Proceedings of the Workshop on Present Status of Research Activities on Climate Change Adoptions

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Editor in Chief

Prof. Budhdhi Marambe

Sri Lanka Council for Agricultural Research Policy

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Message from the Chairman

I'm honoured to send a message to the Committee on Natural Resources Management, Sustainable Agriculture and Climate change, on the occasion of launching of the proceedings of the workshop on "Present status of research activities undertaken by NARS scientific institutes" on Climate Change Adaptation and Mitigation.

Natural Resources committee is one of the important committees appointed by SLCARP, recognizing the importance of impact of Climate Change on agriculture. SLCARP is charged with the responsibility of preparing the National Research Priorities in the agriculture sector, which covers Plantation, Non-Plantation, Fisheries, Livestock and Forestry sectors. SLCARP organized the above workshop with a view to asses evaluate and ascertain the adequacy and find gaps in National Research agenda with a view to ensure and effective research agenda in place to face the future challenges due to Climate change. The summery proceedings of the above workshop, I hope will be of immense use to the research leaders in evaluating the national preparedness in the agriculture sector to face emerging challenges due to Climate Change.

I take this opportunity to extend the appreciation of the Sri Lanka Council for Agricultural Research Policy to the Chairman members of the National Committee for their untiring efforts in organizing this important workshop.

Chairman
Sri Lanka Council for Agricultural Research Policy

Message from the Secretary

Climate Change is a global phenomenon that poses a threat to food security 24 various countries including Sri Lanka. Extreme Climatic conditions such as drought, floods, typhoons etc. brought by the changing climate adversely affect agriculture crop production systems. This phenomenon has serious implications in the agriculture sector in adopting to change climate, particularly in modifying cultural practices and the use of appropriate technologies to mitigate and/ or cushion the impacts of climate change. Climate change adaptation can significantly reduce many potentially dangerous impacts and reduce the risk of key vulnerability factors.

Being a developing island nation subjects to tropical climate patterns, Sri Lanka is highly vulnerable to climate change impacts. Extreme weather events such as high intensity rainfall followed by flash floods and landslides and extended dry periods resulting inviter scarcity are how becoming common occurrences in Sri Lanka. Therefore, urgent action is necessary to take adaptive measures to build resilience of the country to face the adverse impacts of climate change.

In this context, the present status of research activities are important to provide guidance and directions for all the stakeholders to address the adverse effect of climate change efficiently and effectively.

It is hoped that this publication would provide the readers with up-to date information on present status of research activities related to climate change adaptations.

Finally, I would like to sincerely thank all the authors of the papers, editor in chief Professor, Buddhi Marambe and all other contributors who supported directly or indirectly in organizing the workshop and producing this publication.

Secretary

Sri Lanka Council for Agricultural Research Policy

FOREWORD

Production and productivity of food crops and plantation crops mainly depend on the agro ecological setting, which the crop experienced in its lifespan. Out of all the parameters soil moisture availability and the day and night time temperature has significant impact for the production and productivity of crops. Climate change effects, which are now, experience by Sri Lanka is making significant impact to production and productivity of food crops and planation crops. It is also shows significant effects on natural resources and bio diversity of the country.

Extreme weather events such as floods and droughts were more frequent in recent years when compare to past, highlighting the importance of possible adaptation and mitigation measures, which could be practiced to minimize the effect of changing and variable climate effect.

The National Climate Change Policy of Sri Lanka (2012) clearly endorses the need of appropriate adaptation strategies to take timely actions in order to reduce the impacts on crop production while ensuring the national food security.
The National Adaptation Plan (NAP), which is the next logical step of this initiative, is a country-driven, gender-sensitive and a fully transparent approach to deal with climate change impacts on Sri Lanka, was published in 2016.

The National Adaptation Plan (NAP) of Sri Lanka has identified agriculture, fisheries, water, human health, coastal and marine, ecosystems and biodiversity, infrastructure and human settlements as the most vulnerable sectors to the adverse effects of climate change.

Long before the release of NAP, by National Climate change secretariat, scientists of the National Agriculture Research System (NARS) were engaged in research and development programs in developing varieties and associated technologies for drought, high temperature conditions, soil salinity etc. In order to face the challenges for agriculture and plantation sector due to climate variability.

NAP has underscored the importance of strengthening these programs in more effective and coordinated manner to face the climate change impacts for agriculture and plantation sector. As the coordinating body to coordinate the research activities, SLCARP has identified the importance of reviewing the status of the research and development work related to climate change conducted by NARS research system and conducted a "Workshop on Present Status of Research Activities on Climate Change Adaptations" in November 2017.

This workshop has identified the status of climate change related research activities conducted and the importance given by each sector on development of varieties and technologies to face the climate change challenges.

Importance of strengthening the research and development program based on the identified trust areas in the national adaptation plan for agriculture and plantation sector was taken as the priority in the research agenda of the SLCARP in order to minimize the impact to agriculture and plantation crop production of Sri Lanka. Research Institutes/centers of NARS, individually or in collaborative manner coordinating with universities and other relevant organizations will launch vibrant research and development programs in achieving this noble task to arrest the negative effects of climate change for food and plantation sectors of Sri Lanka.

Chairman and Members
National Committee on Natural Resources Management, Sustainable Agriculture and Climate Change

Contents

Proceedings of the Workshop on Present Status of Research Activities on Climate Change Adaptations (Ed. B. Marambe), pp 1-6. Sri Lanka Council for Agricultural Research Policy, Colombo.

Research and Development Activates on Climate Change at the Natural Resource Management Centre of the Department of Agriculture and Future Needs

A.B. Abeysekera
Natural Resource Management Centre, Department of Agriculture, Peradeniya, Sri Lanka

ABSTRCT: There is an apparent increasing trend of heavy and very heavy rainfall events during recent pentads in the Central Highlands of Sri Lanka. It was also evident that the variability of seasonal rainfall during the recent decade of 2001-2010, has increased compared to the previous decade of 1991-2000 in most places of the island. A similar study conducted for the Dry zone has shown that there is an apparent increasing trend of heavy and very heavy rainfall events during both South west and North east monsoon seasons during the last pentad of the study period of 1990-2014. Both daytime and nighttime maximum and minimum temperatures have shown an increasing trend during the period of 1960-2007 while the number of days with warm daytimes and warm night times has also shown an apparent increasing trend. Out of 25 districts, six districts, namely, Kilinochchi, Mullattivu, Mannar, Vavuniya, Puttalam and Ratnapura have shown very high vulnerability to climate change. A proposed cropping calendar compiled after an extensive statistical analysis of island-wide historical weekly rainfall data suggests that it can be effectively used as an adaptation tool in farming activities from land preparation to harvesting in paddy cultivation in Sri Lanka. The off-season cultivation of food crops and cultivation of crops in non-conventional areas has been identified as an adaptation option for climate change in Sri Lanka. Lack of a comprehensive, spatially-covered agro-meteorological observation network for each agro-ecological region of the country and limitations of medium-term and long-term climate predictions have been identified as constraints in meeting the challenges of climate change. The importance of developing mobile applications to deliver current weather and regular agro-met advisories for farming community has also been recognized as a crucial and urgent need.

Keywords: Adaptation, climate change, climate predictions, climate scenarios, extreme events, vulnerability

INTRODUCTION

Climate change significantly influences the global food security, affecting global transformation to sustainable agriculture (FAO, 2017). Human activities, which extensively drive mainly through the emission of the greenhouse gasses (GHGs), which trap the heat in the atmosphere trigger global warming and directly cause climate change. Boer *et al.* (2008) have shown that agriculture is the sector that mainly hit by climate change and developing countries will be the most vulnerable sector to shocks of climate change. The impacts of climate change on agriculture vary widely over the regions (Smit, 1993). Im *et al.* (2017) have shown that climate change will make parts of South Asia unlivable by 2100 and it further emphasizes that South Asia ranks high on the list of the most threatened regions to climate change.

The climate of Sri Lanka is considered as tropical monsoonal with a marked seasonal variation of rainfall (Punyawardena, 2008). Meanwhile, Sri Lanka has recently been confronted with frequent severe droughts, floods and high intensity rainfalls with subsequent damages to livelihood and well-being of people and infrastructure. Studies have shown that food security of Sri Lanka can be adversely affected due to impacts of climate change in future (De Silva, 2006; Punyawardena *et al.,* 2013a). It emphasizes the need to develop sustainable adaptations initiatives against variations in the climate while identifying the key strategic entry points for research and capacity building on adaptation to climate change impacts. With the growing recognition of agricultural research to meet challenges of uncertainty of the climate over agriculture production, several agencies of the country have initiated research and development efforts through a window of climate change. The Natural Resource Management Centre (NRMC), being the mandated agency of the Department of Agriculture (DoA) of Sri Lanka to undertake climate change related research, has successfully completed several studies to monitor climate change of the country, vulnerability to climate change and possible adaptation strategies to minimize the impacts of climate change.

The objective of this paper is to examine the latest research carried out at the NRMC on the issue of climate change of Sri Lanka and its related issues such as impacts, vulnerability and adaptation while identifying the gaps and future research needs.

PRESENT STATUS OF RESEARCH AND DEVELOPMENT ACTIVITIES RELATED TO CLIMATE CHANGE

Evidence of Climate Change in Sri Lanka

Punyawardena and Premalal (2013) has revealed that there are no statistically significant discernible trends in heavy and very heavy rainfall events during the last two decades of 1991-2010. Nevertheless, an apparent increasing trend of such events has been signaled during the most recent pentad of 2006-2010, especially with the First Inter Monsoon (FIM) rains in the Central Highlands of Sri Lanka.

Nissanka *et al.* (2011) reported that the cumulative annual or seasonal rainfall of major climatic zones in Sri Lanka during the last 50 years had not undergone a significant change. The same is true in terms of variability of cumulative and seasonal rainfall during the period of 1961-2010. However, it was evident that the variability of seasonal rainfall during the recent decade of 2001-2010 has increased compared to the decade of 1991-2000 in most places of the island across all three climate zones, with occurrence of more frequent drought and flood conditions.

Abeysekera *et al.* (2015) ascertained the recent trends of extreme positive rainfall anomalies in the Dry zone of Sri Lanka during the period 1990-2014 and reported that there is an apparent increasing trend of heavy and very heavy rainfall anomalies during both South west and North east monsoon seasons. This trend has been clearly evident during the last pentad of the study period of 2010-2014. The same study emphasized the likely impacts of increased occurrence of positive rainfall anomalies during those two rainy seasons in the Dry zone, as these two rainfall seasons coincide with the reproductive phase of most of the crops grown in both *Yala* and *Maha* cultivation seasons in the Dry Zone.

Furthermore, Premalal and Punyawardena (2013) has disclosed that both daytime maximum and nighttime minimum temperature have significantly increased at a rate of 0.01 to 0.03 ^{0}C per year with a few exceptions. Results have also clearly shown that both the number of days with cold daytimes and cold night times have significantly decreased in most places of the country. Meanwhile, a significantly increasing trend was been observed with the number of days with warm daytimes and warm night times. These findings clearly signal a warming trend in Sri Lanka.

Vulnerability to the climate change

The word 'vulnerability' is usually associated with natural hazards like flood, droughts and social hazards like poverty, food insecurity, etc. At present, it is extensively used in climate change literature to denote the extent of damage expected due to climate change. Punyawardena *et al*. (2013a) has shown that urban areas in the Low Country Wet Zone are by far the least vulnerable to climate change in Sri Lanka. Despite exposure to floods and higher population densities, these districts have better infrastructure, education, health services and livelihood diversity. Communities in the Northern Province (excluding Jaffna peninsula) and Puttalam, and Rathnapura districts demonstrated a high degree of vulnerability due to high exposure, high sensitivity of livelihoods and lower socio-economic development. Meanwhile, major rice producing districts of the island located in Dry and Intermediate zones of the country, namely, Anuradhapura, Polonnaruwa, Batticaloa, Hambantota, Moneragala and Kurunegala, possessed a high degree of vulnerability to climate change. Mountainous districts of the western and eastern flanks of the central hills of Sri Lanka, namely, Kandy, Matale, Nuwara Eliya and Badulla along with Trincomalee and Ampara districts in the Eastern Province show a moderate degree of vulnerability to climate change.

Climate projections for Sri Lanka

It is of paramount importance to foresee the future climate scenario of the country through downscaling of General Circulation Models (GCM) to signal or alarm the policy and decision makers on the degree of severity of this global problem for which we cannot find solutions in isolation. Punyawardena *et al.* (2013b) used the ECHAM4 general circulation model (GCM) under A2 and B2 scenarios of the IPCC as the input to the PRECIS Regional Climate Model (RCM) and concluded that the average annual temperature in Sri Lanka will increase at a range of 2.5-4.5 °C by the year 2080 under the A2 scenario with a possible increase of 2.5-3.25 °C under

B2 scenario. In terms of future climate of Sri Lanka, the projections revealed that the Dry zone will become more drier while the Wet and Intermediate zones become wetter than at present as we reach the end of this century.

Adaptation for the variations in the agricultural sector

As the climate change becomes harsh reality, there should be a paradigm shift in our usual farming practices, and 'adaptation' to minimize the impacts of it on our agricultural production to ensure the national food security and livelihood of farming community. It is obvious that the onset of rainfall in two major growing seasons, namely, *Yala* and *Maha* and the length of the seasons are highly variable. Therefore, farmers frequently faced unexpected losses of their harvest and become economically feeble. As an adaptation measure, it is important to find a solution to this issue by either shifting the cultivation season or changing the cropping patterns.

Chitranayana and Punyawardena (2014) has proposed a cropping calendar to use as a tool in farming activities from land preparation to harvesting. Such information could assist to reduce the amount of irrigation water required and the frequency of water issued from the tanks in respective regions to save the available storage of irrigation tanks for post operations. It can also be used as a decision support tool in planning rainfed upland agricultural systems as well.

Another vital adaptation procedure is the off-season cultivation of food crops and cultivation of crops in non-conventional areas. Punyawardena *et al*. (2015) has identified an extra 500 ha for potato cultivation from Kandy, Kegalle, Mannar, and Mullativu districts. However, Punyawardena *et al.* (2015) suggested that the exact extent of cultivation in these areas should be determined through an assessment of willingness of farmers, easy access to market and land suitability in the context of soil erosion.

IDENTIFIED GAPS

Among the main important factors of crop growth and development, climate is one of the vital limiting factors. Therefore, the changes of climate cause several impacts on farm operations from land preparation to storage of the yield. Long-term, medium-term and short-term climate predictions is the most crucial information needed by all sectors of the agriculture value chain. Although the NRMC has taken initiatives to issue Agro-met advisories in collaboration with Department of Meteorology (DoM), one month before the start of the growing season, its coarse spatial resolution is still a major setback in terms farmers point of view in the decision making process. One of the hindrances for lack of finer spatial resolution for medium- and long-term climate predictions is the inadequate ground coverage of meteorological stations covering all agro-ecological regions (AERs). Therefore, actions should be taken to strengthen the meteorological observation network of the country at the earliest possible.

Agro-met advisories play a vital role in minimizing the climate related shocks on agricultural production process. These advisories should be made available to farmers at least with 10-day intervals backed by alerts on bad weather conditions that could suddenly develop. As the mobile applications have become an important tool in information and communication technology (ICT), actions should be taken to compile 10-day agro-met advisories in collaboration with the DoM and mobile service providers.

FUTURE RESEARCH NEEDS

Future research, related to climate change should be mainly based on addressing of the above stated research gaps. Strengthening of observation network to represent all AERs is a vital need. Using the available data and information, it is important to use recently developed global and regional climate models (GCMs and RCMs) with high spatial resolution to improve the skill of climate projections so that the required policy decisions can be made in advance to ensure future national food security. Use of novel approaches such as Crop Growth Modeling to predict the expected yields of important food crops in a given season is another important area to be researched. Drought monitoring using GIS and Remote Sensing technology coupled with modern ICT tools can be effectively used in decision making process at macro level on national food security and follow up actions.

CONCLUSION

Despite on-going debates on whether the climate change is a reality or myth, there are overwhelming evidence from the scientific research conducted by the NRMC and other agencies that Sri Lanka's climate has two general trends, which has strongly affected the crop production and food security in the country. These two are increasing ambient temperatures resulting in more heat stress and frequent and severe occurrence of extreme rainfall anomalies, *i.e.* droughts and floods. Thus, timely adoption of appropriate adaptation strategies is a prime requirement to reduce the impacts on crop production while ensuring national food security.

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Rice Research on Climate Change in Sri Lanka: Impacts, Mitigation, Adaptation Activities and Future Directions

W.M.U.K. Rathnayake, T.K. Illangakoon and R.S.K. Keerthisena
Rice Research and Development Institute, Batalagoda, Sri Lanka

Abstract: Achieving food security, especially by enhancing the rice productivity to meet the increasing demand, has become a daunting task due to development of many abiotic and biotic constraints that are mainly governed by the climate factors. The impact of such stresses may significantly greater in the future with climate change. The research work carried out by the Rice Research and Development Institute (RRDI) to-date has been focused to meet the above challenges. Rice varieties tolerant to drought, salinity and flood have been developed. Advanced technologies such as laser leveling for precise land leveling, seedling broadcasting to minimize seed paddy requirement and alternate wetting and drying practices to preserve water have been identified. Adjusting the planting dates to avoid flowering during the periods of high air temperatures and relative humidity are being implemented. Efficient use of fertilizer for paddy cultivation is been practiced by using leaf colour charts, alternate P application by developing fertility maps. Integrated management packages to combat with soil salinity, iron toxicity, pest and diseases, weeds and weedy rice have also been recommended introduced to farmers. Development of multi-stress tolerant varieties, improving rice productivity especially in the WZ, improving soil fertility and enhancing rice quality, which are beneficial to overcome the impact of CC should be priority in future Research.

Keywords: abiotic stresses, adaptation, improved varieties and technologies

INTRODUCTION

Rice (*Oryza sativa* L) is one of the world's most important food crops and is the main staple food over 20 million Sri Lankans. With the introduction of new improved rice varieties (NIVs) along with proper technologies and increased cultivated extent, the rice production and productivity have increased gradually but steadily, particularly in the Dry and Intermediate Zones of Sri Lanka leading to achieve self-sufficiency in rice. The total paddy production is around 4.42 million mt from 1.14 million ha of cultivated lands. This production gives 3.09 million mt of milled rice even though the total annual rice requirement at is around 2.29 million mt (Table 1). However, demand for rice is increasing continuously with population growth and therefore the production should be increased in future.

Table 1. Facts on important aspects relevant to cultivation, production and consumption - 2015

Aspects	Value
Extent (million ha)	1.14
Paddy production (million mt)	4.42
Average yield (mt/ha)	4.37
Rice production (million mt)	3.09
Total rice requirement (million mt)	2.29
Rice imports (million mt)	0.03
Foreign exchange spent for import (million Rs)	17,956
Per capita consumption (kg/person/year)	110

Source: Department of Census and Statistics, Sri Lanka - 2016

Increasing in rice production to meet the future demand has become a challenge due to occurrence of many abiotic and biotic constraints such as inadequate water, nutrient deficiencies, soil toxicities, comparatively higher day temperatures, lower night temperatures, and changes in weed, insect and disease composition (Weerakoon *et al.*, 2010a). As all the above biotic and abiotic stresses are governed by the climatic factors, their effects on rice production may be greater in the future with climate change (CC) to which rice cultivation itself has contributed through emission of greenhouse gasses. Though higher atmospheric CO_2 is a positive impact, changing temperature and uncertain rainfall events cause negative impacts to rice production. Day temperatures exceeding 35 °C and night temperatures below 19 °C during flowering stage would cause pollen sterility. High temperature also results in the loss of stored food due to higher respiration and creates a favorable condition for some pests and diseases. Higher rainfall inundates paddy fields, and washes plant nutrients off making the soils unfertile. In addition, high rainfall washes pollens off leading to development of unfertile grains. Low rainfall increases moisture stress and soil salinity in paddy fields causing severe crop losses.

Rice scientists have identified the importance of finding sustainable solutions to above constraints in order to meet the future demands and food security in Sri Lanka. This paper includes the research conducted by the Rice Research and Development Institute (RRDI) to assess the contribution of rice cultivation to GHG emission, to develop mitigation options, to assess the impacts of CC on rice cultivation and to develop adaptation measures. It also discusses the gaps identified and future research needs relevant to CC and helps all stake holders to be aware on the activities done by the RRDI to meet the above challenges.

GHG emission by rice cultivation and mitigation strategies

In paddy fields, emission of CH_4 occurs due to flooding and N_2O due to application of nitrogenous fertilizer. Experiments conducted at the RRDI has revealed that the average CH_4 emission of rice fields in the Intermediate Zone was 0.79 $gm^{-2}d^{-1}$ (Sirisena *et al.*, 2005) while the total CH_4 emission from rice cultivation in the year

2000 was 121.8 Gg (Weerakoon *et al*., 2010a). Direct and indirect emission of N_2O from N inputs used in rice cultivation was also estimated as 0.974 Gg (Weerakoon *et al*., 2010a). Though research works have demonstrated that incorporation of rice straw and green manure to rice soils dramatically increases CH_4 emission due to anaerobic decomposition under flooded condition, a study done at the RRDI has shown that there was no significant increase in CH_4 emission when compost was incorporated during land preparation as the inherent soil organic C content was low (Sirisena *et al.*, 2004).

Conversion of additional lands for rice cultivation to fulfill the future demand has been reduced through the improvement of the productivity of rice varieties (Weerakoon *et al*., 2010a) where the average productivity has increased more than 4-folds during the past 50 years (1.062 t ha^{-1} and 4.37 t ha^{-1} in 1961 and 2016, respectively). Studies have also revealed that AWD can reduce use of water and emission of CH_4 (Sirisena *et al.*, 2005). However, AWD is highly favorable to emit N_2 through nitrification and de-nitrification processes of added nitrogen. Application of Urea, when N is needed, by using leaf colour chart avoids unnecessary addition N to the rice fields (Sirisena *et al.,* 2006).

Studies related to impacts of CC for rice

Elevated atmospheric [CO_2]:

Studies have revealed that if N availability does not limit plant growth, elevated atmospheric [CO_2] would increase the photosynthesis and growth of terrestrial plants (Weerakoon *et al.*, 2005) while increased atmospheric [CO_2] have increased leaf photosynthesis of all rice varieties (Weerakoon *et al.*, 1999; De Costa *et al.*, 2003). Weerakoon *et al.* (1999) also found that rice leaves do not respond to increased atmospheric [CO_2] beyond 550 μmol/mol. Increase of leaf photosynthesis and radiation use efficiency (RUE) with increased atmospheric [CO_2] are also depended on leaf-N concentration (Weerakoon *et al.*, 2000c).

Increased atmospheric [CO_2] has resulted in higher root density due to enhanced tillering, resulting in an increase in N uptake and fertilizer-N recovery, but decreasing N-partitioning towards leaves (Weerakoon *et al.*, 2005). Therefore, elevated atmospheric [CO_2] results in an increase in dry matter accumulation and final grain yield of rice (Weerakoon *et al.*, 1999). All Sri Lankan rice varieties have shown positive responses (De Costa *et al.*, 2007) to elevated atmospheric [CO_2] and the increase in grain yield could be as high as 30% depending on the variety (Fig. 1). The longer duration varieties have shown a greater positive response to increased atmospheric [CO_2].

Since 1960 to 2007, the grain yield of rice per unit increase in atmospheric [CO_2] was 0.042 tμmol^{-1} in the irrigated and 0.019 tμmol^{-1} in the rainfed production systems. These results suggest that varieties and technologies developed in Sri Lanka have been able to effectively capture the beneficial impact of increased atmospheric [CO2] in the irrigated ecosystem but not been effectively used in the rainfed ecosystem (Weerakoon *et al.*, 2010a).

