ABSTRACT: Vulnerability of coconut plantations to climate change mainly depends on exposure (intensity of atmospheric or soil drought), adaptations and sensitivity (varieties). Climate change adaptation interventions provide a buffer against economic risk to minimize the economic vulnerability of the sector. As the fruit set of coconut is the most sensitive process to heat and water stress, the research conducted on the effect of short-term climate variability on fruit set related processes and possible adaptation options for its improvement are discussed in the paper. Thus, the research conducted on screening coconut varieties and coconut-based mixed cropping systems, with special emphasis on improving microclimate for coconut, identifying the level of competition for water and nutrients between coconut and intercrops, and estimating carbon sequestration potential of the systems as main adaptations to climate change effects, are highlighted in this paper. Strengthening research on adaptation measures to climate change and carrying out awareness programmes for growers to minimize the yield reduction due to heat and water stress (drought) are of utmost importance.

Keywords: carbon sequestration, Cocos nucifera L, dwarf x tall hybrids, heat stress, pollen physiology, water stress

INTRODUCTION

Coconut (Cocos nucifera L) is one of the major plantation crops in Sri Lanka, which covers about 440,000 ha and grown in different types of soils with diverse moisture and nutrient regimes in different agro-climatic zones. The annual national production of coconuts vary between 2300 - 3000 Mn nuts mainly depending on the climatic conditions. Nearly 70% of the total coconut production is being consumed domestically, with a per capita consumption of about 85 nuts/year and the balance is used for industries. Coconut significantly contributes to the foreign exchange earnings to the country accounting for 1.0% of the GDP.

Global climate has been changing mainly due to rapid increase of emission of greenhouse gases through anthropogenic activities. The Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC, 2007) has documented that the global temperature had increased by about 0.74 °C during the period 1905–2006. Warming over the past 50 years was nearly two times higher compared with the past 100 years (IPCC, 2007). There is also evidence that the 11-year period from 1995 to 2006 was the warmest on record (IPCC, 2007). This was accompanied by regional level warming patterns. Trend analysis of temperature in Sri Lanka reveals that both the daytime maximum and nighttime minimum temperatures have significantly increased at a rate of 0.01 to 0.03 °C per year with
a few exceptions. In addition, the number of days with higher temperature values has also been reported during recent years. Compared to the global trend of increasing temperature (0.74 °C during 1905-2006), the increasing trend in Sri Lanka is very significant (Premalal and Punyawardena, 2013).

The optimum climatic conditions for growth and yield of coconut production are, a well-distributed annual rainfall between 1300 and 2300 mm, mean annual temperature of 27 °C with diurnal variation of 5 °C, and abundant sunlight ranging from 250 to 350 W m⁻² with annual sunshine of 2000 hrs (at least 120 hrs per month). The coconut palm experiences moisture stress when exposed to irradiance around 265 W m⁻², temperature of 33 °C and vapour pressure deficit of 2.6 KPa, aggravated by soil water deficit due to dry (rain free) periods longer than two months (Kasturi Bai et al., 2003). Nevertheless, coconut is frequently exposed to soil water stress (due to low precipitation, water infiltration, water retention and rapid drainage) and atmospheric water stress (resulting in from high vapour pressure deficit due to low relative humidity associated with high temperature) because it is mainly a rainfed palm with a long productive life span.

Reproductive organs of a coconut palm (from flowers to mature nut) are more sensitive to water stress and high temperature than the vegetative organs. Coconut palm produces one inflorescence every month and the crown of a healthy palm generally bears 14-16 coconut bunches of different developing stages. The stages of coconut inflorescence development from primordial initiation to the inflorescence opening (non-visual phase) takes about 26-27 months (Perera et al., 2010) and from female flower fertilization to nut maturity (visual phase) it takes about 11 months (Ranasinghe et al., 2012, 2013, 2014). The ‘sensitive stages’ of inflorescence development such as ovule and pollen formation takes place within the last three months before opening of the inflorescence (Perera et al., 2010) whilst pollination and button nut formation take place within the first month of inflorescence opening. The climatic condition during the first three months after inflorescence opening determines the number of set fruits. The principal deleterious effect of high temperature and water stress of coconut is on the fruit set, which is the main yield determining factor. The reduced fruit set of a palm can be due to reduced supply of assimilates to fruits, poor quality of female flowers and pollen, or due to reduced pollen germination under heat stress conditions (Ranasinghe et al., 2010; 2012). For Sri Lanka Tall cultivar (SLT), the critical temperature for fruit set under both heat (atmospheric drought) and water stress (soil drought) is 33 °C and under atmospheric drought alone (under irrigation), it is about 35 °C. In addition to reduced fruit set, the climate variability can affect the quality of fruits and rate and duration of assimilate production depending on the intensity of exposure and sensitivity. The focus of this paper is to review the current status of research on climate change impacts on coconut, adaptation and mitigation strategies, conducted in Sri Lanka during recent past, with special emphasis on reproductive survivability.
PRESENT STATUS OF RESEARCH AND DEVELOPMENT ACTIVITIES RELATED TO CLIMATE CHANGE

Selection of heat and drought-tolerant varieties of coconut

Use of varieties with heat and drought tolerant characteristics is one of the major adaptation options to effects of climate change. There can be several approaches to select such varieties i.e. by evaluating annual yields and fruit components of different varieties grown under different growth conditions, monitoring physiological parameters such as water use efficiency and related morphological parameters, and evaluating the reproductive organ development, pollination and fruit set under climatic variability. As there had been adequate publications and reviews on yield reduction and physiological parameters during the last few decades, the present paper mainly focusses on screening cultivars based on reproductive organ development, pollination and fruit set.

Female flower production and fruit set of different varieties under heat and water stress:

A study that assessed the response of female flower production and fruit set of different coconut varieties revealed that the major problem associated with poor yield in the Dry Zone is lower female flower production and fruit set under heat and water stress conditions. None of the hybrids evaluated, i.e. two tall hybrids namely, Tall x Tall (TT) and Tall x San Ramon (TSR); four dwarf x tall hybrids namely, Dwarf Green x Tall (DGT), Dwarf Green x San Ramon (DGSR), Dwarf Brown x Tall (DBT) and Tall x Dwarf Brown (TDB), showed tolerance to severe water and heat stress condition with respect to female flower production and fruit set (Fig 1). The same effect was observed in the Intermediate Zone, but the reduction in female flower production and fruit set under heat and water stress was more prominent in the Dry Zone due to high severity of the drought.

