monthly rainfall of IU3a, IU3c, IU3e, IM1a and IM2b (intermediate zone) during the SWM is also less than 100mm/month. Hence, these regions can also be considered as vulnerable to climate change.

Table 2 Mean monthly rainfall (mm) during 1961-2010

AER	NEM	1st Inter -monsoon	SWM	2nd Inter-monsoon
WU1	130	249	397	398
WU 2a	112	174	294	297
WU 2b	127	212	233	323
WU 3	123	153	188	262
WM 1a	163	299	423	460
WM 1b	172	277	294	387
WM 2a	103	189	270	339
WM 2b	91	183	194	329
WM 3a	89	181	149	331
WM3b	146	143	123	303
WL 1a	173	303	365	454
WL 1b	139	244	305	413
WL 2a	137	201	251	347
IU 1	311	172	129	361
IU 2	274	167	106	313
IU 3a	146	223	90	325
IU 3b	159	265	104	343
IU 3c	186	187	99	298
IU 3d	158	153	117	259
IU 3e	166	145	87	243
IM 1a	289	156	75	302
IM 2a	157	256	138	336
IM 2b	177	233	83	339
IM 3a	151	135	125	288
IM 3c	211	139	104	289

The rainfall variability is very high during NEM monsoon period while that of the SWM period was the lowest. The variability of first and second inter-monsoon rainfall has been increased during 1991-2010 period as compared with the base period (1961-1990). Highest increase (>10%) in rainfall variability during the 1st Inter-monsoon has been recorded in AERs such as WU2a, WU2b, WU3, WM2a, WL1b, IU2, IU3d and IU3e. Similarly, WM3a and IU3a have recorded an increase in the 2nd inter-monsoon rainfall variability during 1991-2010 in comparision with the base period. When SWM monsoon is considered, rainfall variability has been increased in IU3a and IM2b regions. Increase in rainfall variability during SWM and the 1st Inter-monsoon is not favourable for tea in the intermediate zone (I) due to lack of rainfall and its poor distribution.

Analysis of rainfall over the 50 year period have also shown that the total rainfall of NEM and the 1st inter-monsoon in WU3 (wet zone) and that of 1st inter-monsoon and SWM in IU1, IM3a and IM3c (intermediate zone) was significantly low during the past two decades compared with the base period (Figure 2).

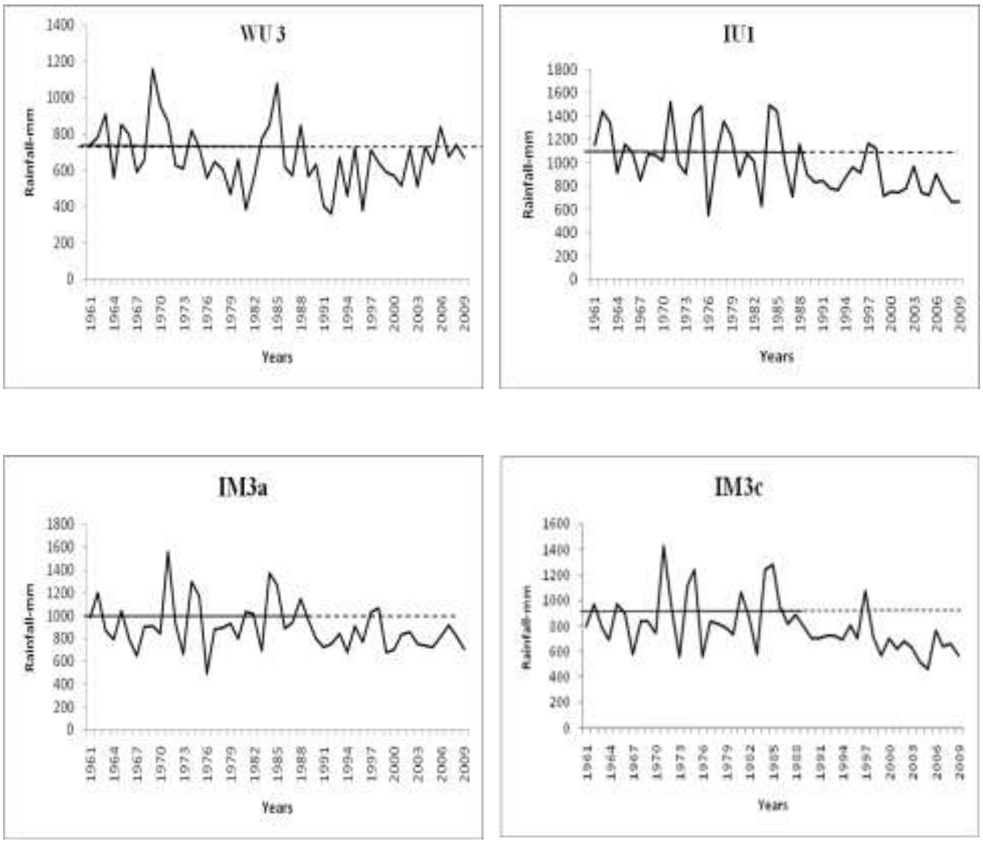

Figure 2 Rainfall of WU3 during NEM & 1st Inter-monsoon; Rainfall of IU1, IM3a and IM3c during 1st Inter-monsoon and SWM; Straight line indicates the mean rainfall during the base period; 1961-1990

Results in the Table 3 shows that the total rainfall of WU1, WU2b, WU3, WM1a, WM2a, WM2b, WM3a, IU1, IU3d, IM3a and IM3c has shown to have a significant negative trend over the last 50 years.

Table 3 Linear regression output (regression coefficient; mm/yr) of rainfall during the 50 year period; 1961-2010 (*significant r^2, $p<0.05$)

AER	Total	NEM	1IM	SWM	2IM
WU1	-16.6*	-1.63	-0.1	-14.0*	-1.2
WU 2a	-4.49	-0.1	-0.5	-3.91	0.31
WU 2b	-6.94*	-0.1	0.0	-6.6*	-1.0
WU 3	-7.77*	-1.63	-1.2	-3.58	-1.1
WM 1a	-10.31*	-1.3	0.3	-8.23*	-0.9
WM 1b	-8.09	-0.27	-0.6	-7.03*	-0.6
WM 2a	-13.1*	-0.64	-0.1	-11.6*	-1.95
WM 2b	-10.9*	-0.8	0.2	-7.32*	-2.13
WM 3a	-11.8*	-1	-1.41	-6.93*	-1.7
WM3b	-4.8	-0.7	0.8	-4.21*	-0.6
WL 1a	-6.72	-0.1	-1.1	-6.22*	0.5
WL1b	-7.68	-0.14	-0.87	-6.9*	-0.1
WL 2a	-5.8	-0.8	-0.4	-4.76	-0.6
IU 1	-18.9*	-4.63	-1.72 P	-7.87*	-2.04
IU 2	-3.87	-1.3	0.1	-0.9	0.1
IU 3a	4.45	-0.1	1.8 P	0.7	2.94
IU 3b	-3.87	-0.6	0.1	-1.51	-0.9
IU 3c	0	-0.7	-0.0 P	-0.5	1.6
IU 3d	-6.52*	-2.95	-1.32	-0.07	-0.5
IU 3e	-3.41	-1.6	-0.06	0.5	0.3
IM 1a	-3.87	-1.4	0.02	-0.2	0.9
IM 2a	0	-0.6	2.45 P	-2.4	1.31
IM 2b	0	-0.3	1.71 P	-1.2	1.2
IM 3a	-6.91*	-1.4	0.7	-4.39*	-1.89
IM 3c	-10.2*	-3.27	-0.8	-4.43*	-1.6

3.2 Trend Analysis of Temperature in Tea Growing Regions

Results of the linear regression analysis of maximum and minimum temperatures of selected locations representing different elevation categories are given in the Table 4. The ambient temperatures (maximum and minimum) of almost all the tea growing regions have been increased over the last 50 years except maximum temperature in Nuwara Eliya (highest elevation). The temperature rise in tea growing regions over the 50 year period (1961-2010) has been in the range of 0.5-2^{o}C.When the optimum temperatures for tea cultivation (22^{o}C) is considered, increasing temperatures at low (WL) and mid (WM & IM) elevations can adversely affect growth & yield of tea. Rising temperatures above the optimum not only bring direct (adverse) effects on tea but also can make tea lands vulnerable to moisture stress condition due to high rate of evapo-transpiration. Of these regions, IM and WL are more vulnerable for adverse impacts of rising temperatures due to less rainfall of the former and high temperatures of the latter.