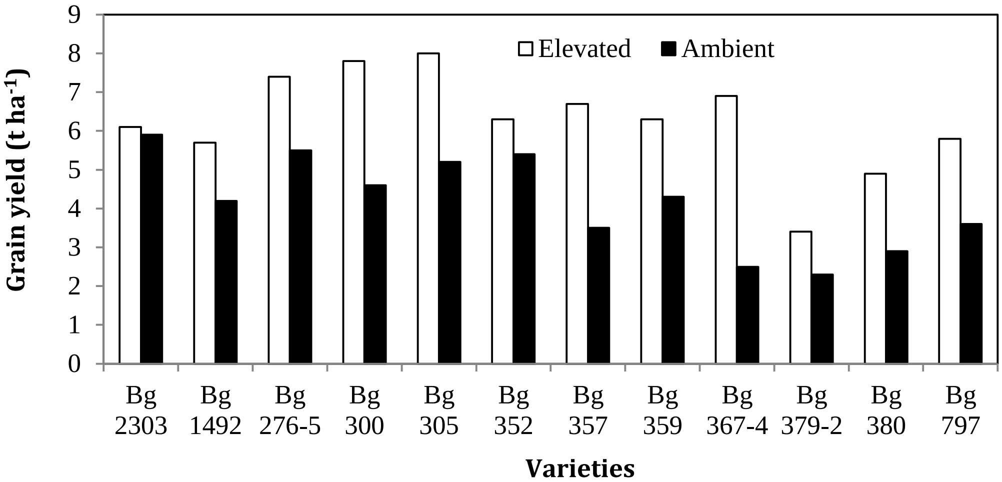

Figure 1. Change in grain yield of different rice lines with enhanced atmospheric CO_2 concentration

Increased air temperature:
Increased maximum air temperature above the threshold value at flowering has negatively affected the productivity of rice in Sri Lanka due to spikelet sterility (Weerakoon *et al.*, 2008). A field experiment conducted using open top chambers revealed that the pollen fertility of rice was reduced significantly at air temperatures of 32.1±1.9 °C (Weerakoon *et al.*, 2005). Increasing temperature inside the spikelet is a function of air temperature and relative humidity (RH). A RH of 85-90% at the heading stage induces almost complete grain sterility in rice at a day/night temperature of 35/30 °C (Abeysiriwardena *et al.,* 2002). Weerakoon *et al.* (2008) also reported that the difference between air and spikelet temperature increased with decreased humidity and the magnitude of change varied with the rice variety. This mechanism is a way of "avoidance", which cools the spikelet under low RH (around 65%) due to evaporation of water vapor from spikelet at higher environmental temperatures. This suggests the variability in "avoidance" for high temperature in its use as a tool for selecting varieties to high temperature tolerance. The results of these studies also explained the reasons for grain sterility observed in farmers' fields in humid Wet Zone and certain parts of the Dry Zone of Sri Lanka during the month of August (Weerakoon *et al.* 2010a).

The critical night temperature to reduce pollen sterility has been found to be 19.9 °C (Silva *et al.,* 2012). The variety Bg94-2 was one of the most adaptable varieties

(Silva *et al*., 2012) for sudden temperature changes in the environment. The rice-growing locations with high and low temperature have been identified and mapped and suitable dates to establish the rice crop has been determined precisely (Rathnayake *et al*., 2016).

The effect of increasing temperature on rice production was simulated where, increase in average temperature beyond 2 °C would have a strong negative effect on rice production while a 4 °C increases could lead to approximately 30% yield drop (Walisinghe *et al.,* 2017). This highlights the need of prioritizing the policies for food security as well as enhancing varietal development to cope up with this situation under CC.

An increasing tendency for pest and disease incidences in rice is expected with increase in temperature. Though Sathischandra *et al*. (2013), who used 30 years of rainfall and temperature data, reported no apparent relationship between the incidence of weeds, insect pests and diseases and climate change in several rice-growing regions of Sri Lanka, Mandanayake *et al.* (2015) reported that the maximum temperature had a significant positive relationship on the population levels of brown plant hopper, green leaf hopper, white back plant hopper, zig-zag leaf hopper and paddy bug.

Weedy rice is a major threat in direct-seeded rice in Sri Lanka (Marambe and Amarasinghe, 2000) and Abeysekara *et al*. (2006) reported that weedy rice is a mixture of off-types comprising of lines related to wild rice and cultivated rice. This suggested that there could be an increased out-crossing within cultivated rice in farmers' fields or between cultivated and wild rice. The increase in out-crossing may be due to high air temperature during flowering. Abeywickrama *et al.* (2009) also observed that the out-crossing percentage in rice had been increased.

Limitation of water availability together with high temperature is more favorable to the emergence of many of the problematic weeds in rice ecosystems. Studies at the RRDI showed that the growth and germination of weeds especially *Echinochloa crus-galli, Leptochloa chinensis, Lindernia rotundifolia* and *Monochoria vaginalis* increased at elevated temperatures of 35 °C (Bandara *et al.,* 2017).

Water scarcity:
Water limitation is one of the severe problems which has negatively affected the rice cultivation during the past few decades. During *Yala* 2017, the cultivated extent was reduced by 44% while 18% of the cultivated extent was damaged due to drought (DOA, 2017). Among the cultivated crops in Sri Lanka, rice is the crop that consume the highest amount of water. Depending on the soil type, season and maturity duration, about 900-1300 mm of water is used from land preparation up to harvesting in rice cultivation. Majority of this water is used for land preparation. However, water required to maintain saturated condition in direct-seeded lowland rice was found to be 24% and 72% lower than that required for flood irrigation in *Yala* and *Maha* seasons, respectively, while maintaining the same yield level

(Weerakoon *et al.*, 2010b). According to Weerakoon *et al*. (2010b) irrigation water productivity was the highest with the saturated culture and saturate to dry soil culture.

Experiments conducted at the RRDI revealed that the water supply is essential during the flowering period of rice plants to avoid crop losses due to pollen sterility (Rathnayake and Nandasena, 2012). Research revealed that drought stress during reproductive and grain filling stages have delayed durations to 50% heading and maturity by 9% and 8%, respectively, while reducing the yield by 58% compared to irrigated condition (Illangakoon *et al.*, 2017). The deep coarse root system and leaf hairiness are associated with drought tolerance in rice (Illangakoon and Somarathne, 2014).

Research and farmers' field studies showed that alternative irrigation is a better way to reduce excess use of water used by farmers. Application of AWD can save 20% of the water used in rice cultivation (Rathnayake and Nandasena, 2012).

Studies related to CC adaptation

Varietal improvement:

In early 1960s, the extent under paddy was 0.59 million ha and the yield potential was around 1.5 tha^{-1},which has increased up to 1.2 million ha and 10-12 t ha^{-1}, respectively, as at present. Improvement of the yield potential up to 10-12 t ha^{-1} has reduced the need to bring in additional land for rice cultivation, which generates GHGs. High yielding NIVs have increased the productivity per unit area and total production from 0.9 million tons (1961) up to 4.42 million tones today (DCS, 2016). From 1960's to-date, scientists have developed 84 improved rice varieties adapted to many climatic and soil conditions in Sri Lanka. At present, NIVs cover more than 99% of the of the rice-cultivated extent in Sri Lanka and out of them, about 10 varieties are more popular covering more than 80% of the extent (Fig. 2).

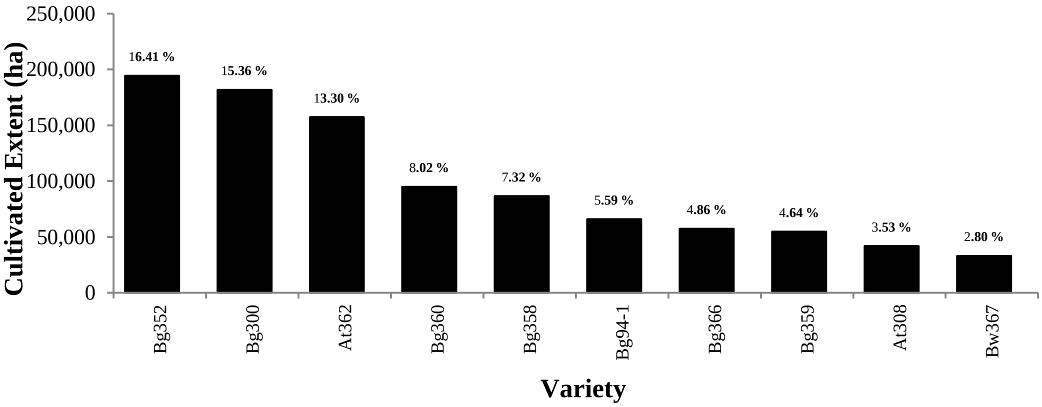

Figure 2. Rice varietal distribution in year 2016 (*Source: Socio-economic and Planning Centre, Department of Agriculture*)

The NIVs are categorized into different age groups based on their maturity durations. Most of the rice varieties that were released in early 1970 to 1980s are medium duration (4-4 ½ months) however, the trend has changed to develop short duration varieties (3-3½ months) mainly due to the limitation of irrigated water for a long cropping season. The first short duration variety (3 months) released by the Department of Agriculture (DOA) is H10 (1968) while Bg750 is the first 2½ months duration variety, which has released in 1981. In addition, several high-yielding short duration rice varieties, which can complete their life cycles around 90 days, have been released (Table 2). Cultivation of these varieties would produce lower amounts of GHGs compared to that from the medium to long duration varieties, and also have the ability to escape drought condition as they complete life cycles without exposing into water shortage at the latter stages of the cropping season. These short duration varieties can also be used for late crop establishment if the previous crop is destroyed by floods or if the cropping season is delayed.

Table 2. Short duration NIVs released from 1968-2016 by the DOA

Year of release	Name of the variety	Duration (months)	Recommendation
1968	H-10	3	General cultivation
1969	62-355	3	Rainfed/Manawari
1971	Bg34-8	3	General cultivation
1979	Bg276-5	3	General cultivation
1981	Bg750	2 ½	Low country intermediate zone
1981	Bw272-6B	3	Low country wet zone for high organic soils- half bog or bog soils
1987	Bg300	3	General cultivation
1987	Bg301	3	Rainfed – Dry & Intermediate zone
1987	Bw302	3	Wet zone
1990	At303	3	General cultivation
1993	Bg304	3	General cultivation
1999	Bg305	3	General cultivation
2004	At306	3	General cultivation
2005	Bg250	2 ½	General cultivation
2005	At307	3	General cultivation
2008	At308	3	General cultivation
2013	At309	3	General cultivation- for rice based product
2014	Bg310	3	Saline prone areas
2014	Bg251	2 ½	Rainfed, low moisture stress prone areas
2015	At311	3	General cultivation(Export quality red Basmathi type rice)
2016	Bg252	2 ½	General cultivation
2016	Ld253	2 ½	General cultivation

Screening and identification of rice lines/cultivars for drought stress was started in RRDI at Batalagoda, Sri Lanka since 2008 through International Network for

Genetic Evaluation of Rice (INGER) and Green Super Rice (GSR) programs (Piyasiri *et al.*, 2012) in collaboration with International Rice Research Institute (IRRI).

Several promising exotic drought tolerant lines namely, Bg 10-9024, Bg 10-9028, IRDTN 7-11, IRDTN 7-56, IRDTN 7-22 have been identified through this collaborative work. The aerobic rice lines, which can be successfully grown under well-drained, non-puddle and non-saturated soil were also tested and four promising lines namely, AERON 9-3, AERON 10-25, AERON 10-05 and AERON 10-26 were identified (Piyasiri *et al.*, 2017). Zhonghua, a line selected from GSR – Rainfed Lowland Yield Trials, is a promising line suitable for cultivation under rainfed condition. The maturity duration and the average grain yield irrigated and rainfed conditions of some of the promising drought-tolerant lines are given in Table 3.

A breeding program has been started at the RRDI since 2013 to develop drought tolerant ultra-short age (80-85 days) rice varieties. Several promising lines namely, Bg 14-2448, Bg 14-2450, Bg 14-2349, Bg 14- 2449 and Bg 14-2437 have been identified and being tested further (Illangakoon *et al.,* 2017).

Table 3. Maturity duration and average yield under irrigated and rainfed conditions of drought tolerant lines

Name of the rice line	**Maturity duration (days)**	**Grain yield (t ha^{-1})**	
		Irrigated condition	**Rainfed condition**
IRDTN 7-11	95-100	8.06	4.06
IRDTN 7-56	100-105	6.26	3.49
Zhonghua	103-107	6.21	4.37
AERON 9-3	100-103	6.36	4.10

Development of cold-tolerant rice varieties has been commenced and few varieties are in the pipe line of crop improvement program of the institute to cope up with low temperature effect. Marker-Assisted Selection (MAS) is currently being used in the breeding programs to speed up the development of drought and submergence tolerant rice varieties.

A promising drought tolerant/escape rice line (Bg10-9028) identified through GSR project was released as Bg251 (GSR) in year 2014 (Piyasiri *et al.*, 2015; Illangakoon *et al.,* 2016). It matures within 80-85 days and gives an average yield of 3.3 t ha^{-1} under rainfed moisture-stressed condition. Among the promising drought tolerant lines identified, IRDTN 7-11, IRDTN 7-56, AERON 9-3 and Zhonghua are now under Variety Adaptability Testing (VAT and LSVAT) and may be released in the near future as drought-tolerant varieties. Currently, these lines are used in breeding programs as parental materials to develop drought-tolerant local varieties. The advanced rice lines developed using those lines as parents are being tested in different agro-ecological zones in large scale.

A flood-tolerant rice variety naming Bg455 (126±8 days) having an average yield of 6 t ha^{-1} (Senanayake *et al.,* 2015) was released for the cultivation in year 2014. Varieties tolerant to ion toxicity (Bw361, Bw364, Bw367 and Bw373) and soil salinity (At354, At401, Bg369 and Bg310) have been developed by the RRDI to adapt to CC impact of deteriorating soil environment.

Crop management:
Owing to labor scarcity and the high cost incurred in transplanting, field establishment was gradually converted into direct seeding (DS), which is the most popular establishment method among farmers at present, as it is economical compared to transplanting. The DS is also preferred for 3-3½ month varieties having shorter vegetative period as there is no transplanting shock. However, in DS, the stand establishment is often low due to poor quality seed paddy, poor land preparation, weed competition, poor water management, unfavorable environmental conditions and physical damages. Therefore, in wet-DS, seed rates of 100 kg ha^{-1} is recommended (for seed having thousand grain weight of 23-24 g) to have a desired panicle number/area. However, the traditional wet-DS in puddled soil is labor-, water- and energy-intensive. Dry DS (*Kakulan* or *Manawari* sowing) with minimum or zero tillage eliminates puddling and is recommended especially when the expected rain gets delayed or when there is less water for land preparation. In dry-DS, a seed rate of 150 kg ha^{-1} is recommended to compensate the losses due to water stress and physical damages.

Seedling broadcasting/parachute technique have been introduced in Sri Lanka and gaining popularity among farmers. The technique substantially reduces the seed paddy requirement (30 kg ha^{-1}) compared to the other crop establishment methods. Other advantages of seedling broadcasting include vigorous plant growth, less weed competition, better yield and irrigation water saving.

The laser-assisted land leveling is another resource-conserving technology recently introduced to the farmers, instead of conventional leveling, which sometimes leads to uneven surfaces. These laser-guided tractors offer more precise leveling. Reduction of water application, improvement of fertilizer efficiency and uniform flowerings & maturities were observed in laser-leveled fields. Combining of plots have also been introduced simultaneously to facilitate laser-leveling to help in increasing land area and reducing labor for bund preparation.

Water management:
Farmers are encouraged to do land preparation and crop establishment using rain water in order to preserve irrigation water for other activities during the cropping season. Further, suitable techniques were introduced to reduce unwanted water use at the initial stage of the crop establishment. The AWD technique for water management is now being successfully implemented in farmers' fields. A low cost simple tool has been developed and introduced to farmers to determine the water level in the field.

Problem soils:
Management packages have been developed and implemented in farmers' field to increase the productivity of saline and iron toxic paddy fields (Sirisena *et al.,* 2006). They include tolerant varieties, land preparation, water management and other agronomic practices to minimize those soil problems. Suitable dates of crop establishment, which are essential to avoid soil salinity effect has also been introduced to farmers (Rathnayake *et al.,* 2015).

Insect, disease and weed management:
Almost all rice varieties released during the recent past are resistant or show medium-resistant to major insect pests and diseases including gall midge, brown plant hopper and blast. Thus, increasing insect pests and diseases incidences may not be a severe problem for rice production even under changing climatic conditions. However, integrated packages for insect, disease and weed management were introduced and shown effective in pest management. An integrated weedy rice management package is also been implemented in the areas infested with weedy rice and have shown some promising results.

GAP IDENTIFICATION AND FUTURE RESEARCH NEEDS

The RRDI has developed many rice varieties and practical solutions to minimize the effects of CC in rice cultivation and further research is continuing. However, in many instances, farmers were unaware about the measures introduced to mitigate and adapt to CC. Therefore, awareness of stakeholders on current mitigation options are needed while continuing research. Extreme weather events such as drought, floods and increasing temperatures occur frequently at present and may continue to happen in more frequent intensities in the future and hence, research related to CC should be intensified.

There is a wider yield gap existing, despite the availability of high yielding NIVs and advanced technologies. The average yield of major rice-growing ecologies are stagnant due to depletion of soil nutrient, cultivation of poor-adapted varieties over the time and adoption of poor agronomic practices, etc. Therefore, much emphasis is needed to develop better adaptable varieties and to test appropriate management practices to enhance the production. Major rice-growing countries such as China cultivate high yielding hybrid rice to generate high income but the hybrid rice production in Sri Lanka is still not successful due to high cost of production and other technical problems. However, it should be given more attention as hybrid rice is one of the key ways to boost the present productivity and to adapt to CC. Site-specific nutrient management (SSNM), which can optimize the use of existing soil nutrients and fill deficits with mineral fertilizer (Buresh and Wopereis, 2014) should be tested to optimize the fertilizer use efficiency and to reduce the cost for inorganic fertilizer while increasing the yield.

The productivity of the rainfed ecosystem is comparatively low due to water stress and weed competition and thus, much emphasis should be given to generate technologies for efficient water use and weed management. Development of ultra-short or short age varieties is effective to escape drought conditions at latter stages of the cropping season. Much attention should be paid to develop varieties that are tolerant to high temperature and submergence conditions as the varieties to overcome these stresses are still not available.

The Wet Zone (WZ) accounts for nearly 25% of the paddy extent but, the productivity still remains as low as 2.75 t ha^{-1}, which is far below the production of Dry (DZ) and Intermediate (IZ) zones (Walisinghe *et al.,* 2013) due to water logging, flooding and soil problems associated with poor drainage. However, WZ is considered as the buffer zone for rice production when DZ and IZ production is affected with drought or water scarcity. Therefore, the need for strengthening research to identify varieties adapted to WZ condition together with appropriate technologies is highlighted. Apart from the productivity, enhancing nutritional value and the quality of rice are key areas to be prioritized as there is a growing concern and demand for quality rice among consumers and other stakeholders at present.

Mechanization is another area to be exploited to enhance profitability, minimize the excessive use of herbicides and as a solution for labor shortage in rice cultivation. Varieties suitable for mechanical transplanting together with suitable agronomic management practices should be identified to obtain the maximum benefit of the technology.

CONCLUSION

Climate change (CC) is a slow process and its impacts are gradual. Many of the research findings of the RRDI help to minimize the effect of CC. Rice varieties have been developed for drought, salinity, flood and cold tolerance. Molecular markers for stress tolerance were also identified. Suitable agronomic and cultural management options have been identified to avoid flowering during periods of high air temperature and relative humidity by adjusting the time of planting. Alternate wetting and drying technique is used to conserve irrigation water. The best management practices for saline paddy fields and integrated weed/weedy rice management packages were introduced. Technologies such as leaf color charts, alternate P application and fertility maps have been developed for efficient use of inorganic fertilizers. The Integrated pest management (IPM) packages were developed and implemented successfully in farmers' fields. However, research should be further focused on developing multi-stress tolerant varieties, enhancing rice productivity especially in the WZ, improving soil fertility and to enhance rice quality which are beneficial to overcome the impact of CC in future.

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Threats and Related Research towards Adaptation of Other Field Crops to Climate Change in the Dry Zone of Sri Lanka

M.A.P.W.K. Malaviarachchi, W.A.K. Karunathilake, R.A.C.J. Perera and M.S. Nijamudeen

Field Crops Research and Development Institute, Mahailluppallama, Sri Lanka

ABSTRACT: Dry zone of Sri Lanka is the major production area of Other Field Crops (OFC) contributing to more than 80% to the national production. Even though these crops have a high potential yield, farmers have failed to realize an acceptable level of this potential yield at field level due to several biotic and abiotic constraints. The main causes for productivity decline in the Dry Zone are deterioration of land resources, erratic weather patterns, biotic stresses and poor adoption of improved agronomic practices. The OFCs mainly grown in the drought prone areas in Sri Lanka are highly vulnerable to the anticipated climatic changes. There are concepts and technologies so far developed to combat the adverse climatic conditions however, some of which are not adopted by farmers. In the future endeavors, development of varieties for adverse climatic conditions, strategies based upon agronomy and surface and ground water management with advanced technology should be given high priority in order to tackle the climate change and its adverse impacts. Evidence on climate variations over the past and in future in Sri Lanka, potential threats, already available strategies for adaptation and present status of research and development activities related to climate change are reviewed in this paper.

Keywords: Other field crops, climate change impacts, adaptation, novel technologies

INTRODUCTION

The Other Field Crops (OFC) category includes condiments such as Chilli (*Capsicum annuum* L) and Onion (*Allium cepa* L), coarse grains such as Maize (*Zea mays* L) and Finger millet (*Eleusine coracana* Gaertn) , grain legumes such as Cowpea [*Vigna unguiculata* (L) Walp], Mungbean [*Vigna radiata* (L) Wilczek], Blackgram [*Vigna mungo* (L) Hepper], and Soybean [Glycine max (L) Merr], and oil crops such as Sesame (*Sesamum indicum* L), Groundnut (*Arachis hypogaea* L) and Mustard (*Brassica* spp.). The Dry Zone is the major production area of these crops in Sri Lanka. The present production of majority of OFCs is far behind their national requirement and therefore a large amount is imported to meet the national demand (Anonymous, 2016). Even though the crops have a high potential yield, farmers have failed to realize it at field level due to several biotic and abiotic stresses and production constraints such as deterioration of land resources, erratic rainfall, pest and disease incidences and poor adoption of improved agronomic practices (Hewavitharana *et al*., 2010).

There are number of records on evidences of climate variations over the past in Sri Lanka. The annual rainfall over a major part of the country has shown a decreasing trend with high variability (Madduma Bandara and Kuruppuarachchi, 1988;

Fernando and Chandrapala, 1995; Katupotha, 2009; Panabokke and Punyawardane, 2009) while an increasing trend in temperature was observed (Fernando and Chandrapala, 1995; Punyawardena and Cherry, 1999; Basnayake *et al*., 2002; Rekha, 2006; Costa, 2008; Katupotha, 2009; Premalal, 2009).

According to the HadCM3 model output for Sri Lanka, the Northeast monsoon rains are predicted to decease by 34% (De Silva, 2009) and Regional Climate Model (PRECIS), predicted that annual temperature of Sri Lanka would increase by 2.5-4.5 °C and 2.50-3.25 °C under A2 and B2 scenarios (IPCC Special Report on Emission Scenarios) respectively, by the year 2080 while the dry zone become more drier than at present under both scenarios Punyawardane *et al.* (2013).

This climate variability would further aggravate the low productivity of rainfed upland farming system in the Dry Zone. In addition, the amount of rainfall received in the *Maha* season would decide the type and extent of both *Maha* and *Yala* cultivation in the lowland rice-based cropping system. Thus, research strategies should be strengthened and ensured that new innovations are adopted by the farmers through an efficient dissemination system.

Present status of research and development activities related to climate change

The majority of research projects, which includes crop improvement, agronomy, soil management, irrigation and plant protection carried out at present addresses the climate change impacts and adaptation strategies. Given below is a summary of some research projects already completed and in progress at FCRDI to cope up with the climate change impacts.

Crop improvement:

The crop improvement program has given the priority for evaluation of varieties and lines for high temperature and water stress tolerance. Germplasm of some crops have been received from the international research organizations and for some crops such as Black gram and Chilli, there is limitation in accessing germplsm. Attempts are been made to introduce some underutilized crops [e.g. Sweet sorghum – *Sorghum bicolor* (L) Moench] to the marginal lands such as salinity-affected lands, water-logged areas and drought-prone areas. The novel techniques being used are mutation breeding, anther culture, double haploid technique and marker-assisted screening. Climate resilient crop management practices include alternative nursery management technologies, off season cultivation practices and locations, management of soil compaction by sub soiling, optimizing bedded-basin irrigation, optimizing micro irrigation by introducing specific management packages, integrated use of micro and macro nutrients, insect pest population dynamics under varying climatic conditions and pest management with light alterations. Physiological responses to changing climate parameters (growth and yield with increasing temperature and nodulation patterns) and possibility of altering some phenological events and physiological processes (bolting in Big onion and hard seed formation in Mungbean) and modifications to cropping systems

(Alley cropping, Multifunctional bunds on rainfed uplands) are also being attempted. Studies have been conducted to adopt mechanization as an adaptation measure to climate change where improving varieties especially Mungbean for synchronized maturity have been carried out at Research centers namely, Mahailluppallama and Angunukolapelessa. Application of abscisic acid (ABS) to increase the filling percentage of groundnut has given encouraging results. However, the effect of ABA on mitigation of drought effect has to be further studied.