Flower carbohydrates of different varieties under heat and water stress:

A readily available supply of carbohydrates to anthers and pistil is essential for successful pollen germination. The starch content of female flowers (at receptive stage) and anthers with mature pollen of above six hybrids were evaluated under non-stress (January, February) and heat and drought stress (March, April) conditions in two years. The study revealed that the level of starch in female flowers and pollen was significantly low in stressed months in all hybrids and none of the hybrids evaluated were tolerant to severe water and heat stress condition with respect to flower starch content at pollination stage (Figure 2).
Figure 1. Production of female flowers (above) and fruit set (below) of six coconut hybrids in two consecutive years in the dry zone. DBT = Dwarf Brown x Tall; TDB = Tall x Dwarf Brown; DGSR = Dwarf Green x San Ramon; DGT = Dwarf Green x Tall; TSR = Tall x San Ramon; TT = Tall x Tall. Letters in the X axis refers to months in a year from January (J) to December (D).

Figure 2. Starch content of female flowers at receptive stage (a) and anthers with mature pollen (b) of six hybrids during stressed (March-April) and non-stressed (January-February) periods. DBT = Dwarf Brown x Tall; TDB = Tall x Dwarf Brown; DGSR = Dwarf Green x San Ramon; DGT = Dwarf Green x Tall; TSR = Tall x San Ramon; TT = Tall x Tall. Letters in the X axis refers to months in a year from January (J) to December (D).

**Pollen germination and pollen tube growth of different varieties under heat stress:**
Successful fruit set in coconut under stress depends on the response of pollen germination and pollen tube growth to under heat stress. High temperature (>33 °C) during flowering reduces fruit set in coconut. Therefore, identification and development of coconut varieties or hybrids with high reproductive heat tolerance will benefit the coconut industry in view of the climate changes. Coconut hybrids have been grouped into different heat tolerant categories on the basis of their temperature tolerances to pollen germination. Pollen germination and pollen tube length of the hybrids ranged from 56% to 78% and 242 to 772 µm, respectively. Cardinal temperatures ($T_{\text{min}}$, $T_{\text{opt}}$ and $T_{\text{max}}$) of pollen germination and pollen tube length varied among the hybrids and $T_{\text{max}}$ (maximum temperature above which pollen grains fail to germinate) and $T_{\text{opt}}$ for pollen tube length (optimum temperature at which pollen tube growth is maximum) were identified as the most important parameters in describing varietal tolerance to high temperature.

The SLGD × Sri Lanka Tall (DGT, CRIC65) and Sri Lanka Brown Dwarf × Sri Lanka Tall (DBT) have been identified as the most tolerant hybrids to high temperature stress. Sri Lanka Tall × Sri Lanka Tall (TT, CRIC60) and Sri Lanka Green Dwarf × San Ramon (DGSR, Kapruwana) hybrids are less tolerant based on their cardinal temperatures for pollen germination and pollen tube length (Table 1). The $T_{\text{max}}$ for pollen germination of the most tolerant and less tolerant hybrids was 41.9 and 39.5 °C, respectively. The $T_{\text{opt}}$ for pollen tube length in the most tolerant and less tolerant hybrids was 29.5 and 26.0 °C, respectively (Ranasinghe et al., 2017).

**Table 1. Classification of six coconut hybrids into high temperature tolerant categories**

<table>
<thead>
<tr>
<th>Heat stress tolerant category</th>
<th>Variety (hybrid)</th>
<th>Group mean* (pollen germination %)</th>
<th>Group mean* (pollen tube length)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$T_{\text{opt}}$</td>
<td>$T_{\text{max}}$</td>
</tr>
<tr>
<td>Tolerant</td>
<td>DBT, DGT</td>
<td>27.35±0.4</td>
<td>41.90±1.10</td>
</tr>
<tr>
<td>Moderately tolerant</td>
<td>TSR</td>
<td>28.30±0.5</td>
<td>40.10</td>
</tr>
<tr>
<td>Less tolerant</td>
<td>TT, DGSR</td>
<td>28.35±0.5</td>
<td>39.50±0.30</td>
</tr>
<tr>
<td>Unclassified</td>
<td>TDB</td>
<td>28.05±0.4</td>
<td>38.95±0.55</td>
</tr>
</tbody>
</table>

An approach to minimize failures in fruit set in the production of Dwarf × Tall hybrid seeds of coconut under heat and water stress:

In the production of DGT and DGSR hybrid seed nuts, emasculated Sri Lanka Green Dwarf (SLGD) female flowers were crossed with the pollen of Sri Lanka Tall (for DGT) or San Ramon Tall (for DGSR), produced in the same month in the seed gardens of Coconut Research Institute at Lunuwila. The critical temperature and rainfall for reproductive success in coconut were 33 °C and 90 mm/month.
(considering the water requirement of 3 mm/day), respectively, and the months exceeding these critical levels cause heat or water stress on developing reproductive organs (Thomas et al., 2012; Ranasinghe et al., 2015).

The coconut palms that were frequently exposed to these stress levels in the warm/drought seasons resulted in significant failures in fruit set and, frequency of these extreme events is in the increasing trend due to effects of climate change (IPCC 2007). The results of a study conducted in this connection revealed that the unstressed pollen had significantly higher germination (PG %), tube growth (PTL) and starch and, female flowers had higher starch content compared to flowers stressed at any stage around meiosis. Water stress particularly at the meiosis stage increased the total soluble sugars (TSS) in pollen and female flowers. When the SLGD female flowers developed under no stress were pollinated with the pollen developed under no stress condition, the FS% in both crosses was higher [88% in SLGD x SR (DGSR), 78% in SLGD x SLT (DGT)] compared to those pollinated with stressed pollen [44% in SLGD x SR (DGSR), 30% in SLGD x SLT (DGT)].

In contrast, when the heat and water stressed female flowers were pollinated with the pollen produced under heat and water stressed condition (Figure 3) the FS% was lower (39% SLGD x SR and 33% in SLGD x SLT) compared to those pollinated with non-stressed pollen [57% in SLGD x SR (DGSR) and 51% in SLGD x SLT (DGT)]. The female flower number ($R^2=0.62$) and pollen tube growth ($R^2=0.54$) were significantly ($p<0.05$) influenced by the cumulative rainfall during final four months prior to flower opening, pollen and female flower starch ($R^2 = -0.61$, $R^2 = -0.67$) was affected by mean $T_{\text{max}}$ of the same period.