Table 4 Linear regression output (gradient; $^oC/yr$) of temperature variation during 1961-2010 period (*significant r^2, $p<0.05$)

Location	Mean	NEM	1st inter-monsoon	SWM	2nd inter-monsoon
Badulla (Max)	0.028*	0.028*	0.040*	0.027*	0.020*
Badulla (Min)	0.010*	0.010	0.006	0.013*	0.010*
Bandarawela (Max)	0.020*	0.015*	0.017*	0.026*	0.013*
Bandarawela (Min)	0.026*	0.021*	0.029*	0.029*	0.025*
Galle (Max)	0.024*	0.029*	0.028*	0.018*	0.026*
Galle (Min)	0.020*	0.022*	0.023*	0.017*	0.024*
Katugastota (Max)	0.015*	0.017*	0.016	0.015*	0.010*
Katugastota (Min)	0.013*	0.011	0.014*	0.013*	0.014*
Nuwara Eliya (Max)	-0.001	-0.002	-0.013	0.005	-0.003
Nuwara Eliya (Min)	0.023*	0.026*	0.033*	0.018*	0.026*

3.3 Tea Growing Regions Vulnerable to Climate Change

Based on the vulnerability indices developed for rainfall, temperature and soil, an overall vulnerability index for each AER was established (Table 5).

Table 5. Overall index of vulnerability to climate change

AER	Rainfall changes	Temperature rise	Soil conditions	Score (No of *)	Overall Index
WU1					
WU 2a					
WU 2b	*			1	
WU 3	**			2	
WM 1a		*	**	3	*
WM 1b		*	**	3	*
WM 2a	*	*	**	4	**
WM 2b	*	*	**	4	**
WM 3a	*	*	**	4	**
WM3b		*	**	3	*
WL 1a		**	**	4	**
WL1b		**	**	4	**
WL 2a		**	**	4	**
IU 1	*		*	2	
IU 2			-		
IU 3a	**		*	3	*
IU 3b			-		
IU 3c			-		
IU 3d	**		*	3	*
IU 3e	**		*	3	*
IM 1a		*	**	3	*
IM 2a		*	**	3	*
IM 2b	*	*	**	4	**
IM 3a	**	*	**	5	**
IM 3c	*	*	**	4	**

Overall Index: * Vulnerable; ** Highly vulnerable

Further, this analysis shows that WL1a, WL1b, WL2a, WM2a, WM2b, WM3a, IM2b, IM3a and IM3c regions are highly vulnerable and WM1a, WM1b, WM3b, IM1a, IM2a, IU3a, IU3d and IU3e regions are vulnerable for climate change (Table 6a & 6b).

Table 6a Approximate locations (DS Divisions) under highly vulnerable AERs

AER	Locations (DS Divisions)
WL 1a	Avissawella, Eheliyagoda, Ratnapura (West), Pelawatta, Nagoda, Akuressa (North) Pitabeddara, Niyagama, Tawalama, Elpitiya, Bulathsinhala, Ruwanwella, Dehiovita
WL1b	Matugama, Dodangoda, Bandaragama
WL 2a	Kalutara, Galle, Akuressa, Mulatiyana, Aturaliya, Yakkalamulla, Imaduwa, Akmeemana, Baddegama, Ambalangoda,
WM 2a	Nawalapitiya, Gampola, Kothmale (West)
WM 2b	Peradeniya, Hemmathagama, Udunuwara, Yatinuwara, Aranayake
WM 3a	Tumpane, Mawanella (East), Hataraliyadda
IM 2b	Imbulpe (East), Balangoda & Weligapola, Badalkumbura, Southern and western parts of Haldummulla, Rattota (West), Central part of Ukuwela and Kundasale, Pathahewaheta (North)
IM 3a	Hangureanketha (North), Kundasale (South), Meda-dumbara (South)
IM 3c	Hanguranketha

Table 6b Approximate locations (DS Divisions) under vulnerable AERs

AER	Locations (DS Divisions)
WM 1a	Deniyaya, Maliboda, Kenilworth, Kotapola (North), Kalawana (South)
WM 1b	Rakwana, Kalawana (North)
WM3b	Kandy, Pathadumbara, Akurana, Harispattuwa, Pujapitiya, Panwila, Central part of Rattota, Ambagamuwakorale
IU 3a	Bandarawela (South), Haputale (East)
IU 3d	Rahangala, Welimada (West)
IU 3e	Welimada, Uwa-paranagama (South), Haputale (Noth), Bandarawela (West)
IM 1a	Badulla, Hanguranketha (East), Walapane (North & East), Haliela (South), Passara (West)
IM 2a	Kolonne-korale, Weligapola (West), Central parts of Balangoda, Imbulpe, Haldummulla

4. RECOMMENDATIONS

4.1 Adaptation Measures to Minimize Adverse Impacts of Climate Change

The degree of vulnerability of tea lands to climate change vary among different AERs. Moreover, the factors responsible for significant impacts too vary from one AER to the other. Hence, most appropriate adaptation measures need to be identified based on the key causative factors.

As the factors responsible for significant impacts are related to rainfall, temperature and soil (moisture retention/availability), adaptation measures should be linked to improvement of (1) crop (2) soil and (3) areal environments. Given below are some of the cost-effective technologies that are available for tea growers as adaptation measures to combat adverse impacts of climate change on the productivity of tea lands. However, the impacts of climate change on two other important facets of tea production and marketing viz. pests and disease infestation and product quality have not been fully understood yet. Therefore, detailed studies are necessary to uncover such relationships between climate change, pest and disease infestations and product quality.

4.2 Adaptation Measures for Low Country AERs

Low country tea lands are vulnerable for climate change due to high temperatures and presence of poor soil conditions. Therefore, adaptations should target the use of drought, pests and disease tolerant cultivars, improving soil conditions to retain more moisture and reducing temperature around tea bushes. Application of compost and green manure will help sustain organic matter status of tea soils. Additionally, such practices will improve fertilizer use efficiency and moisture retention capacity of soils thus sustaining productivity. Soil and soil moisture conservation measures by establishment and maintenance of drain system and stone terraces, mulching, envelope forking or burying of prunings in tea lands also help minimizing adverse impacts. Drip or sprinkler irrigation can be used to mitigate drought effects and improve tea yield. A good stand of shade trees in tea reduces ambient temperature around tea bushes, increase RH, adds organic matter to soil and reduces drought effects. In the long run, crop improvement aiming at developing varieties and graft combination etc tolerant to heat and moisture stress and well adapted to varying soil conditions is vital for sustaining tea production in the low country regions.

4.3 Adaptation Measures for Mid Country AERs

Presently, temperatures in the mid elevation are in the optimum range for tea. However, increasing temperatures (global warming) could make them less productive. Soil conditions in these regions have also been degraded and hence, are not very conducive for growth of tea. The same adaptation measures identified for low elevations are applicable for the mid elevations too. Of the cultural practices, priority should be given for soil and soil moisture conservation and soil improvements in the mid country AERs of the wet zone. Shade is also equally important to minimize adverse impacts on tea in the mid country AERs particularly those in the intermediate zone where the environment is comparatively dry.

4.4 Adaptation Measures for Up Country Intermediate Zone AERs

The tea growing regions of Up country Intermediate Zone commonly known as the "Uva region" are of prime importance to the tea industry in Sri Lanka due to production of unique seasonal quality teas that fetch high prices. Chemical compounds responsible for such seasonal quality are formed during a period of mild environmental stress with lack of soil moisture, blowing (wind) and bright sunlight.

Therefore, changes in the rainfall pattern and its variability as a result of climate change may influence production of seasonal quality teas. Considering these factors, use of drought, pest and disease tolerant cultivars (crop improvement), soil and soil moisture conservation measures, application of compost and organic manure and eestablishment and management of shade trees could be considered as the most suitable adaptation measures. However, irrigation during dry months of the quality season may not be advisable in the intermediate zone AERs famous for seasonal quality as it could deteriorate development of the seasonal quality.