Technological improvement:
Several development projects have been executed even in the past to adopt promising technologies at farmer level with the objective of uplifting the Dry Zone agriculture (Somasiri, 1978; Fernando, 1981a; Fernando, 1981b; Keerthisena, 1998). Such concepts and technologies can be categorized into three basic groups as the strategies focused on moisture retention, plant breeding and agronomic approach. The *Walagambahuwa* concept (Somasiri, 1978) was developed to maximize the utilization of incidental rainfall for rice cultivation while reducing the crop failures due to shortage of water at the tail-end of the cropping season. This was done with the underlying principle of utilization of incidental rainfall in *Maha* cultivation through advancing the timing of field operations for rice and save water for rice/OFC cultivation in the subsequent *Yala* season. However, the rate of adoption of the concept by the farmers was not satisfactory**.**

Soil conservation:
Soil degradation caused by extensive clearing of catchment forest of village tanks for farming without conserving soil had been a major issue in the Dry Zone agriculture (Brohier, 1975). As a result, uplands have become unproductive while the tanks in the lower catena are filled with sediments (Dharmasena 1992). Attempts have been made to solve this problem taking the principles of traditional *Chena* cultivation into consideration. Thus, the concept of conservation farming was suggested to introduce to the upland rainfed farming system as a means of maximizing incidental rainfall and to mitigate the effects of periodic droughts on crop growth by the Department of Agriculture, Sri Lanka (Keerthisena, 1995). The basic technology involved was the cultivation of annual crops between leguminous tree species (Alley cropping). Soil moisture conservation with zero tillage, live or crop residue mulching, green manuring, crop-livestock integration, biological nitrogen fixation, use of low cost energy conserving tools were expected under this system apart from other benefits such as nutrient recycling, weed control, improvement in biodiversity as means of natural pest management systems (Dahrmasena, 2003). Experimental evidence showed that soil fertility depleted quickly and addition of inorganic fertilizer did not give substantial returns unless combined with organic matter. As a result inclusion of pasture fodders on upland cropping systems was studied.

Water management:
With the development of the Mahaweli Diversion Project, irrigation facilities were provided to rice cultivation in the *Maha* season to the Dry Zone region of Sri Lanka.

However, farmers were encouraged to cultivate less-water demanding OFCs during the *Yala* season in paddy lands. Thus, technologies were developed to utilize limited *Yala* rains and use available irrigation facilities efficiently. In this context, suitable crops, varieties, specific growth habits, time of planting, land preparation practices were investigated to support the production system. Short-age legumes were found to be performing well with the soil residual moisture available immediately after rice crop in *Maha* season. The concept of '*Meda kanna*' (mid-season cultivation) was introduced at this stage. Not only legumes but also some other crops showed promising results in terms of water saving; for example Kurakkan was successfully cultivated under minimum moisture at 15-20 days interval.

Short age varieties have been developed as an escape mechanism to alleviate from drought situations such as maize (variety *Aruna*), Black gram (variety *Anuradha*), Mungbean (variety MI-6), Cowpea (variety MI 35), Soybean (variety Pb 1) and Groundnut (variety *Tissa*) (Anonymous, 1998). Cropping patterns and relevant management practices to maximum utilization of the available moisture have been introduced. For example, less water-demanding crops such as Finger millet and Sesame were identified as suitable for the rice-based cropping systems and short age crops for mid-season cultivation with appropriate agronomic management practices. Water harvesting as a technique to mitigate the negative impacts of climate change plays a significant role. The increasing temperature enhances the evapotranspiration and desiccates the soils at a fast rate. Further, the changes in the rainfall distribution over time has been observed where intensity of extreme rainfall events have increased while increasing the length of dry spells even during the rainy seasons. The increasing intensity of rainfall reduces the effectiveness of it due to increase in the runoff percentage. Consequently, this will reduce the fraction of infiltration consequently reduce the moisture storage in the soil profile and retard deep percolations. Both increased rainfall intensity and extended length of dry spells affect the crop productivity reducing the soil moisture availability to the crops. Water harvesting was identified as a better remedial measure to address this issue. With the water harvesting studies carried out, terraces with 1% gradient has been identified as the best structure to harvest runoff into the soil profile. The uniformity of moisture distribution within the surface area of terraces is over 90%. Water harvesting either with terraces or with contour bunds enhances ground water recharge. The terraces with 1% gradient is highly effective for the $DL1_b$, DL3 DL4 and DL5 agro-ecological regions of the country, especially in the areas where the total *Maha* season rainfall is less than 750 mm. In addition, storage of runoff in farm ponds is highly effective for the mid country Intermediate Zone for supplementary irrigation to support vegetables. Construction of eye brow bunds is highly effective for perennial horticultural crops and plantation crops, which have larger spacing between two plants.

Timely cultivation:
Due to the changes in rainfall pattern, farmers have found it difficult in identifying the onset of the season and the dates for planting under rainfed condition. Consequently, they lose their crops due to the failure of rainfall at the beginning of

the season. To avoid such crop failures criteria have been developed to identify the onset of the season and dates of planting. As reported by Punyawardane (2011), onset of the season is determined according to amount of precipitation received in a given period of time. If "*weekly cumulative rainfall of a week equals or higher than to the maximum potential evapo-transpiration of the said week and this condition continues for three consecutive weeks beginning from first of September*" it marks the onset of the *Maha* season. When above condition is satisfied by the country or a region that will be announced by the agro-climatologist of the Department of Agriculture, through electronic media.
A study has been initiated to determine the date of planting for the major soil group in agro-ecological regions taking the several factors into consideration and it was defined as "a date where cumulative rainfall of a week ahead is adequate to soak the first 30 cm of the soil to field capacity". These factors include soil water holding capacity, evapotranspiration rates at the commencement of the season, probability of dry spells, and the length at the commencement of the season,

GAPS IDENTIFICATION AND FUTURE RESEARCH NEEDS

There are significant number of proven technologies developed recently and in the past to cope up with climate change (Dharmasena, 2003; Malaviarachchi, 2003; Nijamudeen, 2003), which consist of both individual crop-based approaches and system-based approaches. Many of them were not published, however, the FCRDI (2003) has compiled most of the past research outputs over a period of 50 years (1950-2000).

Further, the scale of adoption of such technologies by the farmers is low. The process of technology dissemination to convince farmers on threats of climate change should be given utmost priority. The extension component should be harnessed with adequate human resources, which is a significant constraint as at present. The integrated involvement of the stakeholders of the agriculture production process is insufficient. Technical and non-technical authorities do not come into a consensus in addressing agricultural issues on most of the occasions. Thus, not only we must find solutions on the farm land itself but also at the policy level.

In many countries in the region including Sri Lanka, rainfed agriculture is practised in harmony with the distribution pattern of rainfall. Variability of cropping intensity (Dharmasena, 2000) and yield (Panabokke and Punyawardena, 2009) in the dry zone was strongly dependent upon the rainfall pattern. Therefore, technologies focused on productivity improvement of the rainfed farming is essential. Simultaneously, priority should be given for development of short age varieties, tolerant varieties for drought, excess moisture, heat, salinity, pests and diseases using conventional and biotechnological tools. Biotechnological approaches should be prioritized in variety development for stress environments, too. Attention must be paid to incorporate wild relatives in breeding programs as they might be better adapted to new climatic and atmospheric conditions.

High temperature causes changes in insect pest population dynamics resulting sudden in pest outbreaks (Karuppaiah and Sujayanad, 2012; Subasinghe and Amarasena, 1988). High temperature influences the physiological (de-vernalization in onion), and phenological development (hastened maturation) (Brewester, 1994; Craufurd and Wheeler, 2009). Ghannoum *et al.* (2000) and Leakey (2009) predicted that C_4 plants would get more advantages if they are exposed to low moisture situations at elevated CO_2 concentrations, which could be observed with time (. Thus, weeds in C_4 group would get comparative advantage over C_3 crops under water shortage situations. In this respect high competitiveness of Purple nut sedge *(Cyperus rotondus* L), *Kukul Atawara* [*Cynodon dactylon* (L) Pers], and *Atawara* (*Panicum repens* L.), which are at present the threatening weeds on uplands in the Dry Zone would be unavoidable. At the same time, problematic C_4 weeds common in the lowland rice fields such as *P. repens, Echinchloa spp.*, *C. rotundus, Leptochloa chinensis* (L) Nees, and *Ischaemum rugosum* Sal. would flourish during comparatively drier *Yala* season where OFCs are grown under rice-based cropping systems. Most of the current noxious weeds being C_4 plants may become highly competitive with the C_3 crops. Thus, farmers would be compelled to apply higher rates of herbicides, which ultimately could contribute to the cost of environment pollution. Therefore, novel weed control measures should be identified specially, in a situation where some systemic chemical herbicides like Glyphosate are currently unavailable due to a ban imposed by the government of Sri Lanka.

Under moisture-stressed environments, and with erratic rainfall patterns, the fertilizer use efficiency (FUE) get drastically reduced. Thus, farmers may tend to apply higher amounts of fertilizers expecting higher yields. Thus, research to increase FUE must be initiated. Similarly, to take advantage of the potential for enhanced crop growth resulted in from increased atmospheric [CO_2], plants have to be supplied with adequate amounts of nutrients. This requirement would be mostly met with inorganic fertilizers rather than the organic sources at an increasing environmental cost, which should be avoided by introducing an Integrated Plant Nutrient Management system. Studies are required to understand the soil, plant and environmental interactions under variable climate for predicting the crop growth and yield using "Crop Growth Models". Developing models based on water balance for the tank-based agricultural systems would minimize risk of farming under climate variability. Except for few, studies focused on the crop physiology and related aspects are rare with respect to OFCs; e.g. De Costa *et al*. (1999); Malaviarachchi *et al.* (2013); Malaviarachchi *et.al*. (2016). The latest hybrid maize variety, MI Maize H1 has shown an appreciable tolerance to moisture deficit conditions.

The traditional cropping calendars have been outdated due to climate changes. Although a criteria for identifying the onset of the season and the and date of planting has been developed, still there are issues in determining the date of planting as the length of the rainy season and the crop duration are not matching as in previously recorded. Hence, further studies on new cropping calendars are imperative.

Changes in quality of legume seeds have been reported by the farming community and researchers to have affected by the temperature changes due to climate change. The physiology of these changes has yet be understood and development of new varieties that are adaptable to fluctuating temperatures is an urgent and timely need. Lowering temperature from 23 °C to 13 °C has increased the vegetative growth of crops and reduced the N availability at the expense of filling seeds (Larmure *et al*. 2005). Further, increasing temperature above 23 °C would result in a decrease in the rate of N remobilization from vegetative parts to growing seeds (Pellissier *et al*. 2007; Ito *et al*. 2009). Eventually, temperature variations can affect seed N concentration, one of the main criteria of determining the quality of grain legumes. Remedial measures for these changes have to be identified in the future. Nitrogen-fixing in legumes are highly sensitive to environmental stresses (Sprent *et al*., 1988), especially to temperature, water, salinity, sodicity, acidity, and nutrient disorders (Chalk *et al.*, 2010; Hungria and Vargas, 2000; Jayasundara *et al.*, 1998). This also will reduce the productivity of legumes. Hence, identification of suitable measures to overcome the negative impact of climate change for Nitrogen fixing in legumes is a need.

In addition to the technical approaches, institutional and attitudinal changes should take place within the farming community to cope up with climate changes. Village level organizations should take common decision as to how the limited natural resources are used, and how to face natural disasters through exchanging their own experiences and knowledge within and between farmer organizations. One of the effective strategy currently practiced is the *Bethma* cultivation system in rice-based lowland cropping systems where the paddy land is shared in water shortage situation. Farmer's attitudes must be focused towards the efficient utilization of available rainwater along with suitable techniques such as micro-level rain water harvesting systems for OFCs.

CONCLUSION

The OFC group, which has a significant contribution to the Sri Lankan economy are mainly grown in the drought prone areas in Sri Lanka. These ecosystems are highly vulnerable to climatic changes. As most of promising technologies so far developed are not readily adopted by farmers, effective dissemination strategies have become crucial to obtain the anticipated benefits Development of varieties and associated technologies for adverse climatic conditions, management of quantity and quality of surface and ground water using advanced technologies, and publications emanating out of those research should be given high priority to overcome climate change and its adverse impacts.

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Impact of Climate Change on Vegetable Cultivation in Sri Lanka: A Review

R.G.A.S. Rajapakse, P. Malathi, W.A.P. Weerarathna, J.P. Marasinghe and K.W.D.P. Nishantha

Horticulture Research and Development Institute, Gannoruwa, Sri Lanka

ABSTRACT: Vegetables are known as protective food as they supply essential nutrients, vitamins and minerals to the human body and are the best resource for overcoming micronutrient deficiencies. The production of vegetables in Sri Lanka has increased during the last decade despite the climate changes. The annual cultivating extent was were 102,364 ha and 99,219 ha and production was 1.1 million t and 1.12 million t in 2015 and 2016, respectively. The average yields of vegetables in upcountry (14 t/ha) are higher compared to that of the low country (10 t/ha) where the climate is comparatively cooler in the former. Presently, year-round cultivation is a common practice especially, in the upcountry and irrigable lands in low country because of the introduction of high yielding, temperature/drought-tolerant hybrids and selected traditional vegetable varieties, and adaptation of newly developed integrated crop and pest management practices. Research and development activities of the vegetable production are mainly focused to meet the recommended per capita vegetable intake of 200 g/person, which will need to require around 1.8 million t of vegetables per annum. However, limited land availability, unavailability of high yielding stress-tolerant varieties for all major vegetables and poor management strategies for soil nutrients, water post-harvest and value addition are the major constraints in improvement of annual year-round vegetable production and productivity of the crops under climate change. Therefore, development and adaptation of new varieties capable to tolerate stresses and novel technologies of integrated crop and pest management packages is a necessity to minimize the impact of climate change on vegetable cultivation in Sri Lanka.

Keywords: Climate change, vegetables, pest and disease, production problems

INTRODUCTION

Vegetables are an important component of human diet as they are a rich source of nutrients, vitamins and minerals. Vegetable crops are generally sensitive to environmental extremes, and thus fluctuations in temperature and limited and excess soil moisture are the major causes of low yields as they significantly affect several physiological and biochemical processes like reduced photosynthetic activity, altered metabolism and enzymatic activity, thermal injury to the tissues, reduced pollination, fruit set, etc., which will be further magnified by climate change. Increasing pest and disease problems are common and they render the vegetable cultivation unprofitable.

There are two main vegetable growing zones in Sri Lanka namely, up country and low country, having two temperature regimes. The production of vegetables in the country has been increased during the last decade despite the climate change (Table 1). The average vegetable prices also drastically reduced in 2016 compared to that of 2015 (Figure 1), which could be a result of increased year-round production of vegetables. The annual cultivating extent in low and upcountry country was 64,521 ha and 31,940 ha and production was 700,639 t and 465,997 t in 2015 and 2016, respectively (Table 1). The average yields of vegetables in the upcountry are the highest compared to the low country where the climate is comparatively cooler in the former.

The increased global temperatures and carbon dioxide levels over the past six decades coupled with greater weather variability and higher extreme weather conditions such as droughts and floods have impacted crop yields and shifted the geographical ranges of crop cultivation (Ewerta *et al*., 2005). Sri Lanka is an island having mainly tropical climate. The country and consists of three major climatic zones, *i.e.* wet, intermediate and dry zone, based on the average rain fall >2500 mm, 1750-2500, and <1750 mm, respectively. Further, the county is sub divided into 46 agro-ecological regions based on the rainfall pattern, elevation, land form, temperature range and type of soil (Punyawardena 2008; Mapa *et al.,* 1999).

Table 1. Extent and productivity of vegetable cultivation in agricultural seasons.

Parameter	**Vegetable extent and productivity in agricultural seasons**					
	***Yala* 2014**	***Maha* 2014/15**	***Yala* 2015**	***Maha* 2015/16**	***Yala* 2016**	***Maha* 2016/17 (up to March)**
Up country (ha)	13,694	16,774	14,613	15,201	16,739	16,799
Low country (ha)	19,462	38,600	32,373	39,112	28,170	32,776
Total extent (ha)	33,157	55,378	46,986	54,313	44,906	49,575
Total production (t)	357,181	615,477	452,532	621,507	545,129	586,663
Productivity (t/ha)	10.772	11.114	9.631	11.443	12.139	11.893

(Source: DOA – various issues.)

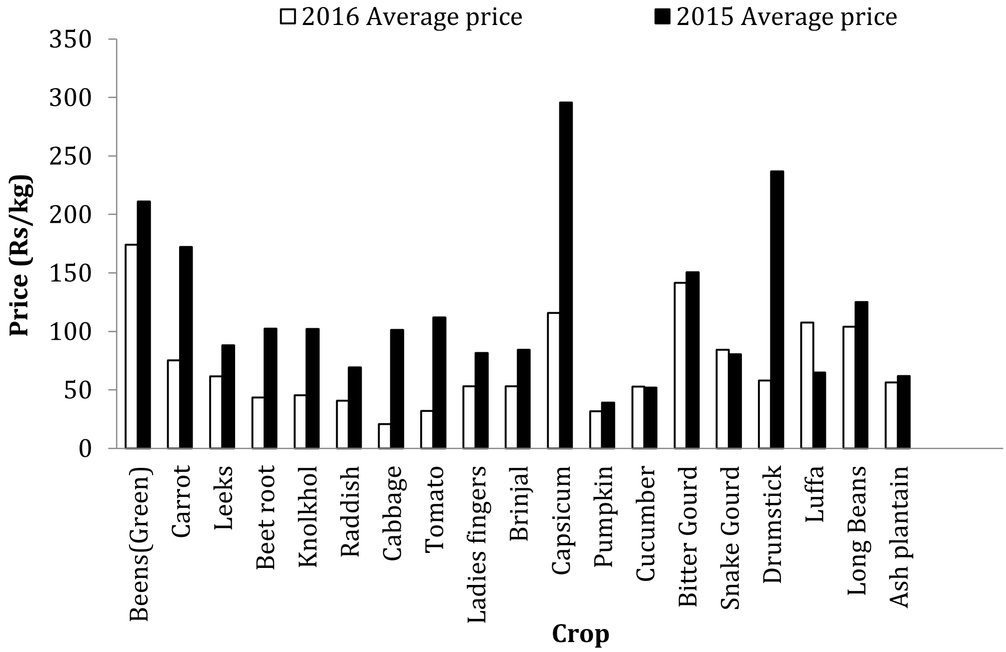

Figure 1. Average price fluctuation of vegetables 2015 -2016 (Source: DOA – various issues)

There are two monsoon, namely, South-West and North-East that occur from May to September and December to February, respectively. Climate change impact in Sri Lanka is due to increasing variability of rainfall intensity and regimes, frequency of storms, mean ambient temperature, variation in diurnal temperature range and changing monsoonal pattern (CCS 2010; Basnayaka *et al.,* 2007). The rainfall intensity, amount of rainfall per rainy day and the average rainfall per spell have increased in most parts of the country (Rathnayaka and Herath, 2005), while the mean temperature has increased by 0.016 °C per year during 1961-1990 (Chandrapala, 1996).

Several disorders have been reported in the recent past in the vegetable cultivations mainly due to climate changes. Absence of fruit formation in tomato (*Solanum lycopersicum* L) and vegetable capsicum (*Capsicum* spp) grown in the dry zone areas and pod formation of bean in Matale, poor head formations of cabbage and cauliflower in Marassana and Dambulla area (Kandy and Matale districts), abnormal fruit shape of tomato and okra [*Abelmoschus esculentus* (L) Moench] grown in dry areas, fruit drop of bitter gourd (*Momordica charantia* L) and luffa [*Luffa acutangula* (L) Roxb.] grown mainly in the dry and intermediate zones (Researchers at HORDI and Provincial Departments of Agriculture – personal communications) in the vegetable cultivation are some of such impacts reported. Climate change is predicted to have a direct impact on changes in the seasonal and monsoon pattern, biotic and abiotic factors, occurrence and severity of pest and diseases in crops and salinity build up in soil, which will have a serious impact on food security (Esham and Garforth, 2013). Despite having a direct effect on rainfed vegetable cultivation, climate change affects water storage and availability of water for irrigation. The failure of the monsoons results in water shortages, leading to below-average crop yields. High temperatures and inadequate rainfall at the time of sowing and heavy rainfall at the time harvesting would cause severe crop losses in the dry and intermediate zones in the country. This is particularly observed of vegetable production in the low country in *Yala* season 2015. The productivity of the vegetables was low (7.82 t/ha) in *Yala* 2015 compared to that of *Yala* 2014 (10.31 t/ha) and *Yala* 2016 (10.51 t/ha) because of the drought condition prevailed in Sri Lanka during 2015 (Table 1).

In addition to the physiological and biochemical changes in crops, climate change influences the pest and disease incidence, host-pathogen interaction, distribution and ecology of insects, time of appearance, migration to new places and their survival capacity in the vegetable ecosystems. Sri Lanka is rich in biodiversity of insect pests, mites, nematodes and their natural enemies, and pollinators. Insect, mite and nematode pests sometimes cause up to 100% economic losses in horticultural crops. The severity of the damage mainly depends on the size of the pest population available in the environment. Ecological factors, climate and agricultural practices play an important role in the pest abundance. Furthermore, the tropical climatic conditions and the vast array of plant diversity are favourable for multiplication of insects. Recent changes in climatic conditions seem to have made a shift in the abundance of certain pest species such as plant virus vectors. Outcomes of surveys and research also show that the change of climatic factors could increase the numbers of important plant virus vectors such as aphids, whiteflies, thrips, plant hoppers and also plant diseases that have not been present under previous climatic conditions (Krishnareddy, 2013).

The vegetable pests such as melon flies (*Batocera* spp. complex) are a major threat to production and marketing of fruits and cucurbits in Sri Lanka and many other countries. The abundance of fruit fly diversity vary with the availability of the host plants, climatic factors, etc. The effect of climatic factors on the distribution and establishment of fruit flies has been studied (Kriticos *et al*., 2007). Statistical models have predicted that with increasing environmental temperatures, the potential distribution of fruit flies includes much of the tropics and subtropics and they extends into warm temperate areas (Stephans, 2007). Similar situations have been reported recently *i.e*. new epidemics of insect vectors such as white flies, mealy bugs, scales insects, plant hoppers, and lepidopteron leaf minor (*Tuta absoluta*) in tomato cultivations in the country (Researchers in HORDI and extension offices of the Department of Agriculture – Personal communication).

Rapidly-changing climate creates favorable conditions for development and increased spread of plant virus diseases due to direct or indirect impacts on population dynamics of virus-transmitting insect vectors. Yamamura and Kiritani

(1998) found that the activity and population of sucking pests such as aphids, whiteflies and thrips increases with increase in temperature. In recent years, diseases caused by plant viruses and phytoplasma have become a significant limiting factor in the sustainable production of vegetables in the commercial and smallholder farming systems of Sri Lanka. A high incidence of leaf hopper-transmitted phytoplasma disease in brinjal (*Solanum melongena* L), cucurbits and okra was reported recently in the dry and intermediate zones and crop losses were reports as almost 100%.

The epidemics of virus diseases such as whitefly-transmitted Begomo viruses in beans and cucurbitaceous vegetables, aphids-transmitted cucumber mosaic virus in pumpkin and capsicum, leaf hopper-transmitted curly top virus in tomato are some of the examples for virus out breaks. Similarly, insects such as mealy bug and scales, mites and root-knot nematodes (*Meloidogyne* spp.) are also becoming a major threat to several food crops, including vegetable capsicum, chilli (*Capsicum annuum* L), tomato, leafy vegetables and many other vegetables grown in commercial cultivations and in home gardens all over the country. Some of the features accounted for the emerge of *Meloidogyne* spp. populations during the recent past in vegetable ecosystems in Sri Lanka are the wide spread cultivation and availability of its host plants, changes taking place in climatic parameters, physico-chemical and biological properties of the agriculture soils, difficulties encountered in controlling these nematodes through nematicide, and adaptation of cropping systems for year round cultivation with introduction of susceptible hybrids.

Increasing trend was reported of the frequency and gravity of plant diseases such as powdery mildew (*Leveilula taurica*), early blight (*Alternaria solani*), fusarium wilt (*Fusarium oxysporum*) and bacterial wilt *(Ralstonia solanacearum*). In contrary, some diseases such as late blight (*Phytophthora infestans*), verticilium wilt (*Verticilium albo-atrum*) and Sclerotinia rot (*Sclerotinia sclerotiorum*) were reported as less prevalent and cause less damage, while some others remained unchanged probably due to unfavorable climatic conditions that prevailed. In potato, economic production is often impossible without controlling blight disease, which is considered to be the most economically important disease of potato worldwide. Application of contact fungicides is the most common practice in controlling blight and usage of fungicides may increase if changing crop physiology interferes with the uptake and translocation of pesticides. Washing away of the contact pesticides due to more frequent rainfall could also lead to more frequent applications. Vegetable farmers tend to use heavy volumes of agrochemicals and other inputs to obtain good yields thus, resulting in higher price increases especially in the months of April to June and November to January. Use of appropriate varieties is the most important strategy to increase the vegetable production and income of farmers during off seasonal cultivation.

The global agricultural regime of monocrops and narrow gene pools is becoming more prone to the effects of climate change creating food insecurity and thus, the lives of farmers more precarious. Traditional crop varieties contain high levels of genetic diversity, which tend to express variations when planted in different agro-ecosystems. The genetically diverse traditional varieties can be utilized to develop new varieties that can increase yield, adapt to climate change, new diseases and other threats to crop production.