![Figure 3](image_url)  
Figure 3. Variation in early fruit setting (%) of two hybrids when SLGD female flowers produced in eight selected months were pollinated with San Ramon (SR) and Tall (SLT) pollen produced in the same months. Upper case letters indicate significance among the months of flower production and pollination and lowercase letters between the variety of pollen used within a month.
The FS% showed the best correlation with starch of female flowers ($R^2=0.78$). The study concluded that heat and/or water stress around meiosis is very critical for reproductive organs and early fruit set in hybrid seeds. The results also revealed two important aspects; (1) the importance of quality of pollen for a successful fruit set in the production of dwarf x tall seed coconuts, and (2) an important strategy to increase the fruit set during stressed months by using non-stressed pollen to pollinate the stressed female flowers in controlled hand pollination (Amarasinghe et al., 2016; Ranasinghe et al., 2016).

**Coconut-based agroforestry systems to change the micro-climatic conditions of coconut plantations**

Along with the concern of climate change impacts on agricultural systems, climate resilient tree-based agroforestry systems have been receiving attention of the researchers and policy makers as an adaptation measure to climate change impacts. For instance, coconut-based mixed cropping systems or coconut-based agroforestry systems can improve the microclimatic condition by influencing air temperature, soil temperature, vapour pressure deficit and soil moisture content of plantations (Ranasinghe et al., 2014). All of these have a significant impact on modifying the reproductive performance, rate and duration of photosynthesis, evapotranspiration, conservation of soil water and fertility, and subsequently, a sustainable growth and productivity making plantations more resilient to climate change impacts.

Three mixed cropping systems, coconut + guava, coconut + banana and coconut + cashew grown in the Dry Zone were evaluated for changing the micro climatic conditions and improving the fruit set of coconut. The air temperature at coconut canopy level during morning (9.00-11.00) and soil temperature throughout the day were appreciably lower in all three mixed cropping systems compared to mono-coconut system during most of the months. The soil moisture level did not improve in the coconut + cashew mixed cropping system. However, in the coconut + banana and coconut + guava systems, the soil moisture content improved consistently compared to the mono-coconut system resulting in early fruit setting (number/palm/month) in those two mixed cropping systems (Figure 4).
Figure 4. Fruit set (number/palm/month) of coconut palms in coconut + Guava system (C+G), Coconut + Banana system (C+B) and coconut monocrop system (C) in the dry zone of Sri Lanka from January 2012 to December 2013.

In contrast, the female flower production and fruit setting of coconut in coconut + cashew mixed cropping system did not improve compared to the mono-coconut system. Instead there a severe reduction in fruit set of coconut was observed in the coconut and cashew mixed cropping system during severe drought years, possibly due to competition between two crops for soil moisture (Ranasinghe, 2014). Hence, it is utmost important to select the correct intercrop/agroforestry system to be adopted in coconut plantations with under correct management practices for improving the micro climatic condition of coconut plantations as an adaptation to climate change. For example in a coconut-Gliricidia intercropping systems, the competition for water and nutrients between the two crops when they are removed from the growing site for generating dendropower, is yet to be determined.

Climate change mitigation potential of coconut: Carbon sequestration

Ranasinghe and Thimothias (2012) have shown that coconut monocrop plantations under different growth conditions have the potential to sequester carbon between 0.4 - 1.9 Mg C ha\(^{-1}\) month\(^{-1}\), depending on the agro-climatic and soil conditions. In the same plantation, C stocks of palms varied between 17 and 25 Mg C ha\(^{-1}\) depending on the growth condition. Coconut stem was found to be the main C storage organ which stored about 56-70% of the total C stock of palms (Figure 5).

In the coconut monocrop system, C stock in the top soils (0-20 cm depth) \((B_{soil})\) varied between 14 and 44 Mg C ha\(^{-1}\) depending on the growth condition (Figure 6a) and total ecosystem carbon stock \((B_{tot-eco})\) (palms and soil) varied between 32 and 72 Mg C ha\(^{-1}\) and this wide range was mainly attributed to variations in agro-ecological condition of the region, physical, chemical and biological factors of soils therein resulting differences in palm growth, litter production and litter decomposition (Figure 6b).
As coconut stem is the main component in terms of long-term C storage in coconut palms, the potential of C storage in coconut stem with age was estimated on S2 soils in the low country Intermediate Zone (IL1a). The study revealed that coconut plantations (Sri Lankan Tall) on most suitable soils (S1-S2) with correct density (160 palms per ha) have the potential to store up to 40 Mg C per ha until the age of maturity at a rate of about 3.25 Mg C ha⁻¹ yr⁻¹ from four years up to about 65 years of age (Figure 7). Coconut-based mixed cropping systems have the potential to sequester more CO₂ from the atmosphere than coconut mono-culture systems.

Figure 5. Carbon stock of coconut palms ($B_{palm}$) (Mg C ha⁻¹) in terms of its components (stem, leaf, nuts) of moncrop system on S2 (most suitable) and S4 (marginal) land suitability classes (LSC) in agroecolocial regions (AER) WL3 (wet) IL1a (intermediate) and DL3 (dry zone) of Sri Lanka (Adopted from: Ranasinghe and Thimothias, 2012)

![Standing stock (Mg C ha⁻¹)](a)

Figure 6. Carbon stock (Mg C ha⁻¹) in top soil ($B_{soil}$) and total ecosystem C stock ($B_{tot-eco}$) (Mg C ha⁻¹) of a coconut mono crop system on S2 (most suitable) and S4 (marginal) land suitability classes in the agro-ecological regions (AER) WL3 (wet) IL1a (intermediate) and DL3 (dry zone) of Sri Lanka (Adopted from Ranasinghe and Thimothias, 2012)

![Standing stock (Mg C ha⁻¹)](b)
Figure 7. Variation of C storage potential of coconut stem with age on S2 (most suitable) soils in the intermediate agro-ecological zone of Sri Lanka (IL1a).

IDENTIFIED GAPS

Drought and heat tolerant varieties of coconut are yet to be recommended. As the traditional soil moisture conservation methods such as husk burying are not practical due to high export demand for coir, new material/methods for soil moisture conservation should be identified. There is a shortage of heat and drought tolerant seed material for growers. Most of the coconut growers are unaware of adaptation and coping strategies to climate change effects. A comprehensive model on the whole coconut industry is not available to-date for taking policy decisions under climatic risks.

FUTURE RESEARCH AND DEVELOPMENT NEEDS

A comprehensive model on the whole coconut industry linking climatic variability, production variations, supply chains and climatic risks should be developed to take correct policy decisions in advance. Research on identifying heat and drought tolerant, high yielding coconut varieties and novel material/methods for soil moisture conservation under field conditions (e.g. Biochar) have to be further strengthened. Development of heat and drought tolerant seed material in the seed gardens has to be increased. Adaptation and coping strategies should be efficiently and effectively transferred to the end users to minimize socio-economic losses of the coconut sector.