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CLIMATE CHANGE ADAPTATION STRATEGIES FOR TEA PLANTATIONS

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ABSTRACT

It is anticipated that climate change impacts on tea will lead to high variability in rainfall, rise in ambient temperature and lower the status of soils. Further, extreme dry spells and long wet periods together with overcast conditions could result in poor establishment, growth, productivity, unusual pest and disease outbreaks and quality of tea affecting sustainability. The different Agro Ecological Regions (AERs) have already been identified as highly and moderately vulnerable for climate change. Hence, climate change adaptation strategies should be clearly identified as long, medium and short term. However, it is mandatory that long term adaptation strategies described under Good Agricultural Practices (GAPs) recommended by TRI be advocated to face extremes in rainfall, rise in ambient temperature and lowering soil conditions as discussed below.

First and foremost, selection of only the most suitable lands for tea cultivation using new tea growing map/AER maps, selection criteria and following Soil Quality Index should be given a high priority. To avert impacts of dry conditions coincided with high ambient temperatures in tea, developing new cultivars resistant to drought, pests and diseases, harnessing biclonal and polyclonal seed cultivars and grafted tea plants as long term strategies should also be prioritized. Planting of healthy and vigorous nursery plants with well established root systems of a basket of cultivars should be encouraged. Rainwater harvesting, construction of small ponds, check dams, tanks, anicuts etc. and strengthening watershed management, expansion of forest trees in hill crests, planting trees on fences, boarders and open areas are important in conserving soil and moisture. Establishment and maintenance of adequate shade tree stands are important to cut down high temperature below lethal levels.

To stand for extreme rain fall in the tea growing regions, construction of leader drains to carry excess water away and terraces to conserve soil in hilly terrains are important. Proper land preparation and cutting of lateral drains of 'lock and spill' type provided with silt pits/reverse slopes to retain more water and arrest soil erosion are also important. In order to minimize potential build up of fungal diseases, lopping of branches should be done before the onset of rains. Grass rehabilitation, mulching, establishment and lopping of green manure crops, incorporation of soil organic amendments will help conserve soil moisture, improve soil fertility, structure and permeability. Burying of pruned litter and green matter will also adequately harvest more rain water, improve soil fertility and enhance tolerance to drought. More integrated approaches should be focused beforehand to manage dry weather pests.

1. INTRODUCTION

Climate change is a long way process. It occurs slowly over many years, may be 100 years. The monthly temperature has been up by 1.4-2.7 ^{o}C over the last 50 years. However, as far as the agriculture sector is concerned climate variability is paramount important, as we have to face to extreme weather situations currently as well as in future that can have a great impact on crop growth. Under such climate variability steady rise in ambient temperature together with severe dry spells and excessive rains or frost damages in the hill country could be experienced. For instance, severe droughts were experienced during the years, 1992, 2007 and 2012, while, excessive rains were occurred during 2013. A similar kind of variability could be expected in the near future as well and as such dry periods become more drier and wet periods become more wetter. The repercussions of such extreme weather situations, otherwise impact of dry weather or excessive wet weather on tea growth and yield; and the possible adaptation strategies are discussed below.

1.1 Extreme Dry Weather Situations

As illustrated below a severe dry weather situation characterized by heavy sunlight which falls over 8-10 hrs within a day, no rain or a very lower rain <100 mm/month together with lower RH and high temperature. The tea bushes, which are directly exposed to heavy sun light result in leaf and bud scorch, leaf and bark desiccation and this will in turn cause to stem and collar canker and wood rot. Shoot dormancy, poor bud break and shoot dormancy are the other unpleasant incidents that occur under low moisture condition in the soil as well as low RH and high temperature in the environment. Plant casualties in new clearings as well as in young tea in most cases are very common scenario under dry weather situation. Prevalence of dry weather insect pests such as mites, nettle grub and tea tortrix also aggravates the situation adding insult to the injury. Some aggressive weeds, which can withstand the drought, could further compete with tea and harm on it and they produce many seeds to perpetuate their future generations. Apart from that with ever rising of temperature with climate change, weeds found in low country could be appeared in the mid country and mid country weeds could appear in the up country in the long run. Moreover, many incidences of hard-to-kill weeds might be reported in future.

High evaporation that takes place particularly through the bare ground could end up with formation of a hard pan on the ground surface giving rise to poor retention of water in soil during rains and severe soil erosion with run off water, as a result. The overall repercussion of such bad situations in the soil, environment and tea bush itself is the low productivity and quality of tea which is harvested (Figure 1).

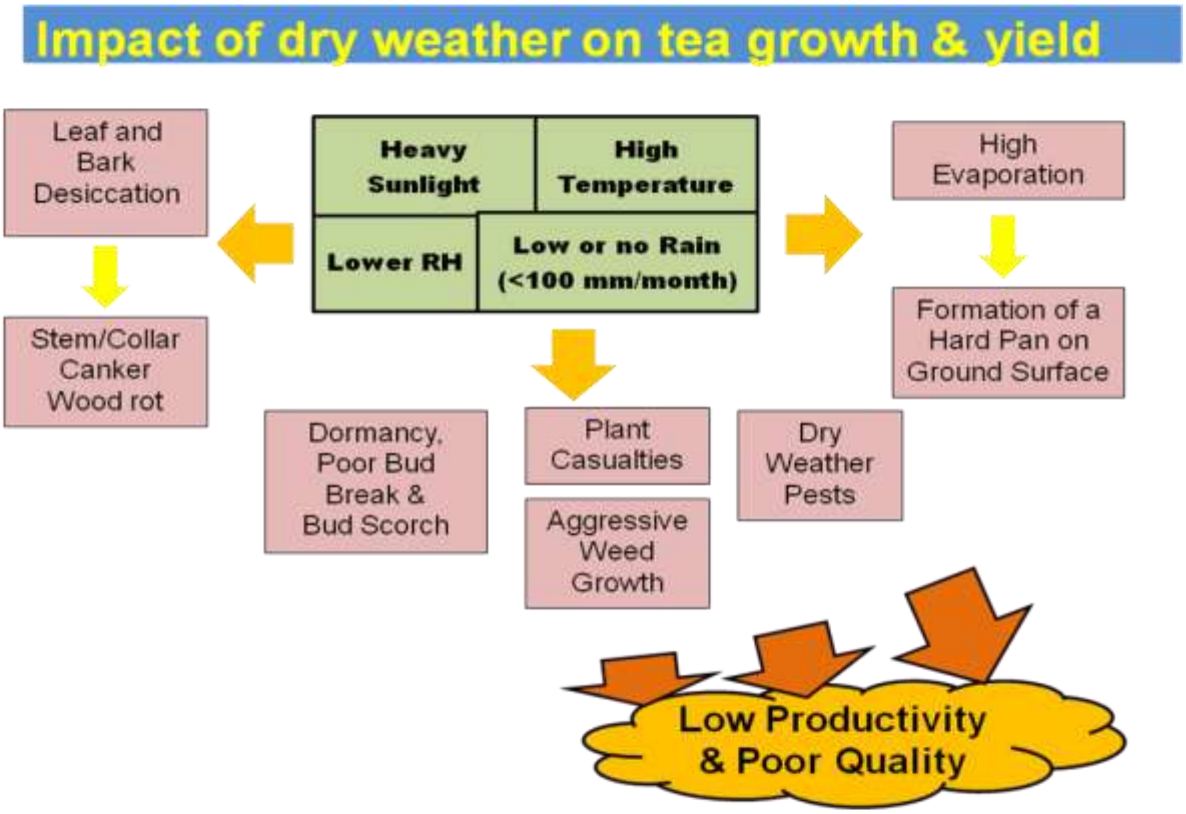


Figure 1 Impact of dry weather on tea growth and yield

As shown in Table 1, tea grows under different optimum rain fall levels in different Agro-ecological regions (AER). Hence, any yield drop due to 100 mm reduction in rainfall per month also varied in different AERs. Yield could thus be dropped by 30-90 kg/ha/month and a massive yield drop due to drought is reported from mid country intermediate i.e. Uva region followed by low country wet zone i.e. Ratnapura, Galle, Matara and Kalutara districts. More concerns are therefore to be given to these regions in soil and moisture conservation activities to mitigate the effects of severe drought conditions.