Even though some IPM technologies related to the control of virus epidemics in vegetables, organic agriculture technologies and improvement of traditional vegetable varieties to mitigate the impact of climatic change on vegetable productions have been introduced, less attention has been paid to develop climate adaptable hybrids and open-pollinated (OP) varieties, and relevant integrated crop management (ICM) practices to mitigate the impact of climate change on vegetable production and productivity in the country. Therefore, it is important to strengthen the crop improvement programs using novel techniques to introduce climate smart varieties compatible with new pest and crop management practices under different climatic situations. In addition, research on soil and water management is important in vegetable production under stress environments. New innovations of postharvest and value addition technologies are important to support the adaptation efforts of vegetable farmers to climate change and also improve farmer income supporting sustainable vegetable production by mitigating the impact of climate change.

PRESENT STATUS OF RESEARCH AND DEVELOPMENT ACTIVITIES RELATED TO CLIMATE CHANGE

Several research and development programs have been carried out at the HORDI and regional research centers with the following objectives:

- Development of adaptable high yielding shot duration, pest and disease resistant and high quality hybrid and OP varieties for cultivation under varied climates in the country. Studies are ongoing with some crops such as pea (*Pisum sativum* L), bean (*Phaseolus vulgaris* L), tomato *(Solanum lycopersicum* L), capsicum (*Capsicum annuum* L), brinjal (*Solanum melongena* L), luffa [*Lufa acutangula* (L) Roxb.], bitter gourd (*Momordica charantia* L), okra [*Abelmoschus esculentus* (L) Moench.] and other major vegetables.
- Modification of the crop canopy and roots architecture, development of sustainable nutrient management plans by scheduling root and foliar feeding to enhance nutrient use efficiency, identify best growing medium and efficient utilization of space to obtain maximum productivity of crops grown in control environment.
- Development of site-specific nutrient management packages for major vegetable crops base on the testing of site plant nutrient availability, plant

nutrient contents, soil conditions and use of biological agents, nitrification inhibitors and vegetable varieties that efficiently uses nutrients..

- To ensure year-round availability of safe and quality-assured vegetables by introducing suitable varieties to off-season cultivation and diverse agro ecological regions, improving present ICM and IPM techniques, introducing cultivation technologies to grow vegetable in abandoned paddy fields and technology of potato tower and sweet potato cultivation in poly sack bags for home garden and urban agriculture systems , and technology development for cultivation of vegetables in protected houses and input supply (rain shelters, micro irrigation systems, water pumps, reflective mulch, insect proof nets, crates for vegetable transportation, etc. under national food production program) with dissemination of relevant technologies for growing vegetables under extreme weather conditions.
- To avoid price fluctuations of vegetables during off season (June-July and mid November-mid December) by introducing selected locally-developed varieties such as Okra, Brinjal, Mae, Winged bean [*Psophocarpus tetragonolobus* (L) DC], Brinjals and some traditional vegetables, and exotic hybrids such as Cabbage (*Brassica oleraceae* L), Cauliflower (*B. oleraceae* var. Botrytis), Beet (*Beta vulgaris* L), Carrot (Daucus carota (Hoffm) Shcubl & Martens], etc., for dry zone and recommendation of crop combinations of traditional varieties for home gardens.
- To reduce post-harvest losses up to 10%, programs for reduction of postharvest losses and development of value addition products based on five colour health concern concept and dissemination through training programs for farmers in Kandy, Anuradapura, Nuwara eliya and Dambulla.
- Development of value addition technologies to introduce nutritionally rich diet with five colour health concept. Studies are ongoing and some products are commercialized by private sectors.
- Value addition technologies were introduced by establishing five food processing centers with modern facilities. Additional five food processing centers will be established in five major vegetable growing areas.
- Development of organic agricultural technologies and introduce safe natural bio-pesticides and botanicals (*Trichoderma* spp, and fluorescent *Pseudomonas* spp., natural polymer-Chito power, neem – *Azadirachta india* A. Juss., annona botanical formulations, etc.) to ensure safe to eat quality vegetables.

Outcome of the all activities will meet the recommended per capita intake of safe and quality assured vegetables of 200 g/person.

IDENTIFIED GAPS

Climate change will continue to have a larger impact on vegetable cultivation as well as food security in the near future. Present evidence indicates that research on shifting of cropping seasons, growth and yield patterns, pest and disease scenario under changing climatic conditions in respect to vegetable crops in Sri Lanka and use of traditional knowledge has been lacking, which has to be taken up as a urgent approach.

Gaps in adoption of novel approaches in variety improvement of vegetables

With biodiversity loss and concentration of control of seeds by various seed sectors, there is an ever increasing need to conserve the genetically diverse, traditional seeds by the farmers themselves. Together, new varieties are also required for obtaining higher yield and resistant/ tolerant to new biotic and abiotic threats to vegetable production. There is a growing recognition and interest in farmer participatory approaches in response to the challenge of making agriculture more sustainable by considering farmers as partners in crop improvement programs from the initial stages of breeding and selections. This can potentially result in varieties adapted to the needs of farmers with low resources in highly stress-prone environments, and lead to enhanced on-farm (*in-situ*) conservation of crop genetic resources. Therefore, major attention should be given to development and selection of climate smart vegetable varieties, improvement of cultivation technologies and IPM techniques specified to different vegetables crops.

Gaps in adoption of novel approaches in pest control of vegetables

Use of biopesticides, botanicals and plant-derived soil amendments would also help in mitigation of climate change as they helps in the reduction of nitrous oxide emission by nitrification inhibitors. However, how such techniques would contribute to shifting of microflora under varied temperature and moisture regimes are not yet understood.

Use and benefits of ecofriendly methods in disease management for sustainable crop production is well understood. In the changing climate and shift in seasons, choice of crop management practices based on the prevailing situation is important. In such scenarios, weather-based pest/disease monitoring and rapid diagnostics would play a significant role. Other multipronged approaches should be included healthy seeds with innate forms of broad and durable disease resistance, and intercropping systems that foster refuges for natural biocontrol organisms. In addition, monitoring and early warning systems for forecasting pest/disease epidemics should be developed for important pest and pathogens which have a direct bearing on the earnings of the farmers and food security at large.

Laboratory and infrastructure facilities and limited availability of literature pertaining to effect of biotic and abiotic factors on vegetable production, new technologies for pest/diseases on changing climatic conditions in respect to vegetable crops in Sri Lanka have hindered the research and development in relation to climate change impacts on vegetable crop production in Sri Lanka.

FUTURE RESEARCH NEEDS

Future research should mainly be focused to fulfill the objectives to ensure year-round availability of safe and quality assured vegetables, to avoid price fluctuations of vegetables during June to July and mid-November to mid-December time periods in given year, to reduce postharvest losses up to 10% and to meet the recommended per capita intake of safe and quality assured vegetables 200 g/person.

Research needs in plant improvement

The research needs identified for vegetable crop improvement are as follows.

- Development and application of molecular and other novel techniques to screen germplasm for quality parameters, pest/disease resistance, and adaptability to different climatic stress (heat and drought/excess moisture tolerance) and to finally identify resistance/tolerance characters during early stages to minimize time taken for breeding varieties.
- Accelerate the development of F1 hybrid for different vegetable production systems such as poly tunnels, rain shelters, and soilless growing systems.
- Accelerate the development of F1 hybrid and OP varieties, which are suitable to mitigate shifting of growing seasons, drought, excess moisture and heat conditions when crop is grown in stress-prone areas.
- Promotion of demand-driven variety development process through farmer participatory breeding programs to develop varieties with higher farmer adoption and acceptance for year-round cultivation and home gardens.
- Evaluating and improving traditional varieties to meet the changing needs of famers (organic or low input agriculture, etc.) and consumers (health concerns, consumer preference, etc.) through farmer participatory plant breeding.
- Strengthening evaluation of high yielding and quality exotic vegetable varieties, which are suitable to dry zone and their ability to mitigate the effect of climate change on vegetable production, and to identify the potato varieties grown in different agro-ecological regions under changing diurnal temperature.
- Production of sufficient quantities of nucleus and breeder seeds of recommended vegetable varieties and parental lines of F1 hybrids to meet

the future targets provide by Seed and Planting Material Development Center.

Research needs in vegetable agronomy

The research leading to advances in agronomy of vegetable crops should focus on developing ICP package for a variety of vegetables growing under different cropping systems. Elaborated studies should be carried out with collaboration of scientists in the fields of soil and water management, plant protection, weed management, physiology and food science, which are necessary to develop sustainable crop management systems, including nutrient management, to mitigate the effect of changing climate parameters on vegetable production.

Research needs in pest/disease control

The research needs focusing on pest/disease control n vegetable crops are as follows:

- Collection, tabulation and summarization of long term climatic data covering major vegetable growing areas in Sri Lanka to study the correlation of climatic parameters and dynamics of recent outbreak of pests and diseases
- The etiology of recently reported vegetable diseases (fungal, bacterial, viral and phytoplasma) in Sri Lanka should be studied in detail.
- The insect involvement as virus vectors and direct injuries onto crops need experimentation.
- Identification of the ecofriendly methods in disease management for sustainable crop production using formulations of biocontrol agents (*Trichoderma* spp. and fluorescent *Pseudomonas*), natural polymers, and plant extracts (Neem) for vegetable crops.

Final outcomes of these research should lead to the improvement of present ICM and IPM packages and Identification of new effective ICP and IPM packages including good agricultural practices for controlling vegetable pest/diseases with climate changes.

CONCLUSION

The climate change is a cause for shifting of agriculture seasons, changing of biotic factors mainly the abundance and dynamic of pest, disease, beneficial insects and microbes, crop physiology and changing of abiotic factors such as heat, drought, excess moisture, temperature regimes, sunshine hours, etc. Absence of climate smart vegetable varieties has significantly affected the vegetable production of the country. Present studies are required to develop systematic study plans to assess

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the long term climate change impact on vegetable productivity and to develop sustainable ICM, IPM and nutrient packages to cater the demands of increasing vegetable production under a changing and variable climate.

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Present Status of Research on Fruit Crops for Climate Change Adaptation and Future Needs of Sri Lanka

K.A. Renuka and E.R.S.P. Edirimanna
Fruit Research and Development Institute, Horana, Sri Lanka

Abstract: Agriculture, especially crop production, is highly sensitive to both short- and long-term changes in climate. Fruit crop cultivation is one of the important sectors of agriculture in Sri Lanka and is influenced by the climate change (CC). Hence, studies on climate adaptation are important to mitigate the CC impacts. This paper provide a literature review of present status of research on fruit crop for CC adaptation and future needs. Limited number of research have been done on water management and soil fertility, breeding and crop management. Hence, future research should be focused on development of new varieties, natural resource management, biotechnological approaches for pest and disease management, cropping systems, orchard management and post harvesting to support the adaptation efforts.

Keywords: Climate change, fruits, future needs, research

INTRODUCTION

Climate change impact in Sri Lanka is due to the increasing variability of rainfall intensity and regimes, increasing frequency of storms, increasing mean ambient temperature (CCS, 2010; Basnayaka *et al.,* 2007). The annual average rainfall in Sri Lanka has decreased by 144 mm during the period from 1961 to 1990, which is a decrease of approximately 7% compared with the period of 1931 to 1960 (Baba, 2010). The rainfall intensity, amount of rainfall per rainy day and the average rainfall per spell have increased in most parts of the country (Ratnayaka and Herath, 2005). The mean temperature of Sri Lanka has increased by 0.016 °C per year during the period of 1961-1990 (Chandrapala, 1996). Basnayaka *et al*. (2007) reported that the mean temperature may increase by approximately 0.9 °C to 4 °C by the year 2100.

According to the United Nations Framework Convention of Climate Change (UNFCCC), Sri Lanka is considered as a vulnerable small island that is under serious threat from various climate change impacts. However, climate change mainly affect for agriculture sector (Esham and Gorforth, 2013). About 3,537,646 ha of land has been used for agriculture and approximately 106,000 ha of lands are utilized for fruit cultivation in Sri Lanka (Ag Stat, 2016). Banana, Mango, Rambutan, Papaya, Citrus, Guava and Pineapple are the major type of fruits grown in the country. The cultivated extent of the fruits vary from region to region.

Climate change will have both positive and negative impacts on fruits in the tropical regions. Most of the perennial fruit crops need a dry period for initiation of flowers. Under dry climatic conditions, flower initiation occurs profusely and resulting in a good harvest when water is available after flowering. In rainy years, most of the fruit crops do not flower with no fruits been developed in these trees. Under the influence of climate shift, both early and delayed flowering are characteristic features in perennial fruit crops. As a result of variations in temperature, unseasonal rains and higher humidity, fruit trees show altered flowering trends. Delays in flower emergence and fruit set have been noticed. Fruit set and availability of hermaphrodite flowers for pollination have an effect on yield due to pollen and stigmatic sterility.

Some perennial tropical fruit trees species in nature are can be used as important units in adaptation strategies for enhancing resilience (Scherr and Sthapit, 2009) to adverse impacts of rainfall and temperature variability depending on the place where they grow. Although perennial fruit trees have a number of survival mechanisms that allow them to cope with stressful environments, these come at a considerable energy cost thereby potentially reducing the fruit productivity. For instance, several fruit crops have modified physiological and morphological adaptations and withstood these changes well. Fig tree (*Ficus carica* L) has adapted to retain high bound water in the tissue, by having sunken stomata, thick cuticle and waxy coating on the leaves. Underutilized fruits such as Ber (*Ziziphus mauritiana* L.), Phalsa (*Grewia asiatica* L.) and Tamarind (*Tamarindus indica* L.) also have sunken stomata, thick cuticle and waxy coating of the leaves. Indian gooseberry or Aonla (*Emblica officinalis* L.) have adapted by reducing leaf area, thereby reducing the transpirational area. Pomegranate (*Puncia granata* L.) is a fairly winter hardy and also drought tolerant. Aonla, being a hardy and drought tolerant sub-tropical tree, can be grown well under tropical conditions. Pineapple (*Ananas comosus* L.), being a CAM (crassulacean acid metabolism) plant, has remarkable adaptability to different climatic regimes and has high water use efficiency (Dinesh and Reddy 2012). However, under Sri Lankan condition few research have been conducted on effect of climatic changes on fruit crops.

Water management and soil fertility

Water management can be used to mitigate climate change impacts in agriculture. In the fruit crop sector, some water management research have been done with the objective of increasing water use efficiency of the crops. Application of drip irrigation system for papaya cultivation has increased the water use efficiency of papaya plants under water-limiting situations (Medagoda *et al*., 2005). Kuruppuarachchi (1981) also reported that drip irrigation is suitable for banana where water availability is limited and cost of provision of water is high. Roonage *et al.* (2012) reported that the '*Amban'* banana had higher water used efficiency than '*Embul'* banana. The *in-situ* rain water harvesting system called 'Eyebrow bund and pitcher system' has served as a soil moisture reserve to support perennial plants like mango during dry periods (Dharmasena *et al*., 2001).

The internal browning disorder of banana is high under low soil moisture conditions. Foliar application of boron (0.5% borax) or calcium (0.5% calcium nitrate) at 3, 5 and 7 months after planting has helped to recover the problem

(Wanniarachchi *et al*., 2009). Jayasundara and Gunathilaka (2006) reported that application of coir dust and poultry litter (1:1) would increase the fertilizer use efficiency of banana.

Crop management

Sirisena and Pinto (1987) have reported that the fruit size and bunch weight of *Kolikuttu* banana, which flower into dry spell, could be increased by removing 80% of each banana leaf of the plant at 4 weeks after flowering. Sweet orange grafted onto wood apple root stock could be used to tackle the moisture stress situation of the low country dry zone (Sirisena, 1991). In rambutan cultivation, air layering under natural condition depends on the rainfall of the month preceding layering (Heenkenda, 1998).

Crop improvement

Twenty two varieties of mango introduced from Pakistan and Australia have been evaluated at Mahailluppallama in Sri Lanka where four varieties, namely, Kensington, Joewelch, Tommy Atkins and Sensation were identified as promising but with irregular bearing pattern (Somadasa and Adikari, 2003). A Philippine lime variety has performed well in different locations of Sri Lanka (Bibila, Rahangala and Mahailluppallama; Somadasa and Adikari, 2003). Banana cultivars such as *Seeni*, *Ambul*, and Ash plantain could be properly grown in unproductive low county wet zone using ditch and dyke system (Bandara and Silva, 2005). Two pomegranate soft seeding varieties have been identified to be cultivated under dry zone condition in the Jaffna district (Vijayaratnam *et al.,* 2009).

On-going studies

Currently, a survey is being conducted to study the behavioral changes that occur in fruit crops under changing climatic conditions, especially the changes on flowering time, flowering intensity, fruiting pattern, etc. Research work has also commenced to study the pest and disease-resistant rootstocks under varied climatic condition to obtain high yields with high quality fruits from different fruit spp. Development of fruit crop varieties adaptable to varied climatic condition are also being carried out focusing on many fruit crops.

FUTURE NEEDS

Development or identification of fruit crop varieties adaptable to moisture stress, high temperature and excess water, identification of resistant/tolerant varieties or rootstock for pest and diseases and extreme climate factors, identification of cropping systems to mitigate the impacts and adapt to climate change, and development of orchard management system for efficient resource management are future research needs.

CONCLUSION

Limited number of research has been done on climate change adaptation of fruit crops in Sri Lanka. Breeding and crop management research are extremely limited. Further, insect pest and disease management and post-harvest research have not been reported. Hence, much attention should be paid for climate change adaptation research in the fruit crop sector of Sri Lanka.

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Climate Change Impacts on Export Agricultural Crops Production and Adaptation Strategies for Productivity Improvement: A Review of Current Status

H.M.P.A. Subasinghe and D.G.I.S. Ariyathilaka
Central Research Station, Matale, Sri Lanka

ABSTRACT: Impact of climate change on spice crops mainly links with frequent dry spells and intense rainfall. Adaptation strategies are focused to mitigate the adverse effects while enhancing possible positive effects. Research strategies are based on short-term and long term mitigation options. Majority of the spice crops are perennial and hence, immediate results of such strategies are impossible. This paper discussed the past and present efforts made in the short-, medium- and long-term to mitigate adverse effects of climate change on spice crops. Short-term strategies included supplementary irrigation, conserving available soil moisture, suitable planting material for higher establishment while the long-term strategies included screening for drought-resistant varieties, and finding suitable non-traditional new niche environments for crops and suitable mixed cropping models to increase the productivity. Farmers have followed feasible methods to combat adverse effect of climate change.

Keywords: Pepper, dry spell, mitigation

INTRODUCTION

A rapid change in the climate has been experienced over the past two decade, mainly in the form of rise in air and sea temperature, and changes in weather parameters such as intensity of rainfall, dry spells, etc. Level and degree of changes of these parameters has been researched substantially. Further, different simulations with multiple scenarios conducted has predicted various possible changes under different circumstances. Despite many attempts to predict variations in climate, efforts to mitigate unfavourable impacts are comparatively low or available suggestions are often impractical. Developing countries are the most vulnerable group to the impacts of climate change where the buffering capacity to the changes are low due to poor economies in these countries. Agriculture is among the sectors that will mainly suffer from the negative impacts of climate change for which major adaptation measures are needed (Verschuuren, 2016).

Sri Lanka is a highly vulnerable state to climate change. Its geographical location, surrounded by vast Indian Ocean has further exaggerated the impact. Spice crop sector plays an important role in the Sri Lankan economy and is the third most contributing component to GDP in the agricultural sector after Tea and Rubber. However, importance of the spice crop sector is more due to high dependency of rural farmers on these crops. Fluctuations in production and price of these crops would hugely impact on the rural economy in wet and intermediate zones as buffering capacity of these farmers are less. The most sensitive climatic parameter that has shown drastic change over the past decade is the rainfall. Spice crops are grown in wet and intermediate zone of Sri Lanka and thus inevitably, they are water-loving crops. Small changes in either the amount or distribution in rainfall would create a significant negative impact on plant establishment, vegetative growth and most importantly reproductive growth of these crops.

Black pepper (*Piper nigrum* L), popularly known as the king of spice, is confined to wet and intermediate zone of Sri Lanka and mainly grown in Matale, Kandy, Kegalle, Ratnapura areas. Being a high-return cash crop, it is the most popular spice crop in above areas. Vegetative and reproductive growth of pepper is coincided with monsoonal rains. Plant establishment is traditionally done with the onset of *Maha* rains (second inter-monsoon), which supply sufficient soil moisture for young plants for 3-4 month for their successful field establishment. However, dramatically low *Maha* rains (second inter-monsoon + north east monsoon) in the last 2 years (2015-2016) has resulted in a significantly high plant casualty rate, which is economically unbearable to rural farmers. Not only the *Maha* rains but also the *Yala* rains (first inter-monsoon + south west monsoon) were received at below average in the last two years resulting in even mature pepper plantations to fail due to dry up and dying.

Flowering of Black Pepper is also coincided with monsoonal rains in Sri Lanka. Black Pepper possess a bimodal flowering pattern where it flowers first in May-June with onset of south west monsoon. The second flowering starts with onset of north east monsoon in November-December period. This is beneficial for farmers as the harvest of first flowering comes in February and that of the second flowering in August in the following year. Both these periods are dry and thus, helps in drying and processing of the product. However, the bimodal flowering pattern has totally changed during the past decade lowering flowering resulting in reduced harvest. Scientists believe that this is due to change in rainfall pattern owing to climate change. Instead of having two flowerings per year, the crop has flowered 4-5 times per year in small quantities, which has created difficulties in harvesting, processing, and marketing.

Tough pepper requires a short dry spell for its flower initiation. Acute stress due to short dry spells triggers flowering while it requires sufficient soil moisture for subsequent pollination and fruit setting. Insufficient soil moisture after flowering would result in low number of berries per spike and small berries. Value of black pepper in international market highly depends on bulk density (weight of berries/L). Small berries lower the bulk density resulting in lower price at the international market.

All other spice crops are affected from short and long dry spells. Impact is profound in plant establishment particularly in Ginger (*Zingiber officinale* Ros.), Clove [*Syzygium aromaticum* (L) Merr.] and Nutmeg (*Myristica fragrans* Houtt.). Clove production has dramatically reduced from 2315 mt in 2009 to 1101.7 mt in 2014 (Anonymous, 2014), which could be attributed to recent changes in the climate.

RESEARCH ACTIVITIES RELATED TO ADAPTATION STRATEGIES TO CLIMATE CHANGE: PRESENT STATUS

Crop productivity has been projected to decrease with the increase in environmental temperature (1-2 °C) at lower latitudes, especially in seasonal dry and tropical regions of the world (IPCC, 2007). The rising atmospheric temperature and carbon dioxide along with rainfall uncertainties may influence future food security in developing countries due to its large population and limited resources. Therefore, suitable adaptation strategies, which make agricultural crops to absorb larger and sudden shocks due to climate change, should be explored. These adaptation strategies have to be designed to accommodate both climatic and non-climatic stresses to sustain the resources base and agricultural productivity. In this review, an attempt has been made to compile the already available technology, which can be used as climate change adaptation strategies to make the agro-ecosystem more resilient and sustaining the Export Agricultural Crops (EACs) production.

ADAPTATION STRATEGIES IN EXPORT AGRICULTURAL CROPS TO CLIMATE CHANGE

Short term climate change adaptation strategies

Major problem in perennial crops under climate change consequences are variation of soil moisture status, increase of canopy temperature and heat stress which directly effect on plant establishment in new planting, flower initiation, pollination, fruit filling and fruit development of the crops. Therefore, various soil, water and crop management strategies are discussed under short term strategies.

Land and water management strategies:
Productions of planting material in EACs are mostly practicing with seeds but use of stem cutting is the main method of planting material production of black pepper. Therefore, plant establishment rate of pepper is comparatively less in pepper as compared to other EACs which varying between 50-60% in almost all areas of pepper cultivation.

Irrigation: Soil water conservation practices and supplementary irrigation techniques are considered as adaptation strategies to reduce the negative impacts of climatic variability (Rockstrom, 2010) aiming at improving in-situ soil water conservation. Micro-irrigation practices have shown a significant improvement in almost all growth and yield parameters of black pepper (Table 1).

Table 1. Impact of microirrigation practices on growth and yield of black pepper

Treatment	Survival and growth performances after one year				Yield (kg/ha) after five years
	Survival %	Plant height (cm)	No. of leaves/plant	No. of plagiotropics/plant	
T1 (16 L/day)	81.2[a]	169.2[a]	112.8[a]	8.6[a]	1624.8[a]
T2 (8 L/day)	70.8[b]	164.7[a]	93.1[b]	7.6[a]	1025.2[b]
T3 (4 L/day)	59.4[bc]	155.8[a]	74.5[bc]	6.9[ab]	997.8[b]
T4 (control)	39.4[c]	124.5[b]	68.8[c]	4.9[b]	602.1[c]

Means followed by the same letter are not significantly different by the Duncan's Multiple Range Test (p=0.05)

As supplying the plant water requirement (16 L/day) may not be feasible with larger extent of cultivations due to water scarcity, the reduced irrigation amounts (Table 2) showed a substantial yield increase coupled with late rains received from first inter-monsoon and then the south west monsoon, after three years of crop establishmentThe highest fresh berry yield per vine was recorded with T1 (8 L/day) and it decreased progressively with decreasing rate of supplementary irrigation.

Table 2. Yield performances of black pepper under reduced irrigation levels.