CONCLUSION

The impact of climate change on yield of coconut is significant. The response seems to vary with varieties. The main long-term sustainable adaptation option for growing coconut under a changing climate is screening of varieties with
reproductive survivability/higher yields with climate change effects. The main short-term adaptation options are improving micro climate and CO$_2$ sequestration with coconut based efficient cropping systems and adhering to moisture conservation and soil fertility management practices which have been already recommended to growers. All of these have a significant impact on sustainable growth and productivity making coconut plantations more resilient to climate change impacts.

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REFERENCES


C.S. Ranasinghe


Preparedness of the Natural Rubber Sector against Adverse Impacts of Climate Change and Variability

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Abstract: The vulnerability of rubber plantations in Sri Lanka to climate change has been identified. The Rubber Research Institute of Sri Lanka (RRISL) has been involved in research in various disciplines in developing adaptation measures to adverse climate change impacts and also in the process of developing the knowledge base for carbon sequestering ability to prove the prospects of rubber plantations in receiving carbon credits. Adaptation measures such as soil and moisture conservation measures, planting material and techniques for avoiding heat and water stress, judicious selection of suitable lands for planting, soil fertility improvement, breeding clones for adaptability to different climates and developing adaptation methods for rain interference are among the areas on which investigations are being carried out. This paper reviews the present status of research and development activities related to climate change focusing on the National Adaptation Plan for climate change 2016-2025. Some important findings through research and related ongoing projects on adaptation to the threats of climate change, together with gaps identified and future research focuses are also discussed.

Keywords: Rubber, vulnerability, adaptation, climate change

INTRODUCTION

Rubber [Hevea brasiliensis (Willd. ex A. Juss.) Müll. Arg.] is one of the major plantation crops in Sri Lanka in terms of export earnings and employment generation. In 2016, this sector has earned Rs. billion 4.758 and Rs. billion 111.02 by exporting raw rubber and finished products, respectively (Anon., 2017). Rubber sector, which comprises of estate and smallholder sectors, provides employment directly and indirectly to over 500,000 people (Anon., 2009).

Productivity of rubber, being a rainfed crop grown in different agro-ecological regions in Sri Lanka, depends on good management practices and also on the environment. All agronomic practices in rubber plantations are linked with the weather pattern, especially the rainfall as it affects the tree at all stages of growth from planting through felling. Hence, planning and management in this sector play an important role in attaining optimum productivity from rubber cultivations.

In general, complete avoidance of the adverse weather conditions or their impacts on long-term crops like rubber is impossible. Therefore, developing countries such as Sri Lanka should focus more on adaptation measures that will help survive adverse impacts of environmental change. At the same time focus should be made on protecting the existing rubber plantations, a self-sustaining,
environmentally acceptable eco-system, which is under a heavy decline due to diversification into other crops or uses. The Rubber Research Institute of Sri Lanka (RRISL) with a mission to revitalize the rubber sector by developing economically and environmentally sustainable innovations and transferring the latest technologies to the stakeholders through training and advisory services, has a great responsibility to address the above issues.

Rubber crop has an inherent adaptive capacity to withstand adverse weather conditions. However, this crop is vulnerable to the impacts of climate change. Hence, RRISL is being involved in research in various disciplines in developing adaptation measures to combat adverse climate change impacts and also involved in developing the knowledge base for carbon sequestering ability to prove the prospects of rubber plantations in receiving carbon credits.

Adaptation measures such as, soil and moisture conservation measures, planting material and techniques, judicious selection of suitable lands for planting, soil fertility improvement, breeding clones for adaptability to different climates and developing adaptation methods for rain interference are among the areas on which investigations are being carried out. This paper reviews the vulnerability of the rubber plantations to climate change, the present status of research and development activities related to climate change and their relevance to the national adaptation strategy, barriers to adaptation and future research needs on adaptation to the threats of climate change.

Vulnerability of the rubber sector to climate change

Climate change refers to any significant change in measures of climate; such as temperature, precipitation, or wind, lasting for an extended period (decades or longer). Between rainfall and temperature, the former has the greater impact on productivity of rubber plantations. The ideal annual rainfall for rubber should fall within the range of 1650 – 3000 mm and be reasonably uniformly distributed throughout the year. It was reported that, in general, the tree performance is severely affected if rainfall over a six-month period is less than 500 mm, especially when it is not uniformly distributed (Yogaratnam, 2001). The ideal mean annual temperature range for rubber was identified as 23°C to 28°C. Temperatures below 20°C aggravate decease incidences and above 30°C, over a prolonged period, also affects physiological processes of the rubber tree (Yogaratnam, 2001). As reported by Fernando (2004), cool nights with mist, dew on leaves, intermittent light rains, low temperature and high humidity aggravate disease conditions in rubber plantations. The climatic requirements of rubber cultivation together with degree of limitation are given in Table 1. Different stages of cultivation have varying degrees of vulnerability to climate change. Some issues, which affect productivity of the rubber sector at different stages and probable causes are listed in Table 2.
Table 1. Climatic requirements for rubber cultivation

<table>
<thead>
<tr>
<th>Climatic characteristics</th>
<th>Degree of limitation*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Mean temperature (°C)</td>
<td>28-25</td>
</tr>
<tr>
<td></td>
<td>29-30</td>
</tr>
<tr>
<td>Mean daily max. temp. (°C)</td>
<td>34-29</td>
</tr>
<tr>
<td>Mean daily min. temp. (°C)</td>
<td>&gt;20</td>
</tr>
<tr>
<td>Mean annual rainfall (mm)</td>
<td>&gt;2000</td>
</tr>
<tr>
<td>Rain interference (days/year)</td>
<td>0-30</td>
</tr>
<tr>
<td>Sunshine (hours/year)</td>
<td>2100</td>
</tr>
<tr>
<td>Mean annual RH (%)</td>
<td>&lt;80</td>
</tr>
<tr>
<td>Dry season length (months/year)</td>
<td>0-1</td>
</tr>
</tbody>
</table>

* 0-No limitation, 4-Very serious limitation; Source: Tillekeratne and Nugawela (2001)

Table 2. Vulnerability of different stages of rubber plantations to climate change