Table 1 The effect of low rainfall on tea production

AER	Optimum Rainfall (mm/month)	Yield drop due to 100 mm reduction in rainfall per month (kg/ha)
Up Country Wet Zone	350±20	29±3
Mid Country Wet Zone	417±49	36±6
Low Country Wet Zone	223±38	55±7
Up Country Intermediate Zone	303±34	39±3
Mid Country Intermediate Zone	227±10	81±11

1.2 Impact of Extreme Wet Weather Situations

As illustrated in Figure 2, under high intensity of rainy weather a cloudy and gloomy situation throughout the day could be experienced. This situation is also coupled with very high RH and low ambient temperature. As a result of such unfavourable conditions, bud break and shoot development become poor. During heavy rains soil is heavily eroded with run off water which flows down at a high velocity particularly in sloppy terrains resulting in the loss of top soil layer and lowering the soil depth. The sub soil layer which is left, has a poor water retention capacity and poor nutrient status and that make an unfavourable soil condition for crop growth. Poor drainage in the low lying areas is another problem faced under excessive rains. Heavy incidences of fungal diseases particularly Blister blight is the commonest problem under gloomy weather situation with a high RH level. This incident is aggravated in those tea lands where the shade is not properly managed. Some insect pests such as nematodes could also be prevalent under wet weather conditions. These overall effects in tea crop and soil will ultimately result in a poor productivity in tea crop.

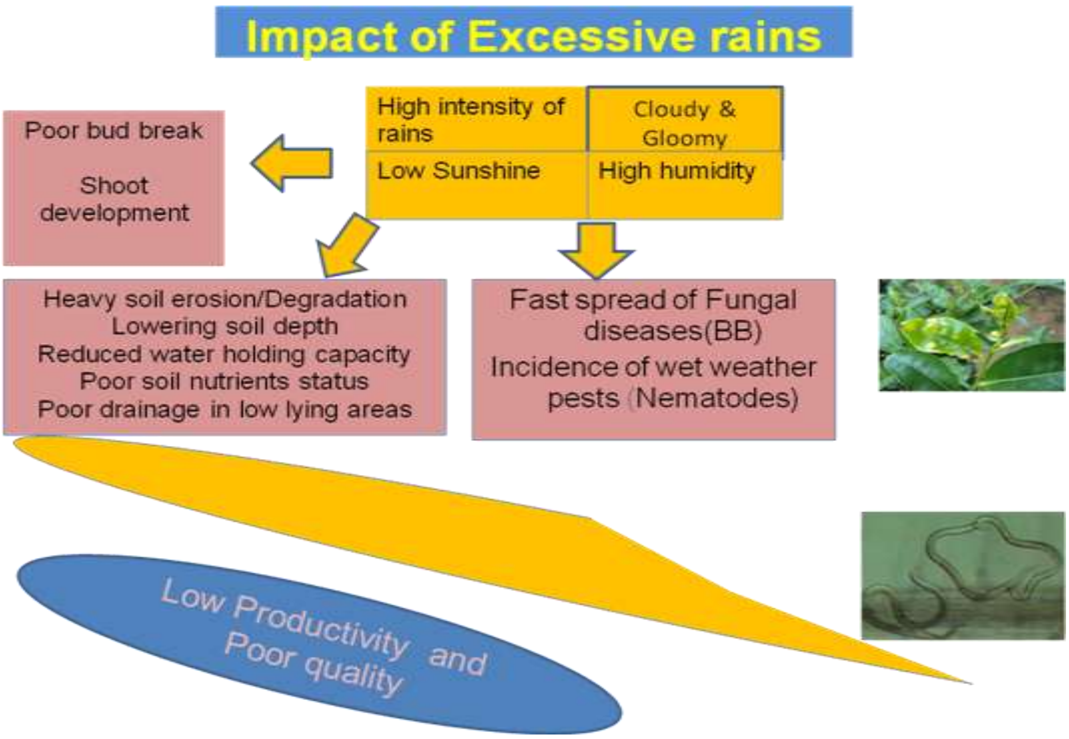
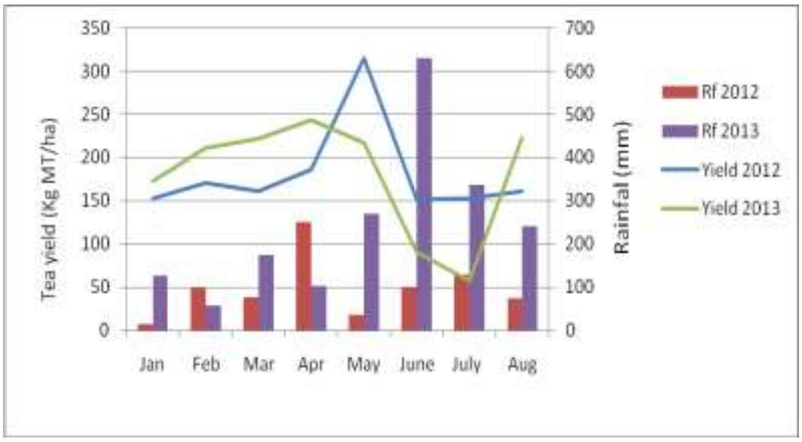


Figure 2 Impact of excessive rains

As shown in Figure 3, tea production has been largely dropped at St Coombs Estate during the months of June/July 2013 due to excessive rains and low sun light as compared with the corresponding months in 2012.



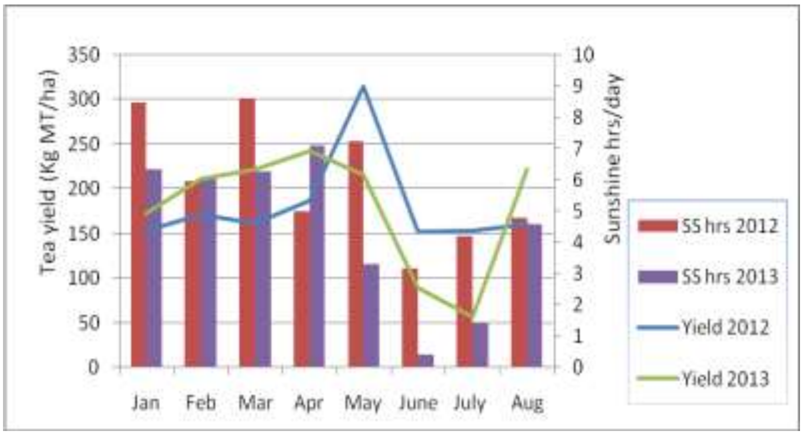


Figure 3 Yield loss due to excessive rains and low sun light during May-July 2013 at St. Coombs Estate

The impact of bad weather could be averted to a certain extent with timely adoption of good agricultural practices. However, according to the Diagnostic survey of the TRI (2011), soil management in the corporate sector tea estates is rather poor. Soil has been highly degraded and shade management is also not in a satisfactory level. There are also many incidences of pests and diseases. As shown in the Table 2 lands have been properly managed with cutting of leader drains and contour drains only by 68% of estates, where the annual yield exceeds 3000 kg MT/ha. This situation is further worsen when it comes to the low yielding estates <1500 kg MT/ha, where only 28% estates have adopted these practices. Shade has been established only in 40-46% estates and 26-34% in high and low yielding estates, respectively. Though properly established, there is no use of shade trees unless they are timely managed i.e. with lopping or pollarding before the onset of rains. However, the survey reveals that the level of shade management is also rather poor in both high and low yielding tea estates. It was reported that about 18,800 ha in the RPC sector are found to be uneconomic and this may be attributed to such poor management status. As such, the conditions of such poorly managed tea lands could be further worsen under the Climate Change in future.

Table 2 Situation in land management and shade management in the corporate sector tea estates

Field operation	% Satisfactory levels	
	>3000 kg MT/ha/yr	<1500kg MT/ha/yr
Land Management (Leader drains/contour drains)	68%	28%
Shade Establishment	40-46%	26-34%
Shade Management	40%	24%

Source: Diagnostic study 2011, TRI (unpublished

Therefore, it is high time to face to such extreme situations more appropriate manner i.e. by minimizing the adverse impacts of Climate Change on tea through practicing of adaptation strategies, which could be long term, medium term or short term.

2. LONG TERM STRATEGIES

2.1 Selection of Most Suitable Areas With the Use of New Tea Growing Map/AER Map

As shown in the new tea growing map, districts such as Nuwaraeliya, Ratnapura, Deniyaya/Kotapola, Kalawana have been identified as the most suitable areas for tea cultivation. As moderately suitable Galle, Matara, Kalutara districts and some parts of Ratnapura, Kandy and Matale districts have been identified.

Lands should therefore be selected more carefully in investing on replanting or new planting avoiding low/unproductive and marginal areas, where the weather condition is dry and soil conditions are poor. Follow all adaptation strategies for existing cultivations in such areas.