Treatment	Fresh berry weight (g)/vine
T1 (16 L/day)	3.810
T2 (8 L/day)	2,715
T3 (4 L/day)	2.230
T4 (control)	1.849

Soil moisture is also a vital factor for almost all growth parameters of ginger and ultimately for its rhizome yield.

Pruning and mulching: Results of studies evaluating different combinations of pruning and mulching practices revealed that pruning of Gliricidia and application as mulch facilitate higher soil moisture conservation, and more dry matter partitioning to both berries and roots of black pepper (Subasinghe *et al.,* 2014). Higher soil moisture level and more fine roots development may support higher nutrient absorption, comfortable phloem translocation as well as reduction of heat and water stress of the pepper vines. Heenkenda *et al*. (2012) reported that enhancement in soil physical, chemical and biological properties may have contributed to significant increase in Black Pepper yields under a Gliricidea [*Gliricidia sepium* (Jacq) Walp.] mulch. This is an economical and feasible strategy to mitigate unfavorable dry spells due to climate change. These strategies would be sustainable due to economic feasibility, availability of mulching material. Application of gliricidia mulch is recommended for organic ginger cultivation over the application of paddy husk and paddy straw while application of compost (30 tons/ha) with gliricidia green manure (50 tons/ha/year) has recorded the highest yield in turmeric (DEA, 2010).

Crop management practices:

Date of sowing: Apart from adverse dry spells, which compel farmers to irrigate ginger fields, dramatic fluctuation of farm gate prices with the harvesting season is one of the major problems in ginger cultivation in Sri Lanka. Farm gate price of ginger goes down approximately fivefold during harvesting season. Ginger is normally cultivated April-May period and the prices would drastically be affected at harvest after 8 month, in January-February period. The results of studies carried out for two years to decide on the effective sowing dates of ginger showed September would be most suitable for sowing ginger in Rideemaliyadda while March is the most suitable for Matale and Narammala to obtain a substantially higher yield (Tables 3 and 4).

Table 3. Final yield (mt/ha) of ginger at different locations - 2013/14

Date of planting	Matale	Narammala	Rideemaliyadda
D1 – Jun, 2013	9.85	8.58	16.64
D2 – Sep, 2013	3.80	5.37	20.25
D3 – Dec, 2013	8.45	7.32	7.66
D4 – Mar, 2014	13.76	15.76	9.43

Table 4. Final yield (mt/ha) of ginger at different locations - 2014/15

Date of planting	Matale	Narammala	Rideemaliyadda
D1 – Jun, 2014	23.01	14.4	27.78
D2 – Sep, 2014	*	*	20.89
D3 – Dec, 2014	5.21	0.98	*
D4 – Mar, 2015	25.11	2.31	16.78

* Not available

Synchronization of flowering

Despite adverse effects of climate (dry spells), dramatic fluctuation of farm gate price, the most important issue in clove cultivation in Sri Lanka is finding labor for harvesting. Tree climbers are difficult to find even after offering a half share of the harvest. This would further aggravate when clove flowers irregularly, 3-4 times per year and appearance of flowers for longer duration in a single flowering cycle. These would result in berries at different maturity stages, which create difficulties in harvesting. In addition, incorporation of immature buds at harvest would ultimately lower the quality of the final product. This also hinders the possibility of applying hormonal methods (ethylene) to drop berries, which is a possible alternative for harvesting. The studies revealed that the use of plant growth regulator Paclobutrazole (PBZ) for induction of flowering and regulating flowering pattern as a productivity improvement measure for clove showed no observed changes within the first three months period. Studies have also indicated that when an adequate soil moisture level prevails, a lengthier dry spells would trigger more flowering while under frequent irrigation conditions, less irrigation amounts would trigger flowering in black pepper.

Different growth media:
Rhizome parts weighing about 40g are considered for planting of ginger. Less germination percentage is one of the problem face by farmers particularly with irregular and short dry spells. A possible strategy to increase the germination percentage would be to plant sprouted ginger. Ariyawansa (2016) reported the highest sprouting percentage in seeds placed in wet coir dust medium with a superior vegetative growth after field planting. Ariyawansa (2016) also stated that the wet coir dust medium is the best to sprout ginger and that sprouted ginger is better than non-sprouted ginger as planting material.

Techniques to produce planting material:
Production of planting material of black pepper in commercial cultivations is done by stem cuttings. Mostly stem cuttings are collected from the ground runners, however, other branches such as fruiting branches (plagiotopics), vertical branches (orthotopics), hanging branches and terminal branches also could be used for production of planting material. However, planting material originated from different branch types behave differently in the way of branching after field planting. Ideal plant type for pepper should have a uniform cylindrical canopy with higher number of fruiting branches, which are responsible to determine the crop yield. Report says that planting material taken from terminal branches can be used for development of ideal type plant canopy and to obtain an above average yield. However, collection of sufficient stem cuttings for large scale planting material production is difficult due to shortage of stem cuttings during the season. Therefore, different rapid multiplication techniques have been introduced. Quality planting material with good root system and high vigour are utterly important to improve plant establishment rate, initial growth and canopy development. Therefore, this study was conducted to compare planting material producing through different rapid multiplication techniques.

The results of studies have revealed that the planting material production through terminal shoots with 'high density standard technique' would be a good solution for further development of commercial pepper cultivation (Tables 5, 6, 7 and 8).

Table 5. Variation of vine length of pepper vines originated from different cutting types at different locations

Treatments	Location		
	Nillambe	Naramala	Matale
T1 - Up rights	137.3	101.2	153.5
T2 - Ground runners	178.3	146.7	166.4
T3 - Plagiotrophics	42.4	26.7	36.3
T4 - Plagiotrophics (Knitted)	39	59.1	32.1

Table 6. Variation of number of lateral branches of pepper vines originated from different cutting types at different locations

Treatments	Location		
	Nillambe	Naramala	Matale
T1 - Up rights	20.4	6.4	11.3
T2 - Ground runners	14.2	3.3	9.9
T3 - Plagiotrophics	9.5	2	2.4
T4 - Plagiotrophics (Knitted)	6.2	2.3	1.9

Table 7. Variation of number of orthotrophic branches per vine which originated from different cutting types at different locations

Treatments	Location		
	Nillambe	Naramala	Matale
T1 - Up rights	2.4	2.2	1.2
T2 - Ground runners	1	2.2	1.2
T3 - Plagiotrophics	0	0	0
T4 - Plagiotrophics (Knitted)	0	0	0

Table 8. Variation of number of spike per vine originated from different cutting types at different locations

Treatments	Location		
	Nillambe	Naramala	Matale
T1 - Up rights	44.3	4.3	46.8
T2 - Ground runners	8.2	0	15.9
T3 - Plagiotrophics	18.8	3	5.8
T4 - Plagiotrophics (Knitted)	4.2	2.6	5.1

The most important factor for increasing yield is number of lateral branches per vine, thus it is interesting observe that plants from terminal branches have given highest number of lateral per plants as compared to other plant types. This character is also related with uniform cylindrical shape of the vine as well as the crop yield. The experiment will be continuing for 3 more years for data recording.

Biological supplements aiding establishment:

One of the possible solutions for lower establishment rate of black pepper with increasing irregular dry spells is the introduction of nutrient supplement biological agents and their favorable conditions to the soil. Weerawardena *et al*. (2017) reported that inorganic fertilization had improved plant growth comparatively to organically-managed plants. However, the effect addition 0.5 and 1 kg of partially burnt paddy husk needs to be evaluated further.

Among effective and feasible ways to mitigate dry spells which adversely affect plant establishment, growth and harvest of black pepper, addition of mulch to conserver soil moisture has abundantly used. However, live mulch would be far more advantageous since it provides additional benefits too. Minimal labour requirement, nitrogen fixation are among these benefits. Gunaratne et al. (2015) reported that among three cover crops evaluated, namely, , *Arachis pintoi* Krapov & W.C. Greg, *Mucuna bracteata* DC and *Desmodium ovalifolium* Merr., Black Pepper vines with *A. pintoi* and *D. ovalifolium* showed comparatively higher vegetative growth. Further, soil moisture content was also increased by 32% with *A. pintoi*, 59% with *D. ovalifolium* and 77% with *M. bracteata* compared to control.

Long term climate change strategies

Change in Land use:

Mixed cropping models: A cacao mixed cropping model planted under coconut with papaw and ginger has shown a significant growth improvement of papaw plants under disc ploughed coconut area compared to the standard unploughed area, while a better growth of cacao was also observed in the ploughed area (DEA, 1998).

Though replacement of one row of Gliricidia with cinnamon did not effectively reduce the total lopping yield of coffee, cinnamon would provide additional income for the farmer (DEA, 1996). Black Pepper (2.44 m x 2.44 m) and Coffee cv. Catimor (1.22 m x 1.22 m) planted with one row of Pineapple in the center (6000 plants/ha) have reported a superior growth of Black Pepper and Coffee in comparison to non-pineapple treatment indicating that this system is economically viable during the first three years of establishment (DEA 1996).

Heat and drought tolerant crop varieties: A research carried out to develop drought tolerant Black Pepper varieties have helped in identification of high-performing lines though the yield was not very attractive (3100 g/vine; DEA, 2008).

CONCLUSION

It is evident that frequent dry spells, unfavourable distribution of rainfall with extreme events are the main impacts on spice crops particularly in plant establishment and growth. Short term mitigation strategies consist with supplementary irrigation, mulching and researching for propagation methods to increase plant establishment rate are feasible to improve the growth, yield and economic return of spice crops. However, long term mitigation strategies such as screening for drought resistant varieties, mixed cropping, finding suitable new niches with changed climate are essential as short term strategies alone would not be sufficient to cope up with the intensity of the climate change. Suitable short term strategies for pepper are well researched, however, applicability of these methods in other crops need to be further investigated.

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Present Status of Research and Development Activities on Climate Change Mitigation and Future Needs: Contribution of Tea Research Institute of Sri Lanka

T.L. Wijeratne

Plant Physiology Division, Tea Research Institute of Sri Lanka, Talawakelle, Sri Lanka

ABSTRACT: Tea being a rainfed crop, the climate change affects directly on the productivity and profitability of the tea industry. Tea Research Institute (TRI) of Sri Lanka had initiated research activities to identify the responses of tea plants to climate change, to assess the vulnerability of tea plantations to climate change, to overcome the deleterious effects of climate change through adaptation practices and to mitigate the climate change well in advance. Consequently, a vast amount of important information has been generated and being used by the stakeholders to avoid/reduce the impacts of climate change. Furthermore, exploring the possibility of generating income through different trading systems such as payments for environmental services is also highlighted. The research activities have continued to to focus on further exploration of the impact of climate change, and adaptation and mitigation activities. The necessity of high tech equipment for multi-factoral studies is also highlighted to get better results.

Keywords: Adaptation, climate change, mitigation, tea plantations

INTRODUCTION

Tea [*Camellia sinensis* (L) Kuntz.] is one of the main commercial plantation crops in Sri Lanka contributing to nearly 1.0 % for the gross domestic product. It is a rainfed plantation crop grown from almost sea level to about 2200 meters covering all three elevation categories namely, the Up-country (UC; >1200 m amsl), Mid-country (MC; 1200 – 600 m amsl) and Low-country (LC; <600 m amsl). Tea is a crop with wide adaptability to different climates and soils in various parts of the world. It is a shade loving plant requiring an annual minimum rainfall of 1200 mm. Under Sri Lankan conditions, a uniform distribution of rainfall throughout the year is important for successful cultivation. Tea plant prefers slightly acidic, well-drained soil of pH 4.5 - 5.5. Growth of tea shoots is optimal at temperatures in the range of 18 - 30 °C. The minimum leaf temperature necessary to initiate shoot extension is about 21 °C and the growth decreases above 35 °C. Long sunshine hours are essential for the maximum yield and dormancy sets in when the day length falls below 11 h and 15 min. It needs a water vapor saturation deficit of the air of at least 2 k Pa to maintain a favorable water balance in the leaves (Carr and Stephens, 1992). Although high winds are considered to be detrimental for the growth of tea, mild dry winds accompanied by the cold nights and bright days are known to be associated with accumulation of characteristic flavors in seasonal teas (Yamanishi *et al*., 1989).

Anthropogenic activities have led to rapid and unprecedented increases in atmospheric carbon dioxide (CO_2) and other greenhouse gases (GHGs), which in turn have resulted in numerous observable climatic changes, such as elevated temperature (global warming), increased frequency and severity of extreme weather events (*e.g.* floods, landslides and droughts, *etc*), and altered precipitation patterns (*e.g.* shifts in monsoons). Under Sri Lankan context, De Costa (2008) reported that there are statistically significant long-term increasing trends for annual mean air temperatures and decreasing long-term trends in annual precipitation in several locations representing different agro-ecological zones of Sri Lanka. De Costa (2008) further stated that there were significant variations in the climate variability at different locations in Sri Lanka. Therefore, the impacts of climate change can directly affect the productivity and profitability of the tea industry.

The objectives of this paper is to review literature related to climate change aspects of tea in Sri Lanka, to identify the present status and gaps in climate-related research and thereby focus on the future needs of research.

PRESENT STATUS OF RESEARCH AND DEVELOPMENT ACTIVITIES RELATED TO CLIMATE CHANGE

Being an important commodity research institute responsible for the sustainability of the tea industry in Sri Lanka, the Tea Research Institute (TRI) had initiated research and development activities in relation to climate change: to identify the responses of tea plants, assess the vulnerability of tea plantations, overcome the deleterious effects through adaptation practices and to mitigate climate change. Consequently, the 1st ever corporate plan of the TRI that was developed for the period 1999 – 2003 also included research area of drought and stress alleviation. Since then, the focus of research activities were more concentrated on different aspects of climate change. Currently the corporate plan of TRI consists of a separate thematic area to address climate change issues in tea. Developing improved planting materials to face emerging challenges and developing adaptation and mitigation strategies to minimize impact of climatic change are included in the goals of TRI, too.

Earlier more research work was concentrated on developing adaptation strategies to overcome the deleterious effects of climate change. Therefore, refinement of agronomic practices such as soil rehabilitation, nursery management, shade management and good agricultural practices were further studied in view of producing tea plants withstand adverse weather conditions. As a result, a drought management package was introduced by Anadacoomaraswamy (1997). Recommendation of spraying K_2SO_4 and muriate of potash (MOP) together with urea prior to and during a dry spell to tea has been found to help the plant to withstand drought conditions better. Development of water management techniques for young tea in drought prone areas to minimize casualties, studies on rainwater harvesting, soil and water conservation measures are also on going.

Collating the results gathered from field experiments, it is expected to provide guidelines on rain water harvesting techniques, irrigation techniques and novel soil moisture conservation measures to the tea growers. Artificial mulch introduced by Bandara *et al*. (2016b) would help in soil moisture retention as well as in suppressing weeds. Breeding new cultivars resistant to biotic and abiotic stresses is also among the top priority of research. In aid of that a Drought Susceptibility Index was tested and being used to screen and identify new cultivars tolerant to drought at early stages of growth (Damayanthi *et al*., 2010). Development of bi- and poly-clonal seedling tea is another invention. Initiatives have been taken to obtain genetic variation and develop new tea cultivars to meet emerging challenges through controlled hybridization *viz.* higher tolerances to biotic and abiotic stresses such as climate change. Investigations on identification of suitable graft combinations having higher degree of drought tolerance is also in progress (Anon, 2017).

Tea plants are raised in a nursery for a period of about one year before planting in the field. Soil that is used in the nursery is fumigated with chemicals to eradicate soil-borne pests and diseases, mainly the parasitic nematodes. Methyl bromide was used until recently to fumigate nursery soil. However, due to its ozone depleting nature and phytotoxicity (producing bromide residues, a groundwater pollutant) its use was banned following the Montreal Protocol in 1997. As a result, the search for alternate methods of soil fumigation began and many environmentally-friendly alternatives are now being tested including soil solarization, the use of metham sodium, dazomet and different organic formulations in different concentrations (Vitarana *et al*., 2002). Sri Lanka has been recorded as the first tea-growing country, which has totally phased out the use of methyl bromide and thereby earned the ozone-friendly label (Gunawardena, 2011).

Before establishing tea plants in the field, extensive land preparation is done by removing all the other vegetation to prevent the possibilities of contamination. During this uprooting of vegetation, the soil is loosened resulting in significant soil erosion. Further, during the crop establishment period, *i.e.* the first two to three years, there is a high possibility that the land is exposed and become eroded (Van der Wal, 2008). Tea lands in many places in Sri Lanka have lost topsoil in the order of 300–450 mm during the past 100 years, which is equivalent to a total of 3–4.5 million kg ha^{-1} of soil loss (Zoysa *et al*., 2008).

Unlike most other perennials, tea is harvested at seven- to ten-day intervals throughout its lifespan. Therefore, it is necessary to replenish the depleting nutrients continuously to avoid any economic loss. These intensive cultivation practices necessitate the use of synthetic fertilizers and chemicals. The monoculture nature of tea plantations aggravates this issue as they are usually lacking natural enemies and heavily dependent on chemicals to protect the tea bushes and to achieve higher productivity (Van der Wal, 2008). The use of such chemicals may cause other environmental hazards such as global warming, soil erosion and eutrophication.

High doses of synthetic fertilizers are conventionally applied to obtain better yields and tea growth. However, it has been reported that the same results could be obtained using low levels of nitrogen (N) and phosphorous (P) together with microbial inoculants compared to the use of a chemical fertilizer alone or the inoculant alone (Nepolean *et al*., 2012; Saikia *et al*., 2011). Recent studies on biofilm-biofertilizers (BFBF) have revealed the possibility of reducing the use of recommended chemical fertilizer by 50% at the nursery stage when it is applied with BFBF (De Silva *et al*., 2014). Furthermore, use of site-specific phosphorous-solubilizing bacteria allows the grower to reduce the use of fertilizer by one-third, which will ultimately reduce the use of synthetic fertilizers (Tennakoon *et al*., 2016). Site-specific fertilizer recommendations prevent the use of chemical fertilizers unnecessarily without compromising the crop yield. It replenishes the soils with only the depleted nutrients and thereby reducing fertilizer wastage, which would ultimately reduce eutrophication and algal bloom. Similarly, slow-release fertilizers release nutrients according to the requirements of the plants thus, reducing environmental pollution. Improving the organic content of soil will also improve the fertilizer use efficiency while reducing wastage. Organic cultivation also increases the soil carbon pool and thereby reducing the atmospheric CO_2 concentration and mitigating climate change (Cracknell and Njoroge, 2014). Furthermore, the addition of organic inputs increases the efficient use of fertilizers and reduces indirect emissions associated with fertilizer production. This would also lead to reduced soil erosion, become another greenhouse gas (GHG) emission source, by binding the soil particles together.

Soil rehabilitation using grasses is identified as an important operation prior to planting of tea in old tea fields with the objectives of improvement of soil physical, chemical and biological properties and means of managing pest and diseases. Soil Quality Index was developed to evaluate the soil chemical, physical and biological parameters (as a composite index) to see whether there is any possibility to reduce the soil rehabilitation time period (Bandara *et al*., 2016a).

Being a rainfed plantation crop, the production of tea is greatly influenced by weather and climatic conditions (Wijeratne, 1994; 1996; 1997; Amarathunga *et al*., 1998). Prolonged dry spells and high intensity rainfall are predicted for Sri Lanka, and particularly the lower elevations and Uva have been shown to be more vulnerable. The variations in temperature and rainfall pattern have been identified as the most influential climatic factors affecting productivity. Dry weather conditions, in particular, severely limits both the growth and yield of tea crop (Wijeratne and Fordham, 1996). Hence, with climate change, tea will be subjected to severe stress bringing in low yields affecting the country's economy, earnings of those who are dependent on these plantations and the industries as a whole. Establishment and management of shade trees in tea plantations will thus, become mandatory requirement to face the hanging climates in the future. A database on potential shade tree species has been compiled by the Plant Physiology Division of the TRI while alternate shade tree species are currently being evaluated.

Trend analysis carried out with the rainfall, and surface and temperature data received from the Meteorological Department for 1961 to 2010 together with soil information to identify vulnerable regions to adverse impacts of climate change in the regions and develop adaptation strategies have been completed. The results of the analysis (Tables 1 and 2) revealed that the Agro-Ecological Regions (AERs) *viz.* WL1a, WL1b, WL2a, WM2a, WM2b, WM3a, IM2b, IM3a and IM3c are highly vulnerable to climate change whilst WM1a, WM1b, WM3b, IM1a, IM2a, IU3a, IU3d and IU3e are vulnerable to climate change (Wijeratne and Chandrapala, 2014; Anonymous, 2016).

Table 1. Approximate locations classified as highly vulnerable to climate change

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

* AER = Agro-Ecological Regions; (extracted from Wijeratne and Chandrapala, 2014)

Over the last century, atmospheric concentrations of CO_2 and other greenhouse gases have increased significantly and are set to rise further, resulting in significant changes in the global climate such as increasing atmospheric temperatures, changing rainfall patterns and increasing frequency of extreme climatic events (IPCC, 2007). As a result, the majority of countries have drawn their attention to reduce CO_2 concentration, the major GHG in the atmosphere and thereby member countries in the United Nations (UN) agreed to follow the Kyoto protocol.

Table 2. Approximate locations classified as vulnerable to climate change

AER*	Locations	Vulnerability to climate change
WM 1a	Deniyaya, Maliboda, Kenilworth, Kotapola (North), Kalawana (South)	vulnerable
WM 1b	Rakwana, Kalawana (North)	vulnerable
WM3b	Kandy, Pathadumbara, Akurana, Harispattuwa, Pujapitiya, Panwila, Central part of Rattota, Ambagamuwakorale	vulnerable
IU 3a	Bandarawela (South), Haputale (East)	vulnerable

IU 3d	Rahangala, Welimada (West)	vulnerable
IU 3e	Welimada, Uwa-paranagama (South), Haputale (Noth), Bandarawela (West)	vulnerable
IM 1a	Badulla, Hanguranketha (East), Walapane (North & East), Haliela (South), Passara (West)	vulnerable
IM 2a	Kolonne-korale, Weligapola (West), Central parts of Balangoda, Imbulpe, Haldummulla	vulnerable

* AER = Agro-Ecological Region; (extracted from Wijeratne and Chandrapala, 2014)

Carbon trading is one of the major components in Kyoto Protocol, which helps to reduce global atmospheric CO_2 gas concentration. Carbon sequestration is comparatively a new idea of climate change mitigation, which refers to the capture and storage of carbon dioxide that would otherwise reside in the atmosphere for a long period of time causing global warming. De Costa *et al*. (2008) estimated the carbon balance (carbon footprint) of tea plantations in different tea growing regions of Sri Lanka using several assumption. The work was a collaborative effort between the TRI and the Faculty of Agriculture, University of Peradeniya, Sri Lanka. Results of the study showed that the Sri Lankan tea industry is a net carbon absorber, with an annual absorption of 7.837 mt of CO_2, thus providing a strong foundation for marketing tea as an eco-friendly product. The annual carbon absorptions in Up-, Mid- and Low-country regions in Sri Lanka were 0.874, 1.278 and 1.426 mt respectively. The corresponding emissions were only 0.430, 0.334 and 0.677 mt per year for the three respective regions. Accordingly, the net carbon balances of the three regions were 0.444, 0.944 and 0.750 mt yr^{-1}, making-up the total carbon balance to be 2.137 mt yr^{-1} (De Costa *et al*., 2015). Furthermore, carbon and nitrogen stocks were also determined in different tea cultivars in view of assessing the potential of different tea cultivars for mitigating climate change (Vinodhini T. *et al*., Unpublished manuscript).

Carbon sequestration measurements in tea plants for both VP and seedling in different elevation zones were completed. Accordingly, seedling tea plants are superior to VP tea plants in sequestering carbon. The differences in percentage distribution of total biomass within the tea bush in seedling and VP tea were identified as the major reasons for this observation. Temperature was identified as the main environmental parameter that determines the measured carbon sequestration rates. Determination of carbon sequestration potential of tea plantations fulfills the documentary requirements for claiming environmental services of tea cultivation, a potential benefit to be harnessed in the context of climate change (Wijeratne, 2015). Addition of shade trees in tea plantations has increased its carbon sequestration potential substantially (Figure 1). Tea plantations with high and medium shade trees in Low-country, Mid-country, Up-country and Uva had carbon sequestration potentials of 6.7, 3.5, 2.3 and 5.1 Mg of C ha^{-1} yr^{-1}, respectively. These values were comparable with the reported carbon sequestration values of smallholder agro-forestry systems and mesic savannas but lower than those for tropical rainforests. This study further emphasized the necessity of establishment and management of shade trees in tea plantations not only for enhancing yields, but also for better environmental resilience (Wijeratne *et al*., 2014a,b,c,d; 2015).