<table>
<thead>
<tr>
<th>Stage</th>
<th>Issue/Cause(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nursery</td>
<td>Erratic seed production/ Erratic rainfall pattern</td>
</tr>
<tr>
<td></td>
<td>Scion dieback/ Prolonged dry spells &amp; high temperatures</td>
</tr>
<tr>
<td></td>
<td>Disease problems/ Low temperatures</td>
</tr>
<tr>
<td>Field establishment</td>
<td>Poor establishment success/ Prolonged dry spells</td>
</tr>
<tr>
<td>Immature stage</td>
<td>Poor growth conditions/ Prolonged dry spells</td>
</tr>
<tr>
<td></td>
<td>Disease problems/ Low temperature</td>
</tr>
<tr>
<td></td>
<td>Disturbed routine agronomic practices/ Erratic rainfall pattern</td>
</tr>
<tr>
<td>Mature stage</td>
<td>Low yield/prolonged dry spells &amp; high rain interference</td>
</tr>
<tr>
<td></td>
<td>Disease problems/ Low temperature</td>
</tr>
<tr>
<td></td>
<td>Disturbed routine agronomic practices/ Erratic rainfall pattern</td>
</tr>
</tbody>
</table>

In the wet traditional rubber-growing areas in the Southwest region of Sri Lanka, moisture deficits are relatively absent while in the dry marginal areas, moisture deficits are severe and extend for a period of 4-5 months. The recovery of rubber plants at the time of planting indicated that the establishment success under dry weather conditions is nearly 30% lower and the girth at six months after planting is 35% lower than that of wet region. Similarly, data on girthing pattern of rubber trees in the two regions indicated that more time is taken to reach the harvesting (tappable\(^1\)) age in the dry regions compared to wet regions (Samarappuli and Wijesuriya, 2006).

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\(^1\) The tappable girth of a rubber tree is 50 cm circumference above 120 cm from the highest point of the bud union
Samarappuli and Wijesuriya (2006) confirmed significant differences between different soil moisture regimes on plant diameter, plant height and leaf area made at the end of 12 months after planting, indicating a decline in all growth parameters with the increase of soil moisture stress. Root length, root spread and root dry weight data obtained also showed significant differences between different soil moisture levels on root length, root spread and root dry weight. Assessments of the leaf water potential (LWP), relative water content (RWC) and transpiration rate (TR) also showed significant differences between different moisture regimes, indicating the effect of soil moisture stress on these parameters.

Seed production is a necessity in rubber plantations since the production of planting materials require grafting of seedlings. Till late 1980s, the seed production had been satisfactory and well above the requirement of nurseries in wet and intermediate zones of Sri Lanka and this situation affected the quality of planting material to a greater extent (Seneviratne, 1999). Nayanakantha and Seneviratne (2007) further investigated the vulnerability of rubber seed production in the intermediate and wet zones to climate change. This study identified that the variation in rainfall pattern has contributed to the low seed fall directly and also indirectly through disease conditions.

Several studies were reported in India, Malaysia and Sri Lanka, where rainfall is considered as a major factor influencing productivity of rubber plantations (Anon, 1998; Devakumar et al., 1998; Samarappuli, 1998). Extended dry periods adversely affect on latex volume and rubber yield of clone RRIC 121 but clone RRIC 100 did not respond to adverse weather conditions in a significant manner (Withanage et al., 2007). Rainfall influences the quantity and quality of latex harvested as it interferes with tapping operations and by contact with latex, respectively. However, no adverse impacts occur if the rainfall experiences in late evening and cease before 03.00 hrs. Rubber is a crop which exhibits seasonal variation in yield (Wijesuriya et al., 1997). Hence, any changes in the seasonal pattern may have adverse impacts on the adoption of recommended agronomic practices and harvesting of latex in rubber plantations. Some important events of interest with respect to rainfall are; start, end and length of the rainy seasons, amount of rainfall in different seasons and risk of extreme events. Rubber growing areas of the intermediate zone of Sri Lanka and the areas of the Dry Zone which are being under experimental trials are more vulnerable to adverse impacts of climate change as these areas have limitations up to a certain degree (Table 1) mainly with respect to rainfall.

**PRESENT STATUS OF RESEARCH & DEVELOPMENT ACTIVITIES RELATED TO CLIMATE CHANGE FOCUSED ON THE NATIONAL ADAPTATION PLAN (2016–2025)**

The relevant adaptation options and actions pertaining to the rubber sector extracted from the Sector Action Plan for the Export Agriculture Sector in the National Adaptation Plan (Anon., 2016b) is given in Table 3. As per the national
adaptation strategy for 2016 – 2025, there have been four relevant adaptation needs for the natural rubber sector; viz. enhance the resilience of the rubber sector against heat and water stress, minimize the risk of crop damage due to biological agents, minimize the impact on export earnings due to erratic changes in precipitation and enhance the resilience of export crops and agro-ecosystems to extreme weather events.

**Actions being taken as adaptation options in par with the adaptation need - Enhancing the resilience of the rubber sector against heat and water stress**

*Germplasm improvement:*
Breeding of new clones is one of the key areas of research conducted by RRISL. Two of the recently released clones; RRISL 217 and RRISL 215 were identified as highly stable for all environments (Withanage *et al.*, 2005). Multiplication, establishment and scientific evaluation of the *Hevea* germplasm collection is being done with the aim of enhancing the productivity through genetic improvement and management of genetic resources of *Hevea*.

Table 3. Relevant adaptation options and actions against climate change for the rubber sector (adopted from Anonymous, 2016b)

<table>
<thead>
<tr>
<th>Adaptation needs</th>
<th>Adaptation options</th>
<th>Actions</th>
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<tbody>
<tr>
<td>Enhance the resilience of the rubber sector against heat and water stress</td>
<td>A. Germplasm improvement</td>
<td>• Screen existing clones for heat and water stress</td>
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<tr>
<td></td>
<td></td>
<td>• Introduce new clones with heat, drought and flood tolerance</td>
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<td></td>
<td></td>
<td>• Develop budded plants with drought resistance properties</td>
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<td></td>
<td>B. Improvement of nursery and plantation management practices</td>
<td>• Develop improved cropping system models for vulnerable areas</td>
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<td></td>
<td></td>
<td>• Promote improved nursery and plant management practices (improvements in irrigation, new planting techniques: root trainers, improvement of soil organic matter: bio-fertilizer development)</td>
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<tr>
<td></td>
<td>C. Initiating research studies to assess climate impacts</td>
<td>• Conduct research on; crop physiology, physiology of flowering, intercropping, planting techniques and cropping systems for climate resilience.</td>
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<td></td>
<td>D. Sector capacity development</td>
<td>• Develop research capacity for conducting research on tolerant clones</td>
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<td></td>
<td></td>
<td>• Develop facilities necessary to undertake research in controlled environments</td>
</tr>
<tr>
<td>Minimize the risk of crop damage due to</td>
<td>A. Germplasm improvement</td>
<td>• Screening of existing clones for pest and</td>
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<tr>
<td>Biological agents</td>
<td>Disease resistance</td>
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<td>-------------------</td>
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<tr>
<td><strong>B. Improvement of land and nursery management practices</strong></td>
<td>• Develop pest and disease resistant clones</td>
<td></td>
</tr>
<tr>
<td><strong>C. Monitoring and surveillance of pests and diseases</strong></td>
<td>• Develop recommendations on best practices of pest and disease management</td>
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<tr>
<td><strong>Minimize the impact on export earnings due to erratic changes in precipitation</strong></td>
<td>• Establish a surveillance programme for early detection of new diseases and pests</td>
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<tr>
<td><strong>• Develop a system of forecasting risks of pests and diseases</strong></td>
<td></td>
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<tr>
<td><strong>Enhance the resilience of export crops and agro-ecosystems to extreme weather events</strong></td>
<td>• Develop a system for timely issuing of seasonal and short-term weather forecasts</td>
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<td><strong>• Develop a system for timely issuing of seasonal and short-term weather forecasts</strong></td>
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</table>