2.2 Selection of Suitable Lands for Tea Cultivation

a) With the use of soil selection criteria:

As TRI has already recommended, there are five criteria such as Climate, Slope, Soil depth, Gravel % and Rockiness in proper land selection for tea cultivation. Based on these criteria lands can be grouped into 4 classes. Lands categorized as Class 1 can definitely be selected for cultivation. Class 2 and 3, which have few limitations could also be selected for tea planting. Whereas, Class 4 category fields are not selected as the number of criteria are not suitable.

Furthermore, selection of low lying areas/ lands subjected to water logging under excessive rainy situations for tea cultivation should be avoided and there should be a proper drainage system on such lands where tea is already cultivated.

b) With the use of Soil Quality Index (SQI)

A soil quality index has been newly formulated with the prime objective of determining the soil quality more precisely taking into consider soil physical (Bulk Density and Available Water Content), chemical (Carbon %) and biological (Microbial Biomass Carbon and Nematode count) properties.

Other objectives are to determine whether soil rehabilitation is required before replanting tea or otherwise to reduce the time period of rehabilitation based on this SQI of a given soil; and also to pay more attention to the lands with poor soil quality.

2.3 Use of Drought Tolerant Cultivars

It can also be proposed to use hardy/drought tolerant cultivars for planting in order to avert the impact of drought together with high temperature. Cultivars such as DN, DG 7, DG 39, TRI 2025, TRI 4042, TRI 4052, S 106, CY 9, KP 204, CH 13 and KEN 16/3 can be used for planting. The biclonal and polyclonal seed stocks could also be selected for planting. In addition, grafted tea combinations, which are found to be promising for dry weather conditions or tolerant to drought such as TRI 4054/DG 7, TRI 4053/DG 39 can be used.

2.4 Establishment and Management of Medium and High Shade Trees

Tea being a shade loving plant it prefers shade to a degree of 35-40% and it will facilitate more favourable growth and high productivity. As far as the low country and mid country - intermediate (Uva region) zones are concerned, shade establishment and management are critically important as these regions are more vulnerable for drought and there ambient temperature is comparatively higher.

The major benefits of shade trees in a tea land are,

- they reduce ambient temperature/ prevent sun scorch, thereby plant casualties.
- when tea is fully exposed to sun light and ambient temperature is 30-32^{o}C, the leaf temperature rises above 40^{o}C. However, if shade trees are present, leaf temperature limits only to >1-2^{0}C above the ambient temperature (i.e. 31-34 ^{o}C).
- other than provision of shade, leaf litter added to the ground through lopping, pollarding and regular leaf fall, covers the ground, reduces weed growth, adds organic matter and enriches the soil with N, P, K, and Carbon following decomposition.
- as other benefits, they also have a major contribution to Carbon sequestration particularly in low-grown tea.
- with maintenance of an optimum temperature, shade trees facilitate to improve net assimilation of tea leaf.
- they minimize wind damage and proper management of shade help to minimize adverse effects of disease problems.

Well establishment of shade i.e. planting at correct spacing and thinning out of trees at correct time are very essential to provide an optimum shade for tea at the beginning. Later it is very essential to manage them at proper time by regular lopping and pollarding, particularly at the beginning of monsoons to prevent from fungal diseases such as Blister blight, Horse hair blight and Lichen growth on leaves. Medium shade such as *Gliricidia sepium* and *Erythrina lithosperma* should be lopped twice or thrice per annum and high shade trees such as *Grevillea robusta* and *Albizzia moluccana* should be pollarded once a year prior to rains.

2.5 Rainwater Harvesting for Use during Dry Spells

Every possible short and long term strategies should be followed to retain a high volume of rain water within the tea land for making use during future dry spells.

A proper water shed management system viz. a good forest cover on hill crests should be established and trees on fences and boarders should also be planted. Such system will help preserving rain water in the soil for a longer duration and to maintain a favourable micro climate within tea lands thereby to sustain the crop even during a dry spell.

2.6 Land Management

Proper land preparation before planting of tea and forking in mature tea fields are essential to loosen the soil or reduce the bulk density in soil thereby to improve the water retention capacity in soil. Both on-farm and off-farm soil conservation measures are to be given a high priority. Under these, cutting of lateral drains of '*lock and spill*' type provided with silt pits / reverse slopes on contour lines serve to retain a high volume of water while depositing soil moves down with run off water during rains and to gradually absorb water into soil. As off-farm (off-land) interventions, connect all contour drains to the leader drain to remove excess in to leader drain.

Soil rehabilitation also serves to improve the water retention capacity in soil during rains and it helps to minimize casualties in new clearings due to drought.

Following a medium term strategy such as burying of pruned litter on trenches cut along tea inter rows will help preserving rain water in soil for more than 2 years other than addition of plant nutrients.

The following ground cover management methods should also be adopted as short term strategies to help preserving rain water in soil through cutting down of evaporation from ground surface under drought situations.

1. Proper mulching of tea inter rows with a suitable thatching material or shade loppings. Ground surface should be mulched with a grass @ 35 tons/ha.
2. Proper tea bush management following suitable pruning practices.
3. Incorporation of organic matter such as compost, weed compost and refuse tea.
4. Establishment of green manure crops and regular lopping of branches before rains and covering the ground with them.
5. Establishment of cover crops and cutting them back to ground level before the on set of drought
6. Leaving of soft herbs on the ground.

2.7 Pruning of Tea

Pruning of tea should be restricted to rainy seasons in all agro-ecological regions. Pruning in to dry weather mainly as a measure of control Blister blight is not recommended during December-March in the up country, mid country (wet zone) and low country regions and; during June-August in mid country (intermediate zone) i.e. Uva and Balangoda, Rakwana, Matale and Upper Hewaheta and Udapussellawa regions as it may cause sun scorch on branches leading to wood rot and frame debilitation.

2.8 Pest Management

It is to be vigilant on the outbreaks of dry weather pests such as mites, tea tortrix, nettle grubs and wet weather pests such as nematodes and fungal diseases as mentioned above and they should be controlled following appropriate integrated methods.

3. SHORT TERM STRATEGIES

Weed Management should be done prior to dry spell to reduce the competition for moisture.

As a preparation for a drought, 2% SOP or MOP can be sprayed to reduce water loss by leaves (transpiration). Spraying should be done one month prior to drought and continue at 2-4 week intervals depending on the severity.

Kaolin can also be applied @ 5-10 kg/100 of water, soon after drought setting to reduce transpiration losses and to reduce the heat of leaf surface.

Light skiffing to remove top most 2-3" of foliage can be practiced when young plants (from 2nd - 4th year) remained wilted during morning hours.

If a water source is available, micro irrigation can also be practiced mainly during new clearing, and young tea phases as these phases are highly vulnerable for drought. Sprinkler irrigations can be practiced at a lower cost compared to drip irrigation for which a high capital investment is required.

Furthermore, water can be collected from roofs of factories, houses, buildings etc. to a small tank to make use of water during short dry spells.

4. CONCLUSIONS

Tea cultivations of Sri Lanka will have to be faced to a climatic variability thereby some extreme situations in future as a result of global Climate Change.

Soil degradation, incidence of pests and diseases, bush debilitation and death etc could be occurred at a greater extent than at present as consequences.

Hence, the most appropriate adaptation strategies should be followed on existing cultivations as well as in new planting and replanting programmes to avert the adverse effect of such excessive rainy and drought situations in future.

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CARBON SEQUESTRATION POTENTIAL OF TEA PLANTATIONS IN SRI LANKA

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ABSTRACT

The concept of Carbon sequestration has gained global attention as a key component in mitigating climate change by reducing buildup of atmospheric carbon dioxide and a way of obtaining additional financial benefits. As a result, carbon sequestration potential has been estimated for several crops and cropping systems but there were no such studies conducted for tea.

Hence, this study was conducted to generate the baseline data on carbon sequestration potential of tea plantations in different tea growing regions in Sri Lanka. The study covered seedling and VP tea and different types of shade trees. Estimations of carbon sequestration potential were based on the rates of average net carbon storage in biomass. Destructive sampling was done to estimate the carbon sequestration potential of tea plants where as allometric equations available in the literature were used for different types of high and medium shade tree species.

Results revealed that seedling tea had higher carbon sequestration potential than that of the VP tea in all the tea growing regions. The results further emphasized the necessity of establishment and management of shade trees in the tea plantations not only to improve the micro climate, but also to enhance the carbon sequestration per se and thereby enhance the environmental sustainability of the tea plantations as a community. Quantifications resulted that Low country, Mid country and Up country tea growing regions have the potential of sequestering 2.81, 1.03 and 0.37 million MT of CO_2 equivalents per year respectively.