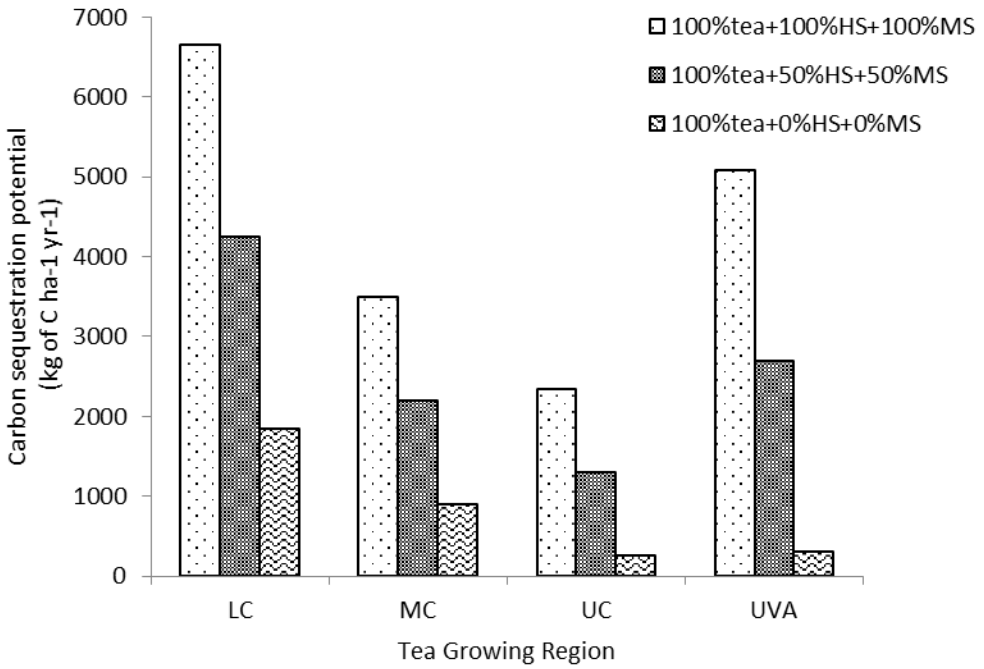

Figure 1. Comparison of carbon sequestration potential of tea lands among different tea-growing regions with different densities of shade trees relating to different levels of compliance with TRI recommendations (Extracted from Wijeratne, 2015).

According to Wijeratne and Bandara (2017), the soil respiration was much higher in Up-country than Low-country tea fields. Soil respiration was significantly higher in wet condition than dry condition, too. In order to establish carbon balance sheets and their variations with anticipated climate change, investigations on soil respiration and organic matter under different soil series in tea ecosystems for wet and dry seasons are in progress. Actions were already initiated to estimate CO_2 emissions to prepare GHG inventories together with the estimated values of carbon sequestration potentials of tea plantations in different regions and in proper documentations of the REDD+ preparation phase.

Use of crop simulation models has become the best choice, as simulating climate change aspects in real world is costly and time consuming. Initially, correlation analysis between the weather parameters and tea crop yield was used to make predictions on the effects of climate change on tea production (Wijeratne and Fordham, 1996; Wijeratne *et al*., 2007). Yield projections made by the crop model developed by Wijeratne *et al*. (2007) showed that rising temperatures and diminishing rainfall reduce tea yield in many tea growing regions except Up-country Wet zone (UW). The results also predicted that tea yields are likely to increase at high elevations while the yields at low elevations are likely to reduce due to climate change. However, as the effects of climate change and plant interactions with the external environment are complex, developing predictive models based on plant processes became necessary. As a result, Sheffield Dynamic Global Vegetation Model (SDGVM), which is a process-based explanatory crop simulation model, was modified and fine-tuned to predict the impact of climate change on tea production and carbon sequestration potential in Sri Lanka (Wijeratne *et al*., 2011; 2013). Agreeing with the model predictions of Wijeratne *et al*. (2007), the tea yields in Low-country are observed having a decreasing trend while in Up-country the yields are showed an increasing trend under the A1F1 scenario, provided that the increasing atmospheric CO_2 is kept constant. However, it explains that the yields and carbon sequestration potential are having an increasing trend in all tea growing elevations due to CO_2 fertilization effect. The observed yield increments were 3.4, 2.9 and 3.6 kg ha^{-1} yr^{-1} for Low-country, Mid-country and Up-country, respectively. Furthermore, the increase of carbon sequestration potential per unit increase of CO_2 will be having a decreasing trend exhibiting plants acclimatization ability (Wijeratne, 2015).

It is expected that the incidence of pests and disease occurrence may change with the climate change. In order to address this, a project is in progress on the impacts of climate change on population incidence and dynamics of *Pratylenchus loosi* in tea plantations through comparative morphometric and molecular analysis as part of a post graduate study. Field experiments in different areas with varying levels of *Pratylenchus loosi* infestations are being monitored for pathogenicity, symptomology and biocontrol efficacy. Determination of impacts of climate change (rainfall and soil temperature) on population incidence and dynamics of *Pratylenchus loosi* in plantations through comparative morphometric and molecular analysis using nematodes as bioindicator are being continued (Anonymous, 2017).

IDENTIFIED GAPS

As climate change is happening simultaneously with the rising in atmospheric CO_2, and that the increasing temperature and extreme weather events such as drought and these factors are interrelated, it is difficult to understand the responses of tea plants to climate change using field or glass house data alone. Therefore, it is necessary to have a controlled environment facility with the ability of controlling different parameters of climate change. This need was clearly identified by the Plant Physiology Division of the TRI, which has been granted the approval by the Government of Sri Lanka for special project to identify the adaptive responses of tea plants to climate change. The study, which is currently in progress, will address especially the heat stress and the data will be useful in developing a cultivar screening method to identify suitable cultivars for future climates.

CONCLUSION

The responses of tea plants to climate change aspects are already explored to a greater extent by the TRI. The future activities are also planned based on the need and sustainability of the industry. However, the TRI should be strengthened with high-tech equipment and better human resources.

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Climate Change Impacts on Coconut Production and Potential Adaptation and Mitigation Measures: A Review of Current Status

C.S. Ranasinghe
Coconut Research Institute, Lunuwila, Sri Lanka

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 micro climate 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.

Proceedings of the Workshop on Present Status of Research Activities on Climate Change Adaptations (Ed. B. Marambe), Sri Lanka Council for Agricultural Research Policy, Colombo.

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).

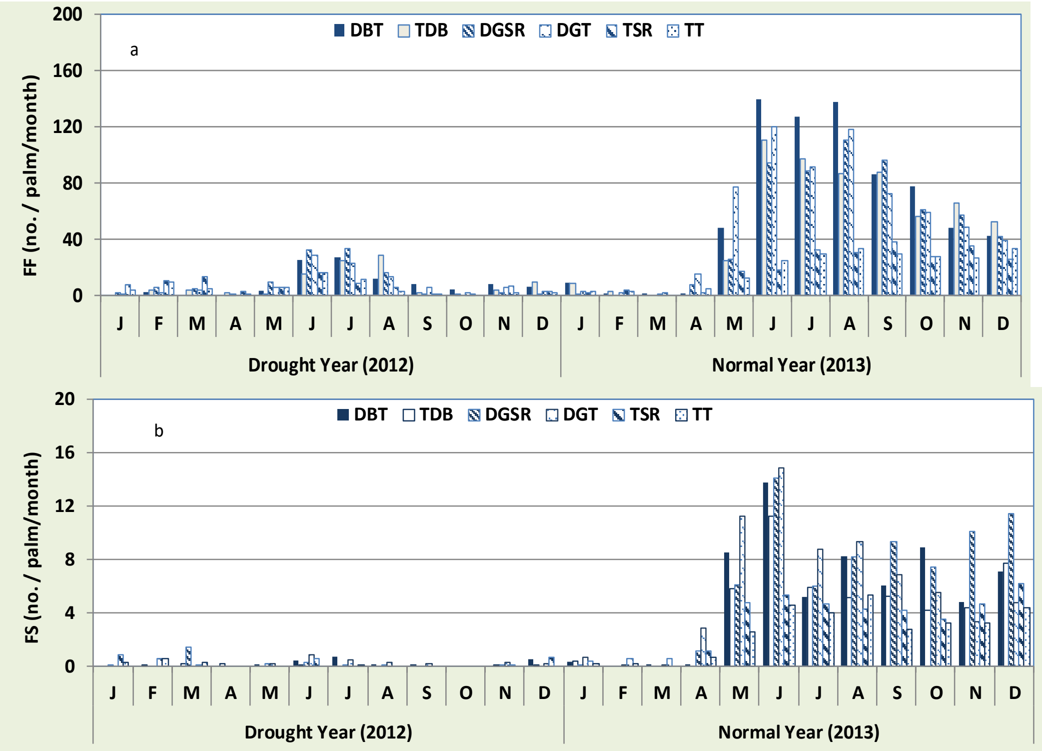
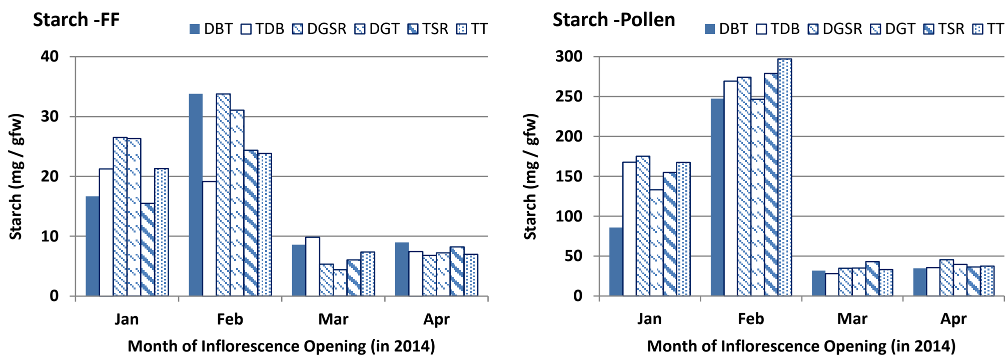


Figure 1. Production of female flowers (above) and fruit set (below) of six coconut hybrids in two consecutive years in the dry zone. DBT = Dwarf Brown x Tall; TDB = Tall x Dwarf Brown; DGSR = Dwarf Green x San Ramon; DGT = Dwarf Green x Tall; TSR = Tall x San Ramon; TT = Tall x Tall. Letters in the X axis refers to months in a year from January (J) to December (D).



(a) (b)

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_{min}, T_{opt}, and T_{max}) of pollen germination and pollen tube length varied among the hybrids and T_{max} (maximum temperature above which pollen grains fail to germinate) and T_{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_{max} for pollen germination of the most tolerant and less tolerant hybrids was 41.9 and 39.5 °C, respectively. The T_{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 Values presented are mean±standard deviation. T_{opt} = optimum temperature at which pollen tube growth is maximum; T_{max} = maximum temperature above which pollen grains fail to germinate (Adopted from Ranasinghe *et al.*, 2017)

Heat stress tolerant category	**Variety (hybrid)**	**Group mean* (pollen germination %)**		**Group mean* (pollen tube length)**	
		T_{opt}	**T_{max}**	**T_{opt}**	**T_{max}**
Tolerant	DBT, DGT	27.35^{a} ±0.4	41.90^{a} ±1.10	29.50^{a} ±0.35	37.10^{b} ±0.22
Moderately tolerant	TSR	28.30^{b} ±0.5	40.10	29.18^{a} ±0.70	40.40
Less tolerant	TT, DGSR	28.35^{b} ±0.5	39.50^{b} ±0.30	26.02^{b} ±0.45	38.41^{a} ±0.19
Unclassified	TDB	28.05^{b} ±0.4	38.95^{b}±0.55	29.46^{a} ±0.40	37.25^{b} ±0.07

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 ºC and 90 mm/month (considering the water requirement of 3 mm/day), respectively, and the months exceeding theses 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_{max} of the same period.

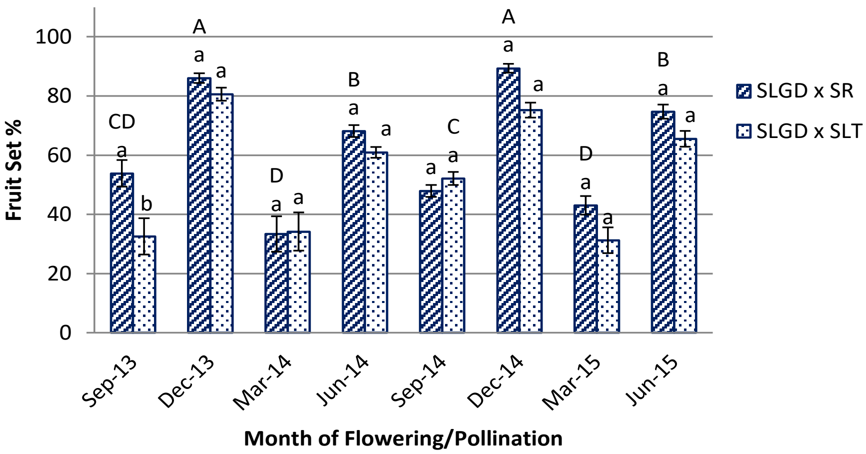


Figure 3. Variation in early fruit setting (%) of two hybrids when SLGD female flowers produced in eight selected months were pollinated with San Ramon (SR) and Tall (SLT) pollen produced in the same months. Upper case letters indicate significance among the months of flower production and pollination 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).

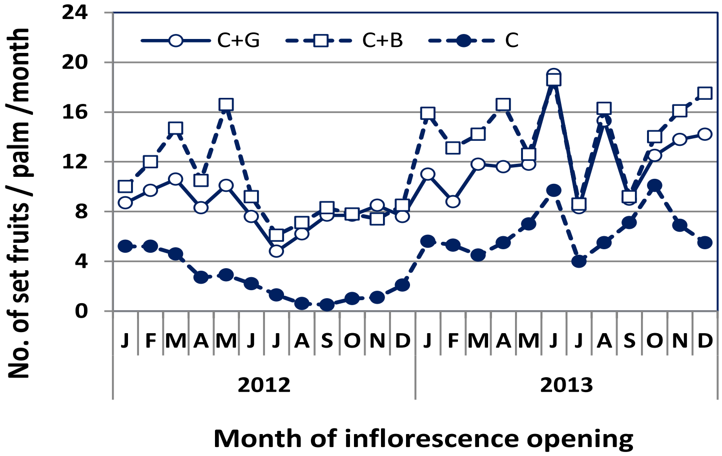


Figure 4. Fruit set (number/palm/month) of coconut palms in coconut + Guava system (C+G), Coconut + Banana system (C+B) and coconut monocrop system (C) in the dry zone of Sri Lanka from January 2012 to December 2013.

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 ($B_{tot\text{-}eco}$) (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 S_2 soils in the low country Intermediate Zone (IL_{1a}). The study revealed that coconut plantations (Sri Lankan Tall) on most suitable soils (S_1-S_2) with correct density (160 palms per ha) have the potential to store up to 40 Mg C per ha^{-1} 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 CO_2 from the atmosphere than coconut mono-culture systems.

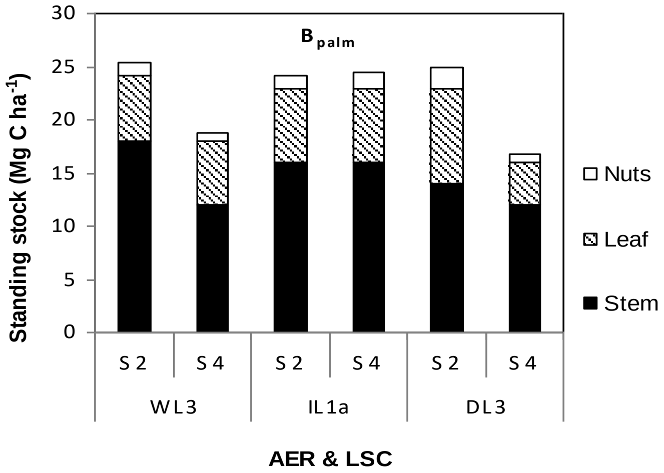


Figure 5. Carbon stock of coconut palms (B_{palm}) (Mg C ha^{-1}) in terms of its components (stem, leaf, nuts) of monocrop system on S_2 (most suitable) and S_4 (marginal) land suitability classes (LSC) in agroecolocial regions (AER) WL_3 (wet) IL_{1a} (intermediate) and DL_3 (dry zone) of Sri Lanka (Adopted from: Ranasinghe and Thimothias, 2012)

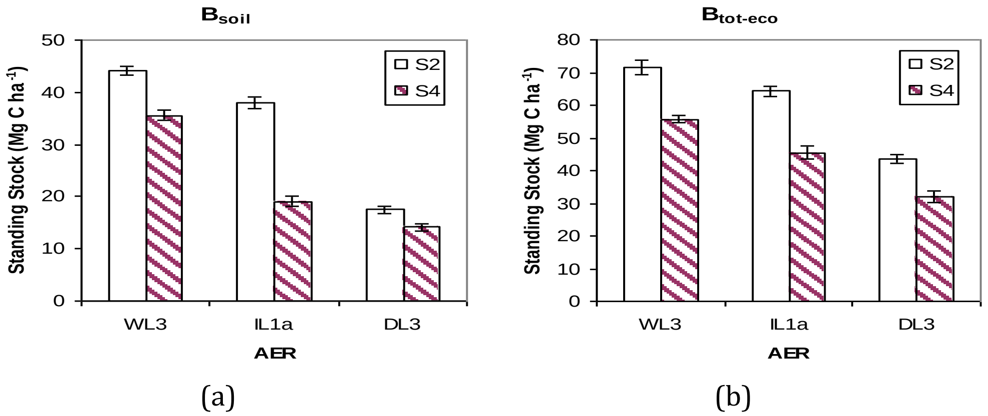


Figure 6. Carbon stock (Mg C ha^{-1}) in top soil (B_{soil}) and total ecosystem C stock ($B_{tot-eco}$) (Mg C ha^{-1}) of a coconut mono crop system on S_2 (most suitable) and S_4 (marginal) land suitability classes in the agro-ecological regions (AER) WL_3, (wet) IL_{1a} (intermediate) and DL_3 (dry zone) of Sri Lanka (Adopted from Ranasinghe and Thimothias, 2012)

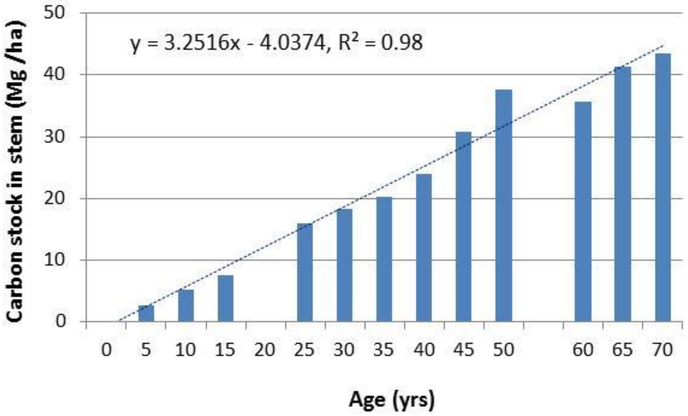


Figure 7. Variation of C Storage potential of coconut stem with age on S_2 (most suitable) soils in the intermediate agro-ecological zone of Sri Lanka (IL_{1a}).

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

Wasana Wijesuriya and Priyani Seneviratne
Rubber Research Institute of Sri Lanka, Dartonfield, Agalawatta, Sri Lanka

Abstract: The vulnerably of rubber plantations in Sri Lanka to climate change has been identified.The Rubber Research Institute of Sri Lanka (RRISL) hasbeing 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 on-going 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 researchneeds 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

Climatic characteristics	Degree of limitation*				
	0	1	2	3	4
Mean temperature (°C)	28-25	24-22	21-20	19-18	<18
		29-30	31-32	33-34	>34
Mean daily max. temp. (°C)	34-29	28-27	26-25	24-23	<22
Mean daily min. temp. (°C)	>20	20-19	18-17	16-15	<15
Mean annual rainfall(mm)	>2000	2000-1750	1749-1500	1499-1250	<1250
Rain interference (days/year)	0-30	31-60	61-90	>90	
Sunshine (hours/year)	2100	2100-1750	1749-1500	1499-1250	<1250
Mean annual RH (%)	<80	80-100			
Dry season length (months/year)	0-1	2-3	4	5-6	>6

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

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

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

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 (SamarappuliandWijesuriya, 2006).

SamarappuliandWijesuriya (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)

[1] The tappable girth of a rubber tree is 50 cm circumference above 120 cm from the highest point of the bud union

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). NayanakanthaandSeneviratne (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 affecton 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 ONTHE 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)

Adaptation needs	Adaptation options	Actions
Enhance the resilience of the rubber sector against heat and water stress	A. Germplasm improvement	• Screen existing clones for heat and water stress • Introduce new clones with heat, drought and flood tolerance • Develop budded plants with drought resistance properties
	B. Improvement of nursery and plantation management practices	• Develop improved cropping system models for vulnerable areas • Promote improved nursery and plant management practices (improvements in irrigation, new planting techniques: root trainers, improvement of soil organic matter : bio-fertilizer development)
	C. Initiating research studies to assess climate impacts	• Conduct research on; crop physiology, physiology of flowering, intercropping, planting techniques and cropping systems for climate resilience.
	D. Sector capacity development	• Develop research capacity for conducting research on tolerant clones • Develop facilities necessary to undertake research in controlled environments
Minimize the risk of crop damage due to biological agents	A. Germplasm improvement	• Screening of existing clones for pest and disease resistance • Develop pest and disease resistant clones
	B. Improvement of land and nursery management practices	• Develop recommendations on best practices of pest and disease management
	C. Monitoring and surveillance of pests	• Establish a surveillance programme for

	and diseases	early detection of new diseases and pests • Develop a system of forecasting risks of pests and diseases
Minimize the impact on export earnings due to erratic changes in precipitation	A. Establishment of an efficient climate information management and communication system	• Develop a system for timely issuing of seasonal and short-term weather forecasts • Adjust calendar of operations with seasonal weather forecasts
	B. Improvements in cropping systems	• Promote sustainable cropping system practices to increase the resilience of plantations (rainwater harvesting, agro-forestry and timber plantations, cover crops, contour drains, land suitability assessment, soil and moisture conservation practices)
Enhance the resilience of export crops and agro-ecosystems to extreme weather events	A. Establishment of an efficient climate information management and communication system	• Develop a system for timely issuing of seasonal and short-term weather forecasts • Strengthen the early warning systems
	B. Improvement of disaster risk preparedness and management	• Identify and collect information on areas that are most vulnerable to flood and drought hazards • Prepare hazard vulnerability maps • Develop guidelines for management of extreme events in vulnerable areas

The RRISL maintains a germplasm collection of foreign and local clones and during 2016, around 1400 accessions were planted at the Nivitigalakele sub-station in Matugama and in 2017, several accessions were established in the bud-wood 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 *Hevea*obtained 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 4. Establishment success and growth after 5 years

Planting material	Establishment success (%)	Girth (cm)
Bare root green budding	91.0	45.8
Bare root brown budding	82.3	45.7
Green budding poly bags	99.2	45.1
Young budding poly bags	100.0	48.6
Brown budding poly bags	98.8	48.5

Source: RRISL (1998)

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 (Samarappuliand 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 RRISLhas being 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 improve 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 *Boralu*series 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).

Improved 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 (Jeewanthi*et 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. Theseasonal 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.Aproject 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; Liyanaarachchi*et 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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Present Status of Research and Development onClimate Change Mitigation and Future Needs in the Sugarcane Sector in Sri Lanka

A.L.C. De Silva, L.M.J.R. Wijayawardhana and W.R.G.Witharama

Division of Crop and Resource Management, Sugarcane Research Institute, UdaWalawe, Sri Lanka

Abstract: Changing rainfall pattern and shiftingmonsoonal weather are critical climatic factors affecting sugarcane production in Sri Lanka.The scarcity of water to fulfill theirrigation requirement coupled with prolonged drought have severely affected the sugarcane production.A shift of fauna, flora, and microbial population with changing climatic conditions,leading to a change in the biodiversity in sugarcane ecosystem would increase insect pest, disease and weed incidences in sugarcane plantation. Weakened plants due to drought, stress are more vulnerable to pest and disease attacks in addition to the retarded growth and yield. Even though the changing of planting and harvesting schedules of sugarcane minimizes the impact of drought, complete adaptation of the crop for such adverse climatic and soil changes is limited in the present context. Hence, development and selection of appropriate sugarcane varieties for different sugarcane-growing environmentsand soil conditions, and improvement of the management practices would help mitigating the impact of changing rainfall pattern, drought and soil degradation on sugarcane production in Sri Lanka. Mulching reduces soil erosion andover-heating by preventing incidence of direct sunlight on the ground, and conserves soil and moisture in addition to supplying of plant nutrients to soil.Conducting regular surveys to find out existing pest and disease situations and emergence of new pests and pathogens in sugarcane plantations would help identifyingthe potential threats and adopt control measures accordingly.In addition, intensive extension and training program has to be carried out to convince the farmers about the risk of future climate change, drought and water scarcity and its impact on their farming.