The RRISL maintains a germplasm collection of foreign and local clones and during 2016, around 1400 accessions were planted at the Nivitigalakele substation in Matugama and in 2017, several accessions were established in the budwood nurseries at Neuchatel estate, where the RRISL germplasm repository is located. In this respect, the Department of Genetics and Plant Breeding of the RRISL is involved in a project “Multiplication and evaluation of the genotype collection of Heveaobtained from 1981 IRRDB expedition to the Amazon”. Molecular level screening is also being carried out to identify drought tolerant clones (Anonymous, 2016a).
Focusing on the evaluation of adaptability and performance of new promising clones for heat and water stress in non-traditional rubber-growing areas (sub-optimal environmental conditions), RRISL-Smallholder collaborative trials have been established in Eastern, Uva, North Central and North Western provinces.

**Improvement of nursery and plantation management practices**

According to the national adaptation plan, two relevant actions have been proposed with respect to improvement of nursery and plantation management practices for rubber planting; viz. promoting suitable operational and management techniques for nursery and planting, develop improved cropping system models and promoting improved nursery and plantation management practices (Anonymous, 2016b).

**Promoting suitable operational and management techniques for nursery and planting**

**Improved planting material:**

Bringing up of plants through proper nursery techniques is essential for the productivity of rubber plantations. Establishing improved planting material is the best remedy against any adverse impacts of environmental conditions during planting. Young buddings introduced by RRISL exhibit better establishment success coupled with enhanced growth (Table 4).

**Priming of seeds to improve germination success:**

One of the constraints for nursery management is the reduced seed production in the recently planted rubber clones due to various reasons and the erratic rainfall behavior is one of the causes. A strategy has been developed to address the uncertainty in seed availability for plant production (Nayanakantha, 2009). It is recommended to identify a suitable clone with a good seed bearing habit and maintain it by adopting recommended agronomic practices. Some clones have been identified for this purpose; namely RRISL 201, BPM 24, RRISL 217, RRISL 220 and RRISL 226 (Anonymous, 2016a). This will ensure sufficient amount of seeds for raising individual estate nurseries. In addition, priming of rubber seeds with Nitric Oxide donor, Sodium Nitroprusside (SNP) has proved improved germination of seeds and tolerance to abiotic stresses (Nayanakantha _et al._, 2016a).

<table>
<thead>
<tr>
<th>Planting material</th>
<th>Establishment success (%)</th>
<th>Girth (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare root green budding</td>
<td>91.0</td>
<td>45.8</td>
</tr>
<tr>
<td>Bare root brown budding</td>
<td>82.3</td>
<td>45.7</td>
</tr>
<tr>
<td>Green budding poly bags</td>
<td>99.2</td>
<td>45.1</td>
</tr>
<tr>
<td>Young budding poly bags</td>
<td>100.0</td>
<td>48.6</td>
</tr>
<tr>
<td>Brown budding poly bags</td>
<td>98.8</td>
<td>48.5</td>
</tr>
</tbody>
</table>

*Source: RRISL (1998)*

**Table 4. Establishment success and growth after 5 years**
Application of SNP for budded plants:
Application of SNP has been tried for budded plants and it has been found that SNP application could enhance the physiological parameters under drought conditions (Nayanakantha et al., 2016b; Ratnayake et al., 2016). SNP treatment has been imposed to several field trials in the immature status of rubber in the areas of the Intermediate Zone and found positive results. These trials are being continued to recommend appropriate levels of SNP, especially to combat stress conditions.

Application of anti-transpirants:
Use of anti-transpirants has been proposed as a measure to combat heat and moisture stress. This technique has been tried and found to have a positive impact as a measure to combat heat and water stress in rubber plants through sustaining the leaf physiology under dry climatic conditions (Rupasinghe et al., 2016).

Irrigation to reduce moisture stress:
Studies are in progress to assess the feasibility of drip irrigation for rubber nurseries in the Intermediate Zone as a water saving method under severe drought conditions. This study compares the efficiency of drip, sprinkler and manual watering for rubber nurseries (Nakandala et al., 2014; Anonymous, 2016a). Use of salicylic acid with irrigation has also been investigated to alleviate drought stress of rubber nursery plants in the Intermediate zone of Sri Lanka by Nakandala et al. (2013) with considerable success.

Mulching during the immature period of rubber:
Among the different soil management practices that were tested for their effects on moisture conservation in rubber plantations, dead mulch exhibited the highest soil moisture storage capacity of 27.6 cm in comparison with other practices such as growing leguminous covers or naturals. Similar results were observed with regard to other parameters such as leaf water potential, relative water content and leaf water deficit (Samarappuli and Wijesuriya, 2006). Application of straw as a mulch reduces the rate of evaporation of soil moisture thus allowing moisture to remain in the soil for a longer period. Mulches also would influence the moisture content of the soil by their effect on water intake through the immediate surface layer and due to improved soil structure by higher organic matter content, which decreases crusting and surface sealing and permits greater infiltration, thereby increasing the water holding capacity. Any reduction in evaporation of soil moisture would be beneficial to crop growth in the same manner as additional water intake by the soil. Therefore, it appears possible to eliminate or at least minimize the adverse effects of moisture stress by mulching.