Although the carbon sequestration potential of tea plantations is comparatively less than that of other C3 crops, it is of significant importance for exploring possibilities as another marketing tool based on carbon friendly management, extent of cultivation and the perennial nature.

Key Words: allometric equations, biomass gain, carbon sequestration, climate change, community, mitigation, tea plantations

1. INTRODUCTION

Carbon sequestration is comparatively a new concept which evolved with the growing global concerns in mitigation of the impacts of climate change and in the process of moving towards a greener economy. It helps to reduce the buildup of atmospheric CO_2 concentration by getting stored in the plant biomass via the balance of photosynthesis and respiration.

Carbon trading schemes are emerging all over the world as many governments try to meet their greenhouse gas emission reduction targets to combat climate change. The information on carbon sequestration had already been generated for several land use types and ecosystems and such experiments continue to gain more attention and high priorities among the other topics due to continuing global trends and demands. As a result, carbon sequestration ability had been determined in many forest tree species, forest types, agro forestry systems and timber plantations etc.

Unlike in developed countries, developing countries do not have carbon inventories and data banks to monitor and enhance the carbon sequestration potential of different plantations. However based on the importance of mitigating climate change and the global effort to reduce the atmospheric CO_2 concentration, baseline data are generating for different land use types even in the developing countries as well. In India attempts were made to assess carbon sequestration at macro level with the available data and also a pilot study was conducted to estimate the carbon stocks in teak ecosystems (Adalarasan *et al*., 2007). In Kenya, the carbon and nutrient stocks in tea plantations differing in age and genotype have been estimated (Kamau, 2008; Kamau *et al*., 2008). Even in Sri Lanka the carbon sequestration potential of rubber plantations (Tilakaratne, 2007) and few other plantation tree species have been estimated. Although approximate estimates of carbon stocks in tea lands in Sri Lanka have been reported on few occasions with many assumptions, no comprehensive studies were conducted so far to assess the carbon sequestration rates of tea plantations.

Tea plantations can be considered as miniature forests where a range of plant species grow together in harmony. Although this is a man-made ecosystem, the resource capture and utilization efficiency in this ecosystem is of considerable importance. Being the main species majority of *Camellia sinensis* plants are grown in tea plantations with a mixture of high and medium shade tree species, wind breaks, green manure crops and weeds etc. All these plant species contribute to mitigate climate change by fixing varying amounts of CO_2 as biological CO_2 scrubbers. The magnitude of their contribution mainly depends on the plant physiological characteristics such as rate of growth, growth stage and age, environmental parameters such as the availability of soil moisture and nutrients, temperature (both atmospheric and soil), solar radiation and rainfall and also the managerial aspects such as planting density, coppicing and pollarding etc. Therefore the variation of carbon sequestration capacity of tea plantations is quite considerable.

Therefore, this study was conducted to generate the baseline data on carbon sequestration potential of tea plantations in different tea growing regions in Sri Lanka for both seedling and VP tea along with the different types of shade trees.

2. MATERIALS AND METHODS

Representative tea fields from Ratnapura (29m amsl), Hanthana (762m amsl), Talawakelle (1382m amsl) and Passara (1028m amsl) were selected for the sampling in each of the tea growing regions of Low country (LC), Mid country (MC), Up country (UC) and Uva respectively. These fields were well maintained according to the TRI recommendations and therefore had the required soil fertility and shade levels etc. Tea plants of TRI 2025 were selected for the sampling of vegetatively propagated (VP) tea as it is a wide spread cultivar which is grown in all tea growing regions. In addition, seedling (SD) tea plants were selected for sampling from the same elevation and tea-growing zones.

In each selected site, a similar set of tea plants in terms of age, stage of the pruning cycle and the external appearance (canopy spread, canopy depth and stem girth) were selected for the determination of biomass and the respective carbon concentrations through destructive sampling in two occasions namely the initial and final measurements. The tea plants were uprooted manually and they were separated into following parts namely, leaves, green twigs, brown twigs, tertiary branches, secondary branches, primary branches, collar, big roots (diameter of the roots>0.5cm), medium roots (diameter of the roots 0.5cm – 0.25cm), small roots (diameter of the roots<0.25cm) and feeder roots (creamy./ milky colour roots). After taking their fresh weights, sub samples were oven dried until reaching a constant weight at 85 ^oC in a hot air oven. In order to make the comparisons easy and clear, the different parts of the tea plants were further categorized into four main parts namely the leaves, stems, collar and roots. Leaves of all maturity stages available in tea plants were categorized as leaves. For the stem category, all the green twigs, brown twigs, tertiary, secondary and primary branches were included. Collar portion was taken as collar and all types of roots, i.e. big, medium, small and feeder roots were categorized.

Biomass distribution pattern within a tea bush was computed and compared for both SD and VP tea in different tea growing regions. Finally, the total organic carbon content of these sub samples was determined by the dichromate oxidation method (Walkley and Black method).

Biomass gain per tea bush during the time period between the initial and the final measurements was calculated for each region and genotype. Biomass data for replicate bushes of each region x genotype combination was averaged when calculating biomass gain and thereby the carbon gain.

Since the destructive harvesting is not feasible for different types of shade trees, the biomass gain of these species was determined using the allometric equations in two occasions as described above (Table 1).

The total above ground biomass values were converted into total biomass with the aid of root:shoot ratio of 0.26 (Mokany *et al*., 2006). The biomass gain per year was then calculated for each shade tree species separately. Assuming 50% carbon is present in biomass (De Costa *et al*., 2008), the carbon content in each tree species were calculated according to its age. Considering the planting density, the carbon sequestration potential of these different shade tree species were then compared as a rate of carbon gain per unit area per unit time for different tea growing regions.

Table 1 Allometric equations used for biomass calculations of different shade tree species

Shade tree species	Allometric equation	Reference
Grevillea robusta		
Branches	$\log_{10}Y = -1.9583+1.9585 \log_{10}X$	Jangra *et al*., 2010
Bole	$\log_{10}Y = -0.2055+1.221 \log_{10}X$	
Roots	$\log_{10}Y = -0.5337+1.2607 \log_{10}X$	
Albizia moluccana	$Y=EXP\{[2.591*\ln D]-3.003\}$	Dharmaparakrama, 2006
Gliricidia sepium	$Y=5.079*e^{(0.151D)}$	Dharmaparakrama, 2006
Erythrina lithosperma	$Y=8.8087*e^{(0.1087*D)}$	Dharmaparakrama, 2006

Note: X is the circumference at breast height (in cm) and D is the diameter at breast height. Y (in kg) represents the biomass in different components for *Grevillea robusta* trees. For the rest of the tree species, Y is the total above ground biomass.

Finally the carbon sequestration potential of the community of tea plantations was compared for different tea growing regions as the rate of carbon gain per unit area under different stands of shade based on the compliance to the recommendations of the Tea Research Institute of Sri Lanka.

The computed per-ha carbon sequestration for different tea-growing regions were multiplied by the respective registered tea extents to compute the total carbon sequestration potential of a given region. Finally the carbon sequestration potential of tea lands were expressed as the rate of sequestering CO_2 equivalents for the low country, mid country and up country tea growing elevations.

3. RESULTS AND DISCUSSION

Both the SD and VP tea showed the similar pattern of variation of fractional biomass distribution among different plant parts (Figure 1). However in VP tea, the fractional biomass distribution towards the leaves and the stems was significantly higher than SD tea. In contrast, the fractional biomass distribution towards the collar and roots was significantly higher in SD tea than VP tea.