Keywords: adaptability, climate, drought,productivity, sugarcane

INTRODUCTION

Sugarcane (*Saccharum*hybrid spp.)has been cultivated in Ampara and Trincomalee districts in the Eastern Province andin Moneragala andBadulladistricts in the Uva Province of Sri Lanka. Itis proposed to be expanded in Batticaloadistrict in the Eastern province and inKilinochchi districtin the Northern Province where theagro-climatic and soil conditions are different to those in the traditional sugarcane-growing areas(Anonymous, 2010).The adaptability and the productivity of currently-cultivated sugarcane varieties under different climatic conditions aremainly dependent on the availability of soil moisture, particularly in rain-fed cultivation which gives about 60% lower cane yield of irrigated sugarcane in Sri Lanka (De Silvaand De Costa, 2004; Ariyawansha, 2014).Soil moisture deficit and the scarcity of water for irrigationwhich occur due to prolonged drought for aboutfour months from June to September in dry zone adversely affect the sugarcane production in Sri Lanka (De Silva, 2007). It cannot be totally overcome by changing the date of planting because the duration of the crop is about 12 months. Thestudies in Sri Lanka have also revealed thatin agronomic and physiological performances of sugarcane reduced with the reduction of rainfall in the dry zone of Sri Lanka (De Silva and De Costa, 2004; 2009; 2012; De Silva*et al*., 2011).However, short-term water stress could be reduced by agronomic practices such as correct land preparation, changing time of planting and harvesting and mulching. Use of drought tolerant varieties is the best way to overcome the yield losses due to drought(Yadava, 1993).Hence, studying the current changes in climate and soil conditions in all sugarcane-growing locations and the evaluation of different sugarcane varieties under varying climatic and soil conditions in different agro-ecological regions of Sri Lanka is very important to develop and introduce better varieties for different sugarcane-growing conditions to improve the productivity of sugarcane in Sri Lanka.

The scientific analysis and projections on climate change have indicated the rising of atmospheric temperature and occurrence of unpredictable monsoon rains, extreme weather events such as floods and more frequent severe droughts (MMDE, 2015). The erratic rainfall pattern and the shifts in monsoonal weather due to climate change,which would intensify the water scarcity and prolonged drought are considered as more critical climatic factors for future sugarcane production in Sri Lanka.Increasingatmospheric carbon dioxide(CO_2) concentration and resulting increase of air temperature and global warming (McCarthy *et al*., 2001)have a positive impact on sugarcane production as sugarcane prefers a high air temperature range of 30 °C for germination and 35°C for vegetative growth (Gascho and Shih, 1983).Further, sugarcane growing t doubled air CO_2 concentrationtogether with high temperature increases crop growth and stem juice production,utilizes water more efficiently and would perform better in sucrose production than plant grown under ambient CO_2 and near-ambient temperature combination (De Souza *et al*., 2008; Vu and Allen, 2009a; Vu and Allen, 2009b). Thus, there is an enhancement of growth, yield and sugar content of sugarcane when growing atdoubledCO_2concentration and high temperature combinations, which will be expected in the future. Rising global CO_2might not have the same effects on different cultivars and plants grownunderdifferent environments and management conditions (Allen and Vu, 2009; Chaves and Pereira, 1992;De Souza *et al*.2008; Vu *et al*. 2006). The predicted rising atmospheric CO_2 and temperature, and erratic changes in rainfall patterns in the future would affect interactively the sugarcane production in Sri Lanka. Therefore, development and introduction of better varieties and altering management practices to maximize the benefits and/or minimizing adverse effects of climate change would be useful to improve the productivity of sugarcane under futureclimatic conditions in Sri Lanka.

PRESENT STATUS OF RESEARCH AND DEVELOPMENT ACTIVITIES RELATED TO CLIMATE CHANGE

Proceedings of the Workshop on Present Status of Research Activities on Climate Change Adaptations (Ed. B. Marambe), Sri Lanka Council for Agricultural Research Policy, Colombo.

Research on the climatic variability and climatic trends

The following analyseshave been carried outbythe Sugarcane Research Institute (SRI)to address the issues in changing climatic and soil conditions in Sri Lanka:

i. Agro-meteorological conditions of major sugarcane-growing areas in Sri Lankaevery year (SRI, various issues).
ii. Characterisation of rainfall in relation to sugarcane cultivation in Sevenagala(Ariyawansha and Keerthipala, 2010a).
iii. Temporal trends of climatic variables in Sevenagala and Pelwatte sugar mill areas of Sri Lanka (Ariyawansha and Keerthipala, 2010b).
iv. Characterisationof rainfall in relation to sugarcane cultivation at Pelwatte (Ariyawansha and Keerthipala, 2012).

A project on the identification of farmers' perception and adaption to climatic change and variability in Sevanagala area has been proposed to be undertaken in 2018.The automated weather stationsinstalled in Kantale and Kilinochchi in 2015and the manually-operated weather stations established inUdaWalawe, Sevanagala, Pelwatte andHingurana are maintained to collect daily agro-climatic variables for analyzing agro-meteorological conditions in major sugarcane-growing areas in Sri Lanka.Daily climatic data collected at the SRI, UdaWalaweis provided to the Department of Meteorology to meet the national requirements.

Changes of rainfall and daily ambient temperature during past 30 years in sugarcane-growing areas of Sevanagala and Pelwatte are described in below:

Rainfall: The mean monthly rainfall values in Sevanagala and Pelwatte for thirty years were classified into two groups,*i.e.*, 1984-1999 (16 years) and 2000-2016 (17 years), and these two groups were compared with paired T test at 5% probability (Table 1). The results showed that, total annual rainfall and total *Yala* and *Maha*seasonal rainfalls in both sites have not significantly changed in the longterm.

Table 1. Average total rainfall for year, *Yala* season and *Maha* season in two periods from 1984-1999 and 2000-2016 in Sevanagala and Pelwatte

Comparison parameter	**Mean (from 1984-1999)**	**Mean (from 2000-2016)**	**t-value**	**p-value**	**Significanc**
Mean annual rainfall at Sevanagala	1389.7±22	1537.9±28	-1.445	0.158	not significa
Yala season rainfall in Sevanagala	523.8±26	550.7±38	-0.572	0.571	not significa
Maha season rainfall in Sevanagala	856.9±51	987.2±48	-1.721	0.095	not significa
Mean annual rainfall at Pelwatte	1503.4±65	1691.1±65	-2.019	0.052	not significa
Yala season rainfall in Pelwatte	479.2±34	539.99±42	-1.115	0.273	not significa
Maha season rainfall in Pelwatte	1024.1±48	1151.1±65	-1.581	0.123	not significa

Source:L.M.J.R. Wijayawardhana (unpublished data)

Wijayawardhana*etal.*(2015) determined the annual one-day and 2-5 consecutive-day maximum rainfall levels and the probabilities of their occurrencecorresponding to various return periods for the sugarcane-growing areas at UdaWalawe using daily rainfall data recoded from 1992-2014. The maximum rainfall expected to occur for one day and 2-5 consecutive days in UdaWalawe in every two-year intervals and probable maximum rainfall values for 5 consecutive days for different return periods (Table 2) could be used effectively in designing a drainage system in sugarcane plantations. Normally, rainfall beyond 50 mm/day is considered as a heavy precipitation (Liesl, 2009). Accordingly, except for one-day maximum rainfall values estimated for 2- and 5-year recurrence intervals, all rainfall events could be classified as "very heavy rainfall" events. All combinations (Table 2) have exceeded the level of "heavy rainfall" events.

Table 2. Variations of probable maximum rainfall for 2-, 3-, 10-, 20-, 30-, 50- and 100-year return periods for one and 2-5 consecutive days

Days	**Return period (recurrence interval) in years**						
	2	**5**	**10**	**20**	**30**	**50**	**100**
1- day max	95.8	117.7	132.2	146.1	154.4	164.2	177.7
2-day max	122.5	146.4	157.9	166.9	171.5	176.5	182.7
3-day max	142.9	167.7	180.7	191.5	197.2	203.5	211.6
4-day max	151.7	172.7	182.5	190.0	193.9	198.0	203.0
5-day max	163.2	187.3	203.2	218.8	227.5	238.2	253.0

Source:L.M.J.R. Wijayawardhana (unpublished data)

Table 3 shows the monthly probabilities of annual maximum rainfall received at Uda Walawe. The second inter-monsoon from September to October period had the highest probability of 54.5% to have the one-day maximum rainfall. However, the highest probability of occurrence of 2-5 consecutive-day maximum rainfall is 54.8%, in the 1st inter-monsoon period from March to April.

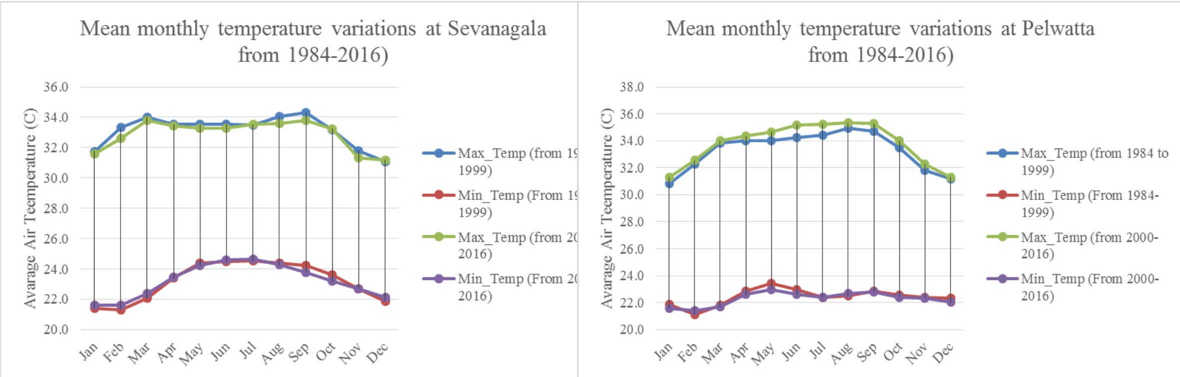
Table 3. Monthly probabilities (%) of annual maximum rainfall occurs at UdaWalawe

Month	**Annual 1 day**	**2-consecutive days**	**3-consecutive days**	**4-consecutive days**	**5-consecutive days**
March	0.0	13.6	9.1	9.1	9.1
April	0.0	4.5	4.5	13.6	13.6
May	0.0	13.6	13.6	9.1	18.2
June	0.0	0.0	9.1	13.6	0.0
July	0.0	4.5	4.5	4.5	0.0
August	18.2	13.6	0.0	4.5	9.1
September	36.4	9.1	4.5	4.5	0.0
October	18.2	4.5	13.6	13.6	13.6
November	4.5	9.1	4.5	4.5	0.0
December	4.5	13.6	9.1	9.1	13.6

January	0.0	9.1	18.2	9.1	22.7
February	18.2	4.5	9.1	4.5	0.0

Source:L.M.J.R. Wijayawardhana (unpublished data)

Temperature:The monthly average minimum and maximum temperature values in Sevanagala and Pelwattewere classified into two groups,*i.e.*, 1984-1999 and



2000-2016 (Figure 1).

Figure 1. Mean monthly temperature variations in Sevanagala and Pelwatte (Source:L.M.J.R. Wijayawardhana, unpublished data)

The maximum and minimum temperature values between the twotime periods(from 1984 to1999 and from 2000 to 2016) in both Sevanagala and Pelwatte sugarcane-growing areas were not significantly different during past three decades (Table 4).

Table 4. Mean annual temperature variations inSevanagala and Pelwatte for two periods from 1984-1999 and 2000-2016

Temperature (°T)	**Mean (from 1984-1999)**	**Mean (from 2000-2016)**	**t-value**	**p-value**	**Significance**
Sevanagala Max. °T	33.1±0.29	32.8±0.28	0.599	0.555	not significant
Sevanagala Min.°T	23.2±0.36	23.2±0.32	-0.034	0.973	not significant
PelwatteMax.°T	33.3±0.40	33.8±0.44	-0.803	0.430	not significant
PelwatteMin. °T	22.4±0.17	22.3±0.14	0.543	0.296	not significant

Source:L.M.J.R. Wijayawardhana (unpublished data)

Research on the adaptabilityof sugarcane to diverse climatic conditions

Development and selection of varieties suitable for different sugarcane-growing regimes and a range of different soil and environmental conditions in different agro-climatic regions would help to mitigate the impact of changing rainfall pattern, drought and soil degradation. Research projects conducted since 2003 on the assessment of adaptability and stability of some sugarcane varieties in different environments in Sri Lanka could identify that varieties SL 7130, SL 88

116, SL 89 1429, SL 89 2227 and SL 97 1442are well-adapted to dry and intermediate zones of Sri Lanka (Ariyawansha, 2012, 2014; Ariyawansha and Perera, 2014; Ariyawansha*et al*., 2009).The results suggested that development of a cropping calendar to cultivate sugarcane in the different agro-ecological regions is important to obtain the maximum productivity of varieties by deciding the period for planting and harvesting. The SL 90 6237 has been identified as a well-adapted rain-fed sugarcane variety having higher plant and ratoon yields (De Silva, 2008). Currently,eight commercial sugarcane varieties,*i.e.*, Co 775, SL 71 30, SL 83 06, SL 88 116, SL 90 6237, SL 92 4918, SL 69 128 and SL 96 328 are being evaluated in seven locations,*i.e*.,UdaWalawe, Sevanagala, Pelwatte, Hingurana, Kantale, Kilinochchi and Bandarawela, representing six different agro-ecological regions to investigate the agronomic and physiological performance of different sugarcane varieties under current conditions in different agro-ecological regions to identify the cultivars with higher performance under current conditions of rainfall, temperature and soil in different agro-ecological regions in Sri Lanka.The same varieties are also being evaluated in 12 open-top chambers at the Sugarcane Research Institute, UdaWalawe, to investigate the agronomic and physiological performance of different sugarcane varieties under elevated atmospheric CO_2concentrations and air temperatures expected in the future and to identify the cultivars with high efficiency in water use and production of biomass and stem sucrose under elevated atmospheric CO_2 and air temperature and to give recommendations to develop varieties having better performance under future sugarcane-growing conditions in Sri Lanka.

Changing cultural and management practices of crop would help to mitigate adverse effects of changing climatic conditions on sugarcane cultivation. Mulching conserves soil and moisture byreducing soil erosion and increasing infiltration and supplyingplant nutrients to the soil. Low soil temperature under soil mulch decreases the rate of decomposition and enhances accumulation of organic matter in the soil. It helps to mitigate adverse impacts of drought and heavy rainfall occurring with changing climatic conditions on soil. Further, under rain-fed conditions, mulching plant and ratoon crops with a mixture of*Gliricidia* leaves and sugarcane trash significantly increased cane and sugar yields in plant and ratoon crops (De Silva *et al.,* 2012).The on-going studies include the varietal response of sugarcane to varying climatic and soil conditions under well-watered and water-stressed conditions in Sri Lanka and the response of physiological processes and parameters related to growth of sugarcane under elevated carbon dioxide and temperature.

Research on water management related to climate change

The scarcity of water and prolonged drought adversely affect the sugarcane cultivation (Shanmuganathan, 1990). As sugarcane is a crop that is planted and harvested seasonally, changes in the monsoonal weather pattern are considered as more critical climatic factors for its growth.Changing the planting and harvesting schedules of sugarcane and establishment of small ponds within the farmers' fieldsto collect run-off water for supplementary irrigation and maintaining the ground water at higher level are recognized as possible adaptationsto minimize the impact of drought (Wijayawardana*etal*., 2011; 2014). However, farmers may not allocate a part of their small land for establishing small ponds (Wijayawardhana*etal*., 2011). Therefore, this should be addressed at policy levels, which include implementation of compensation schemes. Skipping severe dry periods atthe highest water-demanding grand growth stage of sugarcane with changing the time of planting (Figure 2) and practicing alternate-row furrow irrigation instead of conventional every-furrow irrigation could have a significant potential to reduce the irrigation water demand in sugarcane plantations (Wijayawardana*etal*., 2014; 2016).

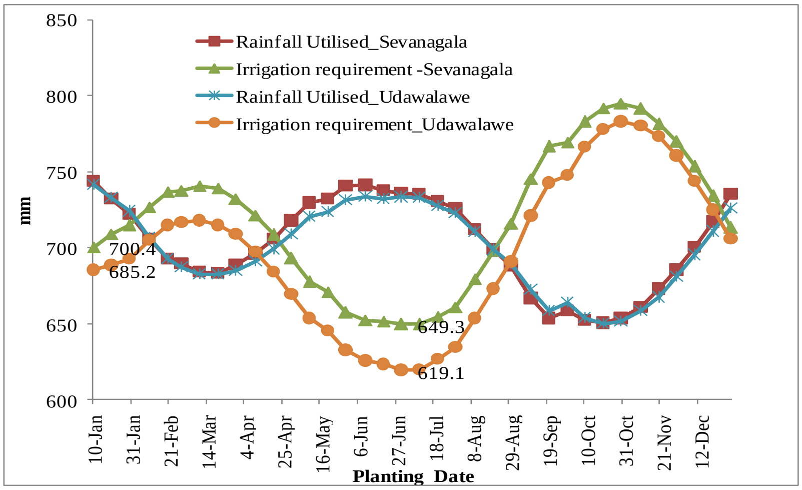


Figure 2. Changing pattern of rainfall utilization and irrigation requirement with changing the time of planting of sugarcane in UdaWalawe and Sevanagala (Source:L.M.J.R. Wijayawardhana, unpublished data)

Research conducted at UdaWalawe confirmedthat the alternate-row furrow irrigation technology saves irrigation water by 37-39% without reducing the attainable yield (Wijayawardana*etal*., 2016). Thus, it could be a worth option to save limited irrigation water in major irrigation schemes as well. However, some of these adaptations should be addressed at policy levels in order to save irrigation water.

Research on the pest and disease managementrelated to climate change

A shift of fauna andflorapopulationwith changing climatic conditions causeschanging bio-diversity in sugarcane ecosystem and increasing pest and disease incidences in sugarcane plantations. Therefore, regular surveysto find out the existing pest and disease situations and emergence of new pests and pathogens in sugarcane plantations help to identify potential threats and adopt control measures accordingly. Smut and white leaf diseases are the most devastating and fast-spreading sugarcane diseases in all sugarcane-growing regions in Sri Lanka. Different strains of smut disease and the relationship between the incidences of sugarcane white leaf disease and the population dynamics of its vector in different regions of Sri Lanka have been identified (Thushari and Ariyawansha, 2014; Chanchala*et al*., 2014). The weed spectrum in sugarcane fields dominated with annual grasses and broad leaved weeds about several decades before has now been changed to the spectrum with more perennial species (Witharama *etal*., 1997; Anonymous, 2014). Regular screening of herbicides and introduction of integrated strategies to control abundant and problematic weeds in sugarcane plantations helps to keep them under control.

FUTURE RESEARCH AND DEVELOPMENT NEEDS

The future researches for mitigating the impacts of climate change on sugarcane should be focusedon (a) development and identification of high-yielding sugarcane varieties with tolerant toabiotic and biotic (drought, salinity, alkalinity, pest and disease)stresses, well-adapted to adverse and diverse climatic conditions, (b) devising new methods and identifyingmaterials for soil moisture conservation under different field conditions and (c) improving the cultural practices for controlling soil erosion, soil and moisture conservationfor optimizing agronomic and crop management practices.Future studies on those aspects should be focused on to develop crop management strategies to conserve soil and moisture, protect crops from extreme climatic conditions such as excessive heating, drought and flood. Planting with zero/minimum tillage, changing cropping pattern and cropping system, development of integrated sugarcane-based farming systems would be effective to mitigate the impact of climate change on sugarcane. Schedules of land preparation, planting, irrigating and harvesting should be changed to maximize the utilization of available rainfall and to minimize the soil erosion and irrigation water requirement. New methods should be developed for runoff water harvesting. Regular monitoring of the dynamics of pests and their natural enemies, diseases and their causal agents and strains and weeds population in different agro-climatic regions of sugarcanegrowing should be continued. Weed management studies should continue while emphasizing on preventing the development of herbicide-resistance weeds and those problematic to the growing crop. In addition, intensive extension and training programs to convince all officers and farmers in the sugarcanesector about future risk of climate change, drought and water scarcity, their impacts on their farming and the importance of saving of irrigation water at national scaleis essential to make a comprehensive model forthe whole sugarcanesector for decide on policy directions to minimize the climatic risks.

CONCLUSION

The erratic rainfall pattern and the shifts in monsoonal weatherwhich create severe drought with climate changewould significantly affectfuture sugarcane production in Sri Lanka.The main long-term sustainable adaptation optionfor cultivatingsugarcane under a changing climate is selection of varieties with higher yields and tolerance to abiotic and biotic stresses due to climate change effects. Main short-term adaptation options are improving efficient cultural practices and cropping systems and adhering to soil and moisture conservation practices which have been already recommended by the sugarcane Research Institute. Regular monitoring of pests, diseases and weeds in sugarcane plantations helps to face the impact of altering diversity of furan and flora under changing climatic conditions. Thus, a comprehensive research program including variety improvement, development of new technologies and/or improvement of existing crop management practices and continuation of studies on dynamics pest, disease and weed populations in sugarcane plantations are required.

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Effects of Climate Change on Livestock:Sri Lankan Perspectives

W.M.P.B.Weerasinghe
Veterinary Research Institute, Gannoruwa, Peradeniya, Sri Lanka

Abstract: Livestock production has increased in Sri Lanka in recent years.The same trend would continue in the future. While providing vital protein for human population, livestock farming contributes to the greenhouse gas (GHG) emissions. Methane is the main GHG emitted by livestock.Emission factors for enteric fermentation in Sri Lankan cattle and buffaloes estimated using IPCC(Tier 2) method has revealed that methane emission from cattle, buffalo and sheep were 50, 49 and 3 kg head^{-1}year^{-1}, respectively, whichwere lower than the respective IPCC default values.According to the production systems, GHG emission is the highest in dry low lands (Dry Zone) and the lowest in wet low lands (Wet Zone). Several studies have been conducted to improve the productivity of livestock through better feeding and nutrition, which will ultimately serve as a mitigation measure to reduce GHG emissions. Adaptive measures on livestock housing; especially to tackle high temperatures, have been introduced and are successful in operation in the country. Sri Lanka should establish GHG measuring facilities for livestock.Further, the country should prioritize and facilitate research and development work on climate change and its effects on livestock production.

Keywords: Adaptation, methane, mitigation, livestock

INTRODUCTION

Crop and livestock are the major sub-economic sectors in agriculture in Sri Lanka, particularly for the rural population. In Sri Lanka, livestock sector contribute to about 0.6% of the gross domestic product (Anonymous, 2015),however, this may increase in the future as milk production has increased by 4% in the year 2014 and has shown an increasing trend over the recent years. This is mainly due to the increase in productivity of an animal and the number of animals. For example, cattle population has increased by 10% while buffalo population by 2% in 2015, compared to 2014(Anonymous, 2015).

The three main greenhouse gases (GHGs) are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) (Steinfeld*et al*., 2006). The animal agriculture sector accounts for approximately 9% of the total CO_2 emissions, of which animal product processing and transport accounts mainly for livestock-related CO_2emission, while the rest is from the crop agriculture sector (Koneswaran and Nierenberg, 2008). The livestock sector is responsible for about 35-40% of the annual global anthropogenic methane emissions, which are the results of enteric fermentation and farm animal manure (Steinfeld*et al*., 2006). Ruminants could produce 250 to 500 liters of methane per day depending on various animal and feed-related factors.This would lead to about 12% loss of the dietary energy in the ration as methane(Johnson and Johnson, 1995). In addition to the contribution by livestock to the global warming, the sector has in turn been seriously affected by the same. Rising temperatures could reduce roughage yields or destroy the harvest due to prolonged drought or heavy rains, which could lead to a feed scarcity and thereby lower productivity of the animals. Amount of milk produced by cattle and buffalo depends mainly on the type of breeds. Temperate breeds and their crosses could perform well in cooler climates and produce relatively higher amountsof milk compared to more heat-toleranttropical breeds. When temperature rises, vast animal-growing areas would become unsuitable for high producing animals, resulting in lower milk production.

In Sri Lanka, cattle and buffaloes are the main livestock groups by numbers while sheep, goat and swine remains as minors (Lokupitiya, 2016). Although the contribution by livestock to the national GDP is low, it is one of the major livelihood and income generator for a significant population in the country. Dairy cattle has multiple functions such as producing milk for household consumption, income and sales, male animals as mode of transport, cash income generated through meat, and their dung as a valuable fertilizer.

The importance and contribution of livestock to the livelihood of the people in Sri Lanka is significant both economically and socially, however, the impact of global warming on the sector in Sri Lankan conditions has been less documented. The objectives of this review is therefore, to compile statistics of GHG emissions by livestock, current research and development activities related to climate change, identification of gaps, and suggest future research and development needs.

Greenhouse gas emissions by livestock

Methane is the main GHG emitted by livestock (Knapp *et al*., 2014).The amount of methane emitted by livestock depends on the body size, metabolism, activity level of the animals, and their feed quality(Steinfeld*et al*., 2006). The author's perception is that the quantity of methane emitted by livestock under Sri Lankan condition has not been estimated scientifically,though few estimates have been already been published.

Lokupitiya (2016) estimated the enteric methane emission of Sri Lankan cattle and buffaloes using the tier 2 method proposed by the Intergovernmental Panel on Climate Change (IPCC) and concluded that the methane emission factor for dairy cows, buffaloes and sheep were lower than the respective IPCC default values (Table 1).As this is an estimate, Lokupitiya (2016) highlighted the need to validate the estimates through adequate measurements.