Studies on root trainers:
Root trainers with different potting mixtures are being compared with normal poly bags filled with normal potting mixture under nursery conditions. However, this experiment yielded non-significant results (Anonymous, 2016a).
Bio-fertilizer development:
The Department of Soils and Plant Nutrition of the RRISL has been involved in bio-fertilizer development as one of their major research focuses with the objective of improving soil organic matter. Bacteria and fungi associated with rubber rhizosphere are used for the preparation of biofilm bio-fertilizer (BFBF) which improves soil fertility parameters such as available K and P contents, microbial activity, while reducing leaching losses of organic carbon, Mg and nitrate nitrogen from soil (Hettiarachchi et al., 2012; 2014a; 2014b). Combined use of environmental friendly agro-management practices; cover management, mulching (2 kg/plant/6 months) and bio-fertilization (250ml/plant/3 months) showed significant enhancement of soil fertility parameters; organic carbon, total nitrogen, ammonium, available P and microbial biomass carbon compared to normal estate practices at the end of six months period in rubber plantations (Anonymous, 2016a).

Use of organic fertilizer:
Results of a study by Dharmakeerthi et al. (2013a) suggest that humic acid based liquid organic fertilizers could be used to cut down the chemical fertilizer usage in rubber plantations while improving the growth of the rubber plants. As per this study humic acid can be applied to both nursery and immature rubber plants in Boraluresis soils.

Bio-char application:
Application of biochar alters availability of nutrients and acidic cations in soils which in turn could affect growth of plant to different degrees. Effect of rubber wood bio-char amendment on the growth and nutritional status of Hevea nursery plants was determined accordingly by Dharmakeerthi et al. (2012) and the benefits of Bio-char have been documented by Dharmakeerthi (2013b).

Intercropping:
Intercropping is mainly recommended for the immature rubber plantations when there is no income from rubber latex usually during the first six years after planting. While serving this purpose, intercropping plays an important role in conserving moisture in the soil micro climate. Intercropping models available under rubber further improve the resilience of the natural rubber sector under erratic rainfall behavior and extreme events.

Testing different intercrops under rubber is the mandate of the Plant Science department of RRISL. Recommendations are already made for intercrops such as, banana, pineapple and passion fruit during the immature period while cardamom, vanilla and rattan are recommended only for the mature period of rubber. Coffee, cocoa, tea and cinnamon are recommended under rubber for the whole life span (Rodrigo, 2001). Intercropping with rambutan, jak, durian and mango, guava and pomegranate are also being tested under rubber as intercrops and agar wood is a recent introduction as an intercrop (Anonymous, 2006a).
Improve cropping system models for vulnerable areas:
Smallholder-researcher collaborative trials are being conducted in non-traditional rubber growing areas in the Intermediate and Dry Zone of Sri Lanka under the project “Empowering rubber farmers in non-traditional rubber growing areas through knowledge on combating adverse impacts of environment for better productivity” a collaborative study between the Biometry section, Advisory Services Department and Soils and Plant Nutrition Department of RRISL funded by the National Research Council.

This study attempted identifying vulnerability of the intermediate and dry zone areas selected for rubber farming and tested several adaptation measures for adverse climatic conditions. Employing the results of analysis of rainfall, the study devised an appropriate crop calendar for rubber farming. Application of compost together with double the recommended dose of Potassium fertilizer was able to successfully maintain a satisfactory growth of rubber plants in drier areas (Anon., 2016a).

Actions being taken as adaptation options in par with the adaptation need - Minimizing the risk of crop damage due to biological agents

Germplasm improvement:
The actions listed under this adaptation option are screening of existing clones for pest and disease resistance and developing pest and disease resistant clones. The Department of Plant Pathology and Microbiology of the RRISL is responsible to screen the Clones for Leaf and Panel Diseases to identify disease resistant/susceptible nature of rubber clones bred by the Genetics and Plant Breeding department. Screening is done mainly focusing on the diseases; viz. Corynespora leaf fall, secondary leaf fall, abnormal leaf fall and Phytophthora bark rot.

Through this screening process, the Genetics and Plant Breeding department has been able to recommend disease resistant rubber clones for the growers, especially the Corynespora leaf fall disease and the outcome of these screening trials are being employed for future breeding programs (Fernando et al., 2015). Disease resistant clones also have been identified for the other economically important diseases like Powdery mildew, Phytophthora leaf fall disease and Phytophthora bark rot.

Further, it has been planned to introduce a molecular based early detection technique for the identification of Corynespora susceptible/resistant clones and screening of Hevea clones under non-traditional conditions to detect any uncommon disease conditions for the prevention of sudden disease outbreaks.
**Improvement of land and nursery management practices:**

The relevant actions under this adaptation option includes developing recommendations on the best practices of pest and disease management through improvements in nursery management and crop sanitation. These two aspects have been adequately covered by the research and development programme of the Department of Plant Pathology and Microbiology of the RRISL (Anonymous, 2016).

The overall objective of this action is to improve the productivity levels of rubber plantations through the introduction of improved management strategies to combat economically important diseases of rubber plantations. Specifically on this aspect, the Department of Plant Pathology and Microbiology of the RRISL has focused on identifying the potential pests and disease problems in non-traditional rubber growing areas, identification of the cropping systems specific to those areas and assessment of them on disease conditions and their cross infection abilities, identification of biochemical, physiological and abiotic factors affecting disease severity levels, developing improved management strategies for the identified problems and dissemination of knowledge through awareness programs.

**Monitoring and surveillance of pests and diseases:**

Establishing a surveillance programme for early detection of new diseases and pests and developing a system of forecasting risks of pests and diseases are the relevant actions under this adaptation option. Surveillance of potential pest & disease outbreaks to avoid unwanted sudden epidemics is one of the research thrust areas of the Department of Plant Pathology and Microbiology of the RRISL. The objective of the projects under this thrust area is identification of new and potential pathogens and their impacts on rubber cultivations, and the projects which are being conducted at present are, surveillance of alternative hosts and new diseases and survey on White Root Disease. The future research plans under this action are to identify any potential threats for the rubber cultivations, in traditional and non-traditional areas and also of the diseases of intercrops to alleviate any sudden disease epidemics for rubber plantations.

**Actions being taken as adaptation options in par with the adaptation need: Minimizing the impact on export earnings due to erratic changes in precipitation**

Recent studies have shown that there exist erratic changes in the rainfall in rubber-growing areas in the traditional rubber-growing areas (Jeewanthiet al., 2016). Extremely high rainfall events were also identified in some of the rubber growing areas in comparatively drier areas and erratic rainfall patterns were also observed in some areas (Wijesuriyaand Herath, 2001). Further it was pointed out by the smallholder farmers in participatory studies that rains interfere with the
peak yielding period of the rubber tree, viz. November to January (Wijesuriya et al., 2006).

Two adaptation options have been suggested in the national adaptation plan for minimizing the impact on export earnings due to erratic changes in precipitation; viz. establishment of an efficient climate information management and communication system and improvements in cropping systems.