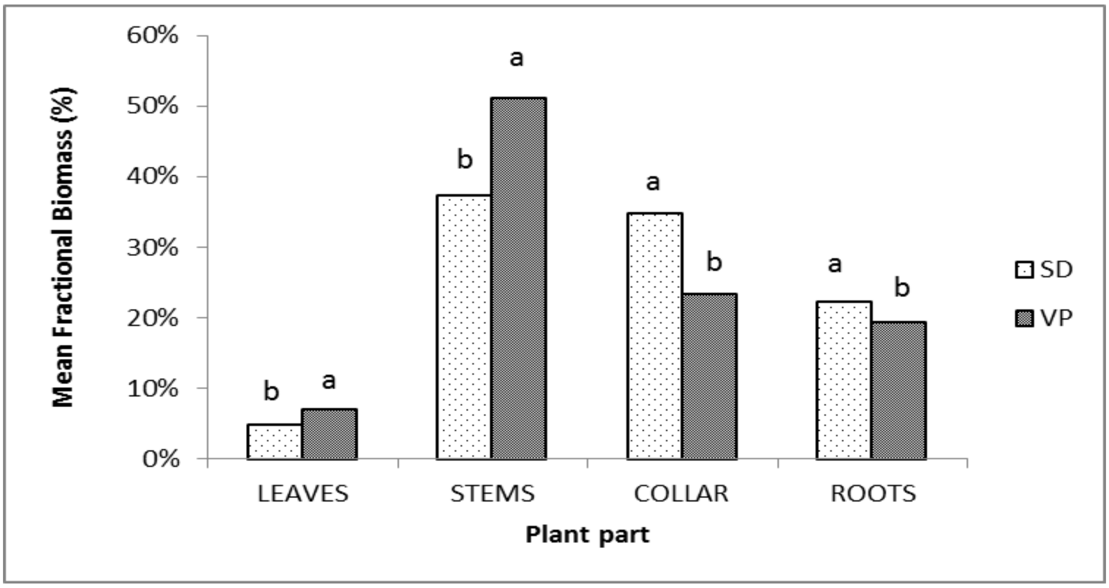

Figure 1 Variation of fractional biomass distribution in tea plants among different parts in SD and VP tea. Within each part the bars with the same letter are not significantly different at the p=0.05.

This difference in biomass distribution pattern in SD and VP tea reflects in the carbon sequestration potential of SD and VP tea plants as well. Based on the management practices of tea plantations, the tea bushes are pruned periodically. Therefore, most of the above ground parts i.e.

mainly the leaves and stems are removed during pruning. Therefore accumulation of biomass in these parts gets disturbed. Since the biomass distribution towards these parts is more in VP tea, this will negatively affect on the biomass and subsequent carbon sequestration potential in VP tea too. On the other hand the biomass distribution towards the collar and roots are higher in SD tea and the disturbance for these parts due to pruning is comparatively less and thereby this will affect positively on the accumulation of biomass and the subsequent carbon sequestration potential in SD tea in all the tea growing regions (Figure 2).

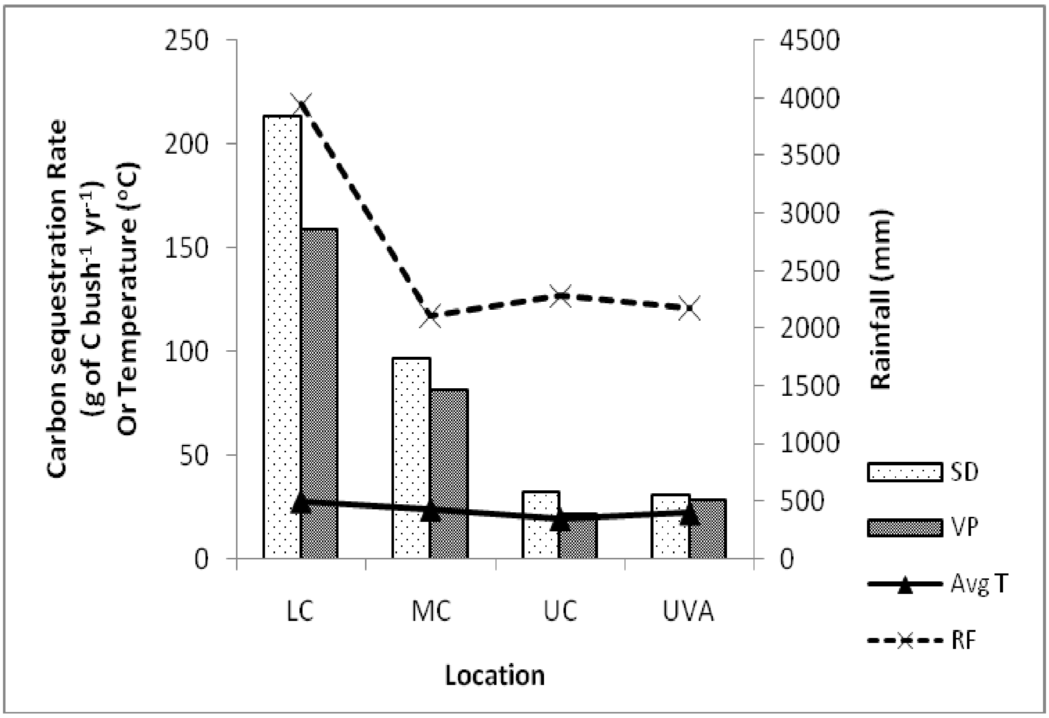

Figure 2 Comparison of carbon sequestration rate of 30 years old seedling and VP tea bushes in different tea growing regions of Sri Lanka and their relationship with the environmental variables

Among different tea growing regions, the highest carbon sequestration potential was observed in the LC, followed by the MC, Uva and the lowest was observed in the UC tea for both SD and VP tea plants.

The mean annual temperature in the four tea growing regions varied from 19.2 ^{o}C in UC to 27.8 ^{o}C in LC which were within the suitable range of temperature for the growth of tea, i.e. below 30 ^{o}C as reported by Carr and Stephens (1992). During the experimental period LC had received a mean annual rainfall of 3946.9 mm which was also favorable for tea with ample amounts of sunshine hours compared to the other locations tested. Thus, it had shown the highest values for the carbon sequestration. In MC the mean annual rainfall as well as the availability of sunshine hours are comparatively less than LC and thereby exhibited a lower carbon sequestration potential too. The lowest temperature and the availability of sunshine hours in up country made the tea plants in UC to have the slower growth rates and thereby the lowest carbon sequestration potential too. Although the Uva had the more or less similar environmental conditions as of MC, due to the erratic rainfall patterns and more frequent occurrence of drought, the growth of tea plants in Uva gets retarded compared to MC and thereby had an intermediate potential of carbon sequestration.

The calculated carbon sequestration values of tea plants based on the bush densities in the absence of shade trees are presented in the Table 2.

Table 2 Comparison of carbon sequestration potential of 30 year old tea plants grown in different regions without shade trees

Region	Type of tea	Bush densities (No. of bushes ha^{-1})	Adjusted C gain Rate ($g\ bush^{-1}\ yr^{-1}$)	C sequestration ($kg\ ha^{-1}\ yr^{-1}$)
LC	SD	8000	213.6	1708.8
LC	VP	12500	159.3	1991.3
MC	SD	8000	96.9	775.2
MC	VP	12500	81.6	1020.0
UC	SD	8000	32.4	259.2
UC	VP	12500	21.6	270.0
UVA	SD	8000	30.9	247.2
UVA	VP	12500	28.8	360.0

Accordingly, the highest carbon sequestration potential was observed in the VP tea fields in low country followed by the seedling tea fields in low country and the lowest was observed in the seedling tea fields in Uva region. The main reason for the higher per hectare carbon sequestration potential in VP tea than SD tea is the difference in bush densities.

Since tea is a shade loving plant, shade trees are usually grown in tea plantations to get better yields. Hence, tea plantations can be considered as a community of tea plants sharing the resources with different species of high shade (HS) and medium shade (MS) trees. It was observed that the addition of shade trees substantially increased the carbon sequestration potential of tea plantations in all the tea growing elevations (Figure 3).