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Table 1. Methane emission factors estimated for enteric fermentation in Sri Lankan cattle and buffaloes estimated using IPCC (Tier 2) method.

Livestock category		Methane emission by Kg $head^{-1}year^{-1}$	
Dairy cattle		50	IPCC default - 58
	Local	52	
	Improved	42	
Buffaloes		49	IPCC default - 55
	Dairy	65	
	Other buffaloes	44	
Sheep		3	IPCC default - 5

Adopted from Lokupitiya(2016)

Recently, FAO and the New Zealand government funded a project on “Reducing enteric methane emissions for food security and livelihoods” and estimated the methane and nitrous oxide emissions by cattle in Sri Lanka considering the feeding type, feeds available, agro-ecological zones of the country and the production systems. Unlike previously, the study also considered the manure management and GHG inventory of roughage production. The results indicated that GHG emission is the highest in the Dry Zone whilst lowest in the Wet Zone. The mid country, which contributes to about 40% of the national milk production but had only less than 10% of the cattle population has showed the second lowest GHG emissions. Comparatively, production efficiency of cattle at Dry Zone is low, resulting in the highest contribution to the GHG emission. This has provided vital information for mitigation and adaptation activities for future (Figure 1).

RESEARCH AND DEVELOPMENT ACTIVITIES RELATED TO GHG EMISSION IN SRI LANKA

Mitigation

In addition to few estimations, the research in the livestock sector conducted directly on GHG emissions, mitigation and adaptation measures in Sri Lanka is in scarcity. This may be due to the non-availability of sufficient infrastructure in the country (e.g. respiration chambers to measure GHG, SF6 tracer technique, etc.) or lack of funds and expertise. However, there are several studies conducted to increase the production efficiency of the livestock, mainly through improving nutrition, housing, welfare and health. They do not directly address or report on reducing GHG emissions or mitigation and adaptation measures to climate change, but indirectly has related the issue up to some extent, for example, improving feeding efficiency has been found to reduce methane emission and increase milk production (Gill *et al*., 2010). Similarly, measures taken to reduce the effects of high temperature and humidity through improved housing designs would also pave the way for adaptation measures for climate change (Table 2).

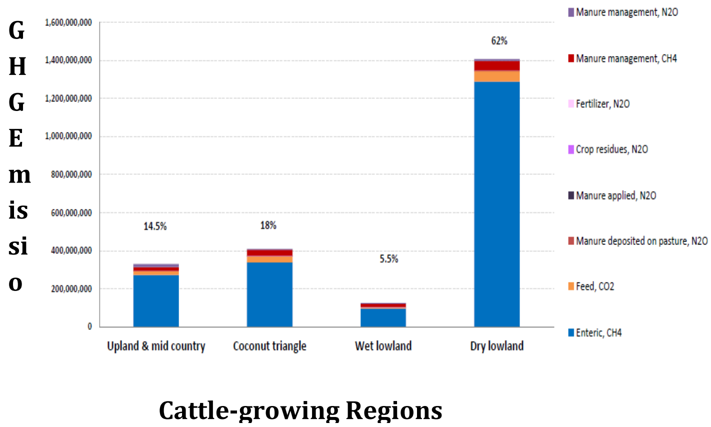

Figure 1. Contribution of dairy cattle production systems to GHG emission.Source: FAO, New Zealand government funded project on "Reducing enteric methane emissions for food security and livelihoods" (Unpublished data).

Table 2. Mitigation interventions and their impacts on some nutrition studies conducted in Sri Lanka.

	Impacts of intervention	**Reference**
Adaptation of Total mixed ration (TMR)	Milk production, milk fat and total solid contents increased	Bodahewa*et al.*(2014)
Supplementation of tree fodder and low cost concentrate to heifers grazed on natural vegetation.	Supplementation increased dry matter, total digestible nutrients, growth and milk production.	Seresinhe*et al.*(2012)
Supplementation of Urea molasses multinutrient block(UMMB) with low quality roughages.	UMMB supplementation increased milk yield and yields of milk fat, protein and the body weight.	Weerasinghe*et al.*(2011)
Supplementation of leaf meal block along with forage diet.	Supplementation increased dry matter intake, daily weight gain and milk production	Somasiri*et al.*(2010)
Exogenous fibrolytic enzymes cellulose and xylanase supplemented with Guinea grass (*Panicum maximum* 'A') and rice straw (*Oryzasativa*)	Weight gain, nutrient intake (DM, OM,NDF) and digestibility increased. Enteric methane production as a percentage for rumen gas production reduced numerically.	Sujani*et al.* (2015)

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Adaptation

High ambient temperature in most parts the country is one of the major problems faced by the livestock farmers. Warm climate does not allow temperate breeds to perform well but the local breeds adapted to those conditions produce less milk. Mid and up country of Sri Lanka have favorable climatic conditions for high producing animals, but land availability is low for livestock farming. Therefore, the dairy farming had to be moved to Intermediate and Dry Zones of the country.Further, the temperature of cooler parts of the county is also likely to increase as a result of climate change. Considering this aspect and that more land is available for livestock farming in the Intermediate and Dry Zones, there is a trend to constructfarm houses to tackle high heat. Most farms consider well-ventilated, high roof sheds to accommodate more air movement and some have introduced cooling and fogging systems. These farms having temperate breeds are located in hot and humid places such as Hambantotain the southern province of the country and have proven to be successful, although no scientific study has been conducted to-date (Figure 2).

Figure 2. Fog ventilated dairy cattle housing at Ridiyagama national livestock development farm, which rare temperate breeds of dairy cattle.

GAPS AND FUTURE RESEARCH NEEDS

Accurate data is a prerequisite for modelling and suggesting mitigation and adaptation plans to overcome the adverse effects of climate change. WhenGHG emissionsare considered, Sri Lanka has only estimates, but emissions under local feeding and management conditions have not been scientifically measured and no facilities are available in the country to measurethese parameters at the ground level. Further, several studies that have been conducted to improve productivity of livestockhave not directly addressed climate change or GHG emissions. Therefore, the country is in urgent need of establishing a GHG emission measuring facility for livestock, which would help in determining the accurate adaptive and mitigating measures that can be implemented. Funding agencies should include climate change as a component in their priority list. All the stakeholders including government ministries and departments, research institutes, funding bodies and universities should be advised to address mitigation and adaptation measures to climate change in their research and development agenda on livestock, whenever possible.

CONCLUSION

Climate change has a negative effect on livestock industry in the country. The data available on GHG emissions is based mainly on estimates, therefore, the capacity building on this aspect should be given priority. Some studies and development projects have been implemented in the country without directly addressing the mitigation or adaptation measures against global warming, but has contributed towards that goal. Therefore, to better prepare for adverse effects of climate change, more research and development programs on this aspect should be implemented in the livestock sector.

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Climate Change Research on Fisheries and Aquaculture: A Review of Current Status

K. Arulananthan

Oceanography Division. National Aquatic Resources Research and Development Agency, Sri Lanka

Abstract: Sri Lanka, the southernmost Island of the north Indian Ocean is blessed with a rich endowment of coastal and marine eco-systems. However, the tropical island positioned at the centre of monsoonal regime is unkindly proneto ocean disasters and climate change. The fisheries industry plays an important role in the economy of Sri Lanka and provides livelihood for more than 2.5 million coastal communities and more than 60% of animal protein requirement of people in the country. Acidification, changes in sea temperatures and circulation patterns, frequent and severe extreme events, and sea-level rise and associated ecological changes resulting in from climate change will affect the fisheries and aquaculture industry. Sea level rise and warming of the sea are the two crucial factors that could impart decisive impacts on coastal fisheries and aquaculture. The coastal stability studies indicate that except for the northern-most coast, the entire coast is under different degree (moderate to high) of erosion. The cumulative implications of climate changes possess the potential of inducing adverse effects on the coastal fishery and aquaculture. The development of the fishery sector should seriously consider the ramifications of climate changeand take steps to strategically adopt appropriate adaptation measures to ensure the continued sustainability of the industry.

Keywords: Climate change, fishery sector, coastal belt of Sri Lanka, sea water intrusion

INTRODUCTION

Fisheries industry plays an important role in food and nutrition security. The sectorcontributes significantly to the economic development of Sri Lanka by providing livelihoods for more than 2.5 million coastal communities,and more than 60% of animal protein requirement of people in the country. In 2015, the share of fisheries to the Gross Domestic Production (GDP) of the country was 1.3%, with a total fish production of 520,190 mt of which the marine fish production was 452,890 mt and the rest (67,300 mt)from inland fisheries and aquaculture. In comparison with 2014, the offshore fish production has increased marginally by 1.9% however, the coastal fish production experienced a 3.5% decline. The total fishing family population amounts to 610,000 in Sri Lanka and more than a million people from the coastal community is estimated to be self-employed traders depending on fisheries for their livelihood. The fisheries sector also contributes to more than Sri Lanka Rs (LKR) 25,000 million in terms of foreign exchange through export of marine and aquaculture products (NARA, 2015).

Climate change will affect fisheries and aquaculture *via* acidification, changes in sea temperatures and circulation patterns, high frequency and severity of extreme events, and sea-level rise and associated ecological changes (FAO, 2016), and Sri Lanka is not an exception. Sea level rise and warming of the sea are identified as the two crucial factors imparting decisive impacts on coastal fisheries, which may further aggravate poverty of the coastal communities in Sri Lanka.The impacts of climate change on sandy coasts will manifest themselves at various spatio-temporal scales (~ 10 m to ~ 100 km and days to centuries; Ranasinghe 2016).

The forecasted sea level rise for 2050 is expected to cause a general shoreline retreat of 10 m along all the sandy coasts. Over a 50-year period, this will correspond to 0.2 m of shoreline retreat per year. Fishing has been a major economic activity in Sri Lanka from time immemorial and has been the major livelihood of the coastal communities. The marine resources base of Sri Lanka has an Exclusive Economic Zone (EEZ) of 517,000 sq. km with rich fish species. In addition, there are 45 major brackish water lagoons and estuaries covering a water area of 158,000 ha. Apart from marine and brackish water resources, Sri Lanka has 520,000 ha of water bodies including irrigation reservoirs, perennial tanks, and seasonal tank.

Fishery constitutes the major economic activity in the coastal region, which contains 25% of the island's population (MoE, 2010). It serves as a livelihood of a considerable segment of Sri Lanka's population, and source of protein for its people. Fishery of Sri Lanka is dominated by coastal fishing and the offshore and inland fisheries are steadily increasing its contribution to the total fish production, while the contribution by the coastal fishing showing a tendency to decline. In general, fishery is heavily dependent on conducive environment conditions for sustainability and productivity thus, making it critically important to consider ramifications of climate change in the development of the sector and strategically adopt appropriate adaptation measures for continued sustainability of the fishery industry.

Sri Lanka is vulnerable to climate change that can have major impacts on coastal ecosystems that nourish the marine food fishery. The consequences of climate change on the fisheries sector have not been assessed or quantified widely, though the production, availability and breeding patterns of aquatic life would be affected (Jayatilake, 2008). Any damage to estuaries and lagoons, coral reefs or coastal wetlands would lead to reduced feeding, breeding and nursery habitats for commercially important coastal and marine finfish and shellfish used in the food fishery.Climate change exerts positive and negative impacts on fishery habitat, fishery stocks, fish stock availability harvesting sector fishing communities

PRESENT STATUS OF RESEARCH AND DEVELOPMENT ACTIVITIES RELATED TO CLIMATE CHANGE

Climate change is a global phenomenon that is predicted to disproportionately impact low and middle income nations and the strata of poor communities. Research and development are aimed at building adaptive capacity to be better prepared to withstand the impacts of climate change that in turn has implications on economic growth and poverty reduction.

Adaptation on fisheries habitat

Coastal Conservation and Coastal Resources Management Department (CC&CRMD) of Sri Lanka had addressed the climate change related issues in its latest Coastal Zone Management Plan. The Coastal Zone Management Plan (CZMP; CCD, 2004)of the country aims for a better coastal environment through the "protection and stabilization" of erosion prone beaches, establishment of beach parks, prevention and minimization of coastal pollution (including water pollution), preparation of shoreline development plans, implementation of special areas management plans in ecologically-sensitive coastal sites and the conservation of coastal habitats. Research is being conducted to identify areas for beach nourishment and bio-shielding on the coast as a counter measure against sea level rise and erosion of the coast line.

Adaptation on fishery stocks

Ocean warming and acidification are expected to directly and/or indirectly determine the stock distribution, recruitment levels, and variability and adult biomass production. Adaptation to these changes can only be achieved by adjusting fishing effort to levels that are consistent with the yield levels that can be sustained by the changed populations. In this respect, the National Aquatic Resources Research and Development Agency (NARA) of Sri Lanka is intended to conduct fish stock survey using S/V Dr. Fridtjof Nansen in 2017-18.

The research and development activities conducted as adaptive measures to mitigate the impacts of climate change on fish stock include reef monitoring to provide early warning alerts of bleaching events and management of the reef habitats, artificial reefs or fish-aggregating devices, and fish stock assessment.

Adaptation on fish stock availability

Climate change results in relocation and redistribution of fish resources. Thus, traditional fishing grounds and gears may not be effective in harvesting. Hence, the fisheries industry need to adapt by adopting vessels and gears that can pursue the resource in its new habitat. This may require larger vessels for longer trips and investment in gear development. The Ministry of Fisheries and Aquatic Resources Development of Sri Lanka is intended to introduce mother vessels, which may be used as supply vessels to fishing vessels in the high seas and fish collector from the vessel for storage and transport. Research and development activities are being conducted to this effect on possible community participation in the management of coastal habitats, and monitoring health problems (e.g. algal blooms, ciguatera, cholera) that could increase under climate change and harm fish stocks and consumers.

Adaptation on the harvesting sector

Less frequent but high intensity cyclones, increasing extreme ocean weather and wind are suspected to be the cause of change in climate. The lower fish production in 2015 than the previous year is attributed to the worse sea conditions for navigation.The identified as research needs in this discipline include enhanced seaworthiness and safety aboard fishing vessels, designing and construction of shore infrastructure, and early warning on potential ocean based extreme events.

Adaptation on costal aquaculture

Aquaculture and mariculture are rapidly growing fisheries sector in Sri Lanka that have already been affected by the climate change. However, Sri Lanka's coastal zone offers high potential for new forms of coastal aquaculture. The extensive lagoon systems of the eastern and northeastern coasts have considerable possibilities to introduce new species with more environmental tolerance. Furthermore, to release the pressure from the coastal fisheries, which is the first to get affected by climate change, the research activities are currently being conducted to identify potential sites to expand aquaculture, including seaweed,clams, spiny lobsters, sea cucumber, oysters, and bivalves to increase and stabilize seafood supplies, help stabilize employment, and carefully augment wild stocks, and to select suitable sites for artificial production of marine ornamental fish.

IDENTIFIED GAPS

Climate prediction remains uncertain mainly because of absence of long term data, especially on sea surface temperature, ocean acidification, ocean current pattern, etc. Thus, a network of automatic recording stations had to be established to measure ocean parameters, essential for climate/weather prediction and forecasting. Research on assessing the vulnerability and impact of climate change on estuaries and lagoons, coral reefs or coastal wetlands and quantify the impact on feeding, breeding and nursery habitats for commercially-important coastal and marine finfish and shellfish used in the food fishery, ocean warming on the distribution, growth and reproduction of fish stocks as commercially important fish stocks may change their spawning areas and distribution patterns and ocean acidification on shellfish, crabs, lobsters and corals to build calcium carbonate shells resulting in diminishing stock and destroying the habitat (in the case of corals) are either absent of scarceIncrease in sea water temperatures will change the distribution and composition of marine and coastal species thus, affecting fish stocks. Inland wetlands important for the food fishery may also be adversely affected by temperature anomalies with resultant changes in water quality that for example could cause fish kills.

FUTURE RESEARCH NEEDS

Fishery is heavily dependent on conducive environmental conditions for sustainability and productivity. Hence, research shall be conducted to assess the impact due to climate change-induced sea level rise, storm surges and coastal flooding on (1) loss or changes in coastal habitats and species distribution, (2) net loss of wetlands and landward migration of coastal wetlands, adverse impacts on mangroves and coral reefs, (3) changes in salinity of lagoons and estuaries due to saline intrusion and coastal flooding, (4) damage to coastal habitats such as coral reefs, mangroves and sea grass beds, (5) impact of ocean warming on the distribution, growth and reproduction of fish stocks – in both marine and inland waters, (6) impact of loss of beach due to sea level on beach seine fishery and beach landing sites, (7) reef monitoring to provide early warning alerts of bleaching events and management of the reef habitats, (8) identifying sites to install artificial reefs or fish-aggregating devices, (9) fish stock assessments to develop fisheries policy, monitor health problems (e.g. algal blooms, ciguatera, cholera) that could increase under climate change and harm fish stocks and consumers, (10) ocean status forecasting for potential ocean based extreme events, (11) designing and construction of shore infrastructure and fishing vessel to withstand extreme events, zonation for aquaculture, mariculture and fish farming, artificial production of marine ornamental fish and (12) potential positive impacts

CONCLUSION

In Sri Lanka, fisheries offers livelihood for one eight of the population and provide more animal protein requirement about 60% of the population in the country, while almost 1/3rdof the population inhabit coastal zone. Implications of the climate change on fisheries and aquatic resources seem to be already underway. The decline in fish production, both in marine and inland production in 2015 than the previous year is a great concern. The decline in marine fish production is due to the reduction in coastal fisheries, though offshore fish production had marginally increased while the decline inland and aquaculture production is attributed to the decline in capture production from perennial waters, though culture-based fisheries and shrimp production had increased. The decline in the production of coastal and inland capture fisheries is under investigation. However, the causes for the decline in inland production are attributed to the dry inland weather, rough ocean weather and/or overexploitation.

Further increase and expansion of capture fishery production is limited due to the impact of climate change and/or over exploitation. However, it is likely that aquaculture, in view of its resilience and adaptability and its cultivation of a wide array of species will be able to respond positively to climate change impacts. The aquaculture industry thus, needs to be supported with related policies, institutional and socio-economic changes and backed up and supplemented by relevant technical developments. It is conceded that there is a need to gather quantitative data/information, policy intervention and setting up of a mechanism to address issues regarding the role of aquaculture and combat the adverse impact of climate change on the aquaculture industry.

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Research and Development on Climate Change Mitigation and Adaptation in Forestry: Present Status and FutureNeeds

R.M.D.Alawathugoda
Forest Research Institute, Forest Department, Battaramulla. Sri Lanka

Abstract: Forestry sector plays a major role in both aspects of climate change: mitigation and adaptation.Major impacts of climate change in forestry are loss of biodiversity, impaired forest health, high weed infestation, severe drought, accelerated fire risk, and spread of invasive species.Forest Department of Sri Lanka has undertaken a number of research studies within these areas related to climate change mitigation/adaptation. Restoration of degraded forests, domestication of local tree species, and evaluation of community managed forest areas are three broad research areas recently conducted, which are related to climate change mitigation through improved carbon absorptionand addressing adaptation to drought, weeds, pest and diseases, etc. Bioenergy production, carbon assessment, weed and invasive species control, and water conservation are among other related studies. However, there are several research gaps in studies related to adaptation mechanisms for drought, prediction of forest health and fire risk, carbon and non-carbon benefits, market-based mechanisms for conservation etc. Therefore, this paper reviews the current status and future requirements of research in the respective fields to be considered.

Keywords: Adaptation, climate change, forestry, mitigation, research gaps

INTRODUCTION

Natural change of climate on earth has been accelerated by human activities after industrial revolution mainly due to increased burning of fossil fuel, land use changes and agriculture. The earth is now bearing the severe impacts of floods, drought, sea level rise, etc., as a result of rising temperature due to increased concentrations of greenhouse gas (GHG) emissions. Global expectations of combating climate change may not be achieved only by reducing emissions of GHGs alone, but efforts should be focused on actively removing GHGs from the atmosphere.

Forestry sector plays four major roles in climate change, by (1) contributing a large share of global carbon emissions when cleared, overused or degraded, (2) reacting sensitively to a changing climate, (3) producing woodfuel as an alternative to fossil fuels, and (4) absorbing a considerable portion of global carbon emissions into their biomass, soil and products (FAO, 2012a). The world's forests and the soil underneath store more than one trillion tons of carbon, which is twice the amount of free atmospheric carbon. Deforestation in different parts of the world is found to contribute to 12-17% of global carbon dioxide emissions each year (FAO, 2012b). Therefore, deforestation and degradation not only disturb the absorption function of the forests but also release carbon stored in soil and plant materials back to the atmosphere further intensifying the climate change issue.Hence, forests act as a carbon source as well as a carbon sink. Therefore forest conservation is a key strategy for both reducing emissions and removing GHG from atmosphere for climate change mitigation.

Government of Sri Lanka has set its targets to increase the present forest cover from 29.7% of the total land area to 32% by the year 2020 in its efforts to mitigating climate change impacts through reducing emissions from deforestation and forest degradation, conservation of forest carbon stocks, sustainable management of forests, and enhancement of forest carbon stocks. Country's comprehensive plan for achieving this includes 13 Policies and Measures (PAM) under three key strategies- improved sustainable management practices, increased supply of fuelwood and timber, and improved regulatory policies and measures, which are proposed to be implemented by involving many stakeholder institutions (REDD+ Sri Lanka, 2017).Accordingly, Forest Department (FD) is committed to undertake activities to improve forest law enforcement and monitoring, forest boundary demarcation and declaration, restore degraded forests, strengthen sustainable management of natural forests and forest plantations, strengthen protection of watersheds, and to develop agroforestry models, for mitigating climate change impacts (REDD+ Sri Lanka, 2017).
The FD is already implementing its plan through various strategies such as restoration of degraded forest, hill top restoration, reforestation, removal of Alien Invasive Plants, agroforestry, homegarden development, habitat management, etc. Challenges and issues faced by the sector while implementing these strategies are addressed through research. Further, when we live in a changing climate, we are automatically compelled to address the issues related to climate change, but these issues are similarly related to other subject areas. Therefore most of the research related to climate change are concealed in other subject areas without much recognition as climate change research.

The forestry sector plays a major role in both aspects of climate change, mitigation and adaptation. Climate change affects biodiversity, forest health, weed infestation, fire risk, drought etc. and henceaddressing these issues are climate change adaptation measures.Climate-driven effects of drought, forest dieback, insect and disease mortality and fire could transform the world's forests from a net carbon sink (sequestering CO_2) into a net carbon source (emitting CO_2) (Kurz *et al.*, 2008, Lewis, 2005).Attempts to increase tree cover and reduce emissions through deforestation and degradation helps mitigating climate change impacts through increased CO_2 absorption from the atmosphere. Therefore, climate change related issues in forestry can be broadly categorized as climate change mitigation and adaptation.

MAJOR IMPACTS OF CLIMATE CHANGE IN FORESTRY

Drought

Drought is becoming more intense and happening more frequently. Drought has caused growth retardation in the dry zone forest and forest plantations and reduces the productivity. Tree plantation establishments usually depend on rain water, and this has been adversely affected by prolonged drought periods and unpredictable changes in rainfall pattern in recent times. Therefore screening for drought tolerant tree species, improved technologies and water conservation methods along with irrigation options have to be adopted in tree planting for climate change adaptation.

Fire risk

As a result of prolonged drought, risk of fire damage is accelerating, and it poses severe threats to the protection of forest, and therefore fire control measures as well as early warning systems have to be adopted as a climate change adaptation strategy.

Forest health

Due to changes in temperature and local climatic conditions both pest and pathogens, and the host tree composition vary and outbreaks may occur due to changes in ecological balance. Further, spreading problem of dieback of forests is suspected to be a result of climate change due to prolonged drought among other factors.

Aggressive weeds and invasive species

Due to changes in climatic conditions different plant species are affected differently. Certain aggressive and invasive species can dominate suppressing other species. This results in loss of biodiversity in natural environments. Aggressive weed growth adversely affects the performance of young plantations which reduces the productivity and makes maintenance extremely difficult.

CLIMATE CHANGE MITIGATION/ADAPTATIONRESEARCH IN FORESTRY SECTOR: PRESENT STATUS

Although not specifically addressedas climate change issues, following research areas under FD can be identified as focused on climate change mitigation/adaptation.

Restoration of degraded forest areas

Rehabilitation of degraded forests through various means is a major implementing program of the FD in its mitigation efforts, and research findings support the efforts to restore different forest ecosystems through testing various methods such as reforestation, assisted natural regeneration, enrichment planting, conversion of monoculture exotic plantations into mixed plantations etc. (Bandumala and Karunarathna, 2008).

Domestication of local tree species

Reduced adverse impacts of exotic monoculture plantations, and increased biodiversity is a main approach of FD reforestation programs and therefore introducing suitable local tree species for various climatic conditions is a major research area continuing in multiple locations in the dry, wet and intermediate zones. This also helps in conservation of local flora as rare species are particularly vulnerable to changes in climate.

Community participation for forest protection and