**Establishment of an efficient climate information management and communication system:**
The relevant actions proposed in the national adaptation strategy under this adaptation option are, developing a system for timely issuing of seasonal and short-term weather forecasts and adjusting calendar of operations in accordance with seasonal weather forecasts. The RRISL is a regular participant in the Monsoon forum organized by the Department of Meteorology, during which the seasonal weather forecast is being discussed for various sectors. Although the forecasts are being received by the RRISL, both short and medium term forecasts, yet a fully functioning network has not been established to pass the information to the estate managers and smallholders. Whenever requested, the RRISL advises the estates and smallholdings on the dates of planting employing the research findings on the probable dates of onset of the rainy season.

**Improvements in cropping systems:**
Almost all the actions proposed under the national adaptation strategy under improvements in cropping systems are relevant to rubber plantations (Table 3). Usefulness of mulching is already discussed in this paper under enhancing the resilience of the rubber sector against heat and water stress.

**Land suitability assessment:**
Judicial selection of land for rubber cultivation is another way of minimizing losses due to adverse climatic conditions. Land and soil requirements for optimum growth and productivity of rubber have been established and reported by Samarappuli (2001). Land selection, which is a routine programme conducted by the Department of Soils and Plant Nutrition of the RRISL serve this purpose.

Land suitability modeling has been tried especially for the non-traditional rubber-growing areas especially to explore suitable areas for expansion of rubber plantations (Karunaratne et al., 2011; Sankalpa et al., 2015). This information is vital for policy makers to make appropriate decisions on expansion of rubber cultivation into non-traditional areas.

**Rain water harvesting:**
Rain water harvesting is a practical solution for nurseries especially in the Intermediate Zone, which is not yet been tried in the rubber sector.
Minimizing the effect of interference to tapping operation of rubber:

Interference from rainfall to tapping operations affects the quality and quantity of latex. These seasonal shifts observed in the rainfall pattern when coincide with high yielding months can make a remarkable decline in productivity. The technology recommended by RRISL to combat this impact is the rainguard which is being practiced by the estates and smallholder rubber farmers. Another associated technology is the low-frequency tapping methods proposed by the Department of Biochemistry and Physiology.

The knowledge on biochemical and latex physiological nature of rubber trees (Kudaligama et al., 2012; Rodrigo et al., 2014) have led the Department of Biochemistry and Physiology to develop new low intensity harvesting (LIH) systems with a view to improve productivity during harvesting on renewed panel. These new tapping systems are not only a remedy for the scarcity of harvesters but also an adaptation strategy for increased number of rainy days.

Actions being taken as adaptation options in par with the adaptation need: Enhancing the resilience of export crops and agro-ecosystems to extreme weather events

Wijesuriya et al. (2005) have reported that there is an increased risk of receiving dry spells in most of the rubber growing areas during the recent years when compared to the period 1941-1970. The two adaptation options identified under this category in the national adaptation strategy are establishment of an efficient climate information management and communication system and improvement of disaster risk preparedness and management.

Establishment of an efficient climate information management and communication system:
This has been already explained under minimizing the impact on export earnings due to erratic changes in precipitation which is also relevant to enhancing the resilience of rubber plantations to extreme weather events.

Improvement of disaster risk preparedness and management:
Under this adaptation option, these actions are proposed; namely, identifying and collecting information on areas that are most vulnerable to flood and drought hazards, prepare hazard vulnerability maps and developing guidelines for management of extreme events in vulnerable areas. A project is in operation covering all the above aspects titled “Indicator based identification and forecasting of droughts in Sri Lanka” which is a collaborative project between the RRISL, Wayamba University of Sri Lanka, Department of Meteorology, University of Peradeniya and Natural Resources Management Centre of the Department of Agriculture. The main objective of this project is to develop and propose a sound methodology to monitor and forecast droughts for Sri Lanka and the specific
objectives are to evaluate different drought indices on their suitability under Sri Lankan conditions giving emphasis on statistical considerations and practical use, to study spatial and-temporal changes of selected drought indices, to employ and evaluate different statistical methods for forecasting of droughts and to predict future droughts using indicators for different climate change scenarios. There have been several publications based on this project on drought indicators and their practical use and employing GIS in spatial modeling of drought indicators (Wijesuriya et al., 2016; Gayan et al., 2016; Liyanaarachchiet al., 2017).

IDENTIFIED GAPS IN RESEARCH AND DEVELOPMENT ACTIVITIES AND FUTURE RESEARCH NEEDS

The research and development programs of the RRISL adequately address that adaptation needs, options and activities according to the National Adaptation Plan for climate change of Sri Lanka. Yet, several research are still on-going and at the initial stages which are to be recommended to the industry in future. Before the recommendation a serious thought should be given on the economic aspects considering the environmental benefits. Another gap that has been identified was the lack of coherence between research programs. Research management of the RRISL should focus on adaptation strategies as a holistic approach by encouraging the scientists to work on a common theme. By doing so, the institute will be able to receive outside grants to facilitate both research and capacity development of scientific and technical staff and also to develop appropriate adaptation strategies. The adaptation options to enhance resilience of the rubber sector against heat and water stress; viz. initiating research studies to assess climate impacts and sector capacity development need more focus in future. The actions under these two options have not been adequately focused in the research and development programme of the RRISL. These actions include, conduct of systematic focused research on crop physiology, physiology of flowering, intercropping, planting techniques and cropping systems for climate resilience, develop research capacity for conducting research on tolerant clones and to develop facilities necessary to undertake research in controlled environments.

CONCLUSION

Researches on rubber have been focused on combating adverse environmental impacts even before identifying the threats of climate change. Moreover, Rubber is a crop has its own adaptive capacity to withstand adverse environmental impacts. Further, a monoculture of rubber is a relatively efficient converter of solar energy into dry matter production. As a consequence, the rubber growers have contributed to the sustenance of an environmentally friendly, ecologically sustainable crop with dual economic potentials of both rubber (latex) and timber production for world consumption, while simultaneously contributing to maintenance of the global carbon balance in the atmosphere. There are some identified gaps in the research and development programs of the RRISL although it addresses the adaptation needs, options and activities of the National
Adaptation Plan for climate change of Sri Lanka. The necessity to look into economic aspects before recommendation of new technologies and promoting more collaborative research future needs.

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REFERENCES

Hettiarachchci R.P., Dharmakeerthi R.S., Seneviratne G, Jayakody A.N., de Silva E., Gunathilaka T. and Thewarapperuma A. (2014b): Influence on shoot and root growth of *Hevea* nursery plants at field conditions by application of
biofilm and biofertilizer. In: Proceeding of the nineteenth International Forestry and Environmental Symposium. Department of Forestry and Environmental Science, University of Sri Jayawardenepura.


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