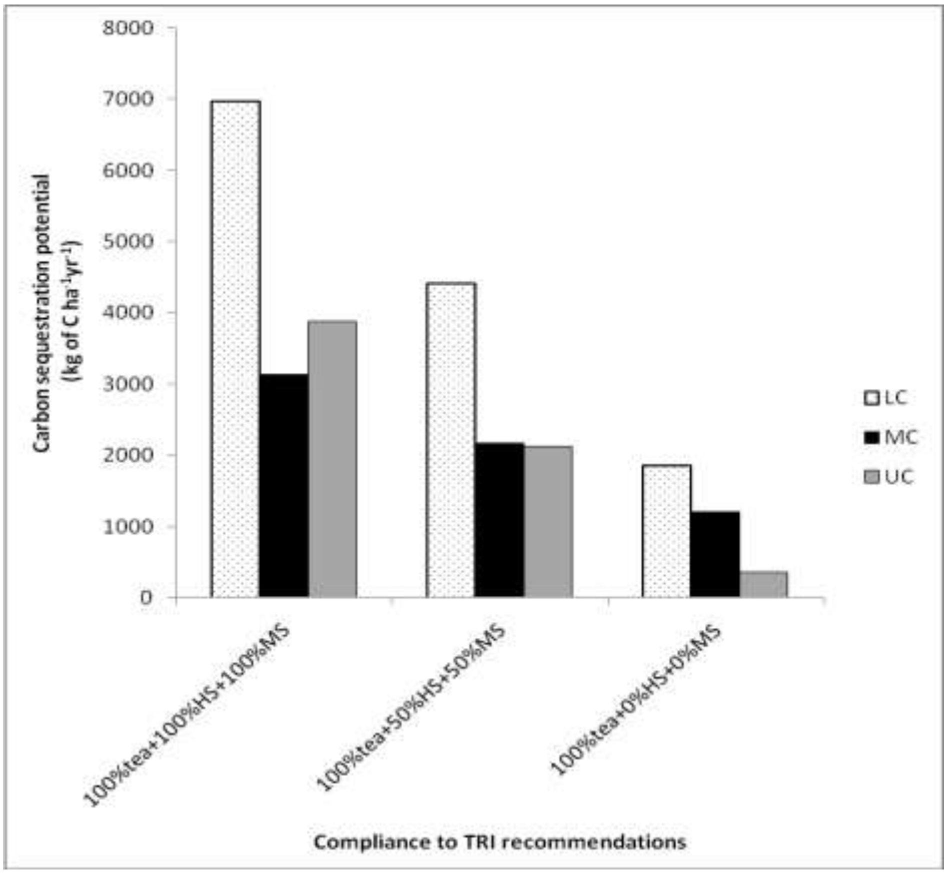

Figure 3 Comparison of carbon sequestration potential of tea lands among different tea growing regions with different densities of shade trees relating to different levels of compliance with TRI recommendations

Therefore, this study further emphasized the necessity of establishment and management of shade trees in the tea plantations not only to improve the micro climate, but also to enhance the carbon sequestration per se and thereby enhance the environmental sustainability of the tea plantations as a community.

Carbon sequestration potential is usually compared in terms of CO_2 equivalents in the different carbon markets available in the world. The figure 4 gives the potential of carbon sequestration of the tea lands in the three elevations by considering the total tea land extents in these three areas.

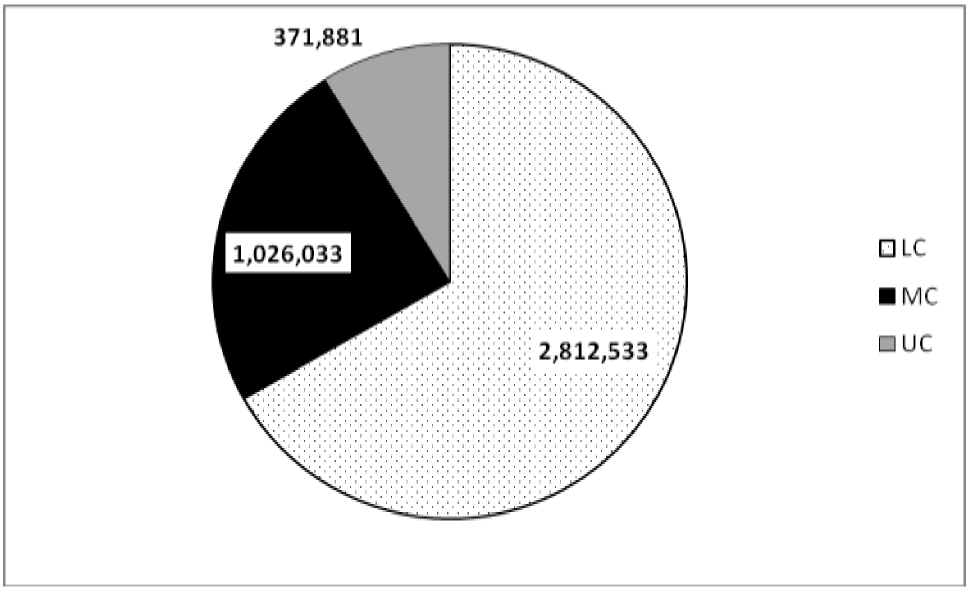

Figure 4 Comparison of carbon sequestration potential of tea plantations in different tea growing elevations in terms of CO_2 equivelents in metric tonnes per year (1 tonne of C = 3.67 tonnes of CO_2 equivalents)

It has been quantified that the low country, mid country and up country tea growing regions have the potential of sequestering 2.81, 1.03 and 0.37 million metric tonnes of CO_2 equivalents per year respectively.

Although the carbon sequestration potential of tea plantations is comparatively less than that of other C3 crops, based on their management, extent of cultivation and the perennial nature, their carbon sequestration potential also of significant importance for exploring possibilities of marketing Ceylon tea as an environmentally sustainable product.

4. CONCLUSION

According to the current study the per plant carbon sequestration potential of seedling tea is higher than VP tea. Incorporation and proper management of shade trees substantially increase the total carbon sequestration potential of tea plantations in low country, mid country and up country and the respective values vary as 2.81, 1.03 and 0.37 million metric tonnes of CO_2 equivalents per year in the three tea growing elevations respectively.

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GENERAL DISCUSSION

While highlighting the relevance of the theme of the 228th E&E Forum "Adaptation Strategies for Climate Change and Carbon Friendly Tea Cultivation" to the tea industry, Dr I S B Abeysinghe, Director of the Institute opened up the technical discussion. As the climate change is inevitable and the consequences to the tea industry are immense with respect to field establishment, productivity, pest and disease management, tea quality as well as other socio economic aspects, he urged the audience to make use of the deliberations aiming at determining short term, medium term and long term approaches for better sustaining the industry. Dr Abeysinghe also commented on fully fledged R&D projects on climate change at the TRI to assist the tea industry and the keen interest shown by the stake holders as well.

Questions directed to Invited Guest Speaker:

Q: (Mr. Kamal Obeysekara)

Is due consideration given when predicting impacts of climate change considering the vast resilience in the environment?

A: (Dr Punyawardena)

Certainly yes, country wise, region wise determinations are in place. For example, under Sri Lankan context, predictions, forecasts and recommendations as adaptations and mitigation measures against climate change are based on the basis of the 46 AERs covering varying rain fall patters, temperature regimes and elevations and specific vulnerable areas to climate change etc. Thereby, crop and variety selections, identification of specific GAPs will be made.

Comment: (Mr. Anil de Mel)

Our experience today is very heavy rains coincide with important field operations such as pruning which invariably leading to environmental effects.

A: (Dr. Punyawardena)

Yes, you cannot avoid it but planning and adjustment of the field operations is very important to minimize the effects to a greater extent.

Q: (Dr. Dan Seevaratnam)

Are there any new important elements included in the soil conservation act and significant laws applicable to the tea industry such as tea cultivation practices and timber harvesting?

A: (Dr Punyawardena)

As yet, there are no changes to the soil conservation act but general requisites such as restriction of cultivation of any crop in land over 5000 ft., tools remain same and tea plantations should adhere to them strictly. Timber harvesting is governed through the environmental acts.

Questions on Climatic Variations in Tea Growing Regions &Vulnerability of Tea Plantations to Climate Change:

Q: (Dr Sivapalan)
What is the % of tea plantations highly vulnerable to climate change?

A: (Dr Wijeratne)
In the preliminary studies, we attempted to identify the areas and vulnerable areas considering rainfall, temperature and other factors will be done in the next step.

Q: (Mr. Hulangamuwa)
Is it worth investing on replanting in vulnerable areas especially in medium grown region?

A: (Dr Wijeratne)
What is important is to make use of such lands with adequate adaptation measures by implementing long term and short term practices with due consideration given to land suitability / categorization.

Questions on Climate Change Adaptation Strategies for Tea Plantations:

Q: (Dr Sivapalan)
Have you got any reasons identified to increase shade density or levels to respond to climate change?

A: (Director)
TRI diagnostic survey results categorically said the need of meeting TRI recommended spacing and shade types which showed clear differences in areas vulnerable to climate change such as in Uva and intermediate zone.

Questions on Carbon Sequestration Potential of Tea Plantations in Sri Lanka:

Q: (Mr. Ousmand)
What is the potential for Carbon trading at national level based on the TRI studies on carbon sequestration?

A: (Mrs. Wijeratne)
Our studies to establish carbon sequestration levels were based only on tea plants but for a national level consideration, other crops, plant species and tree species need to be studies which is being done by various research institutes at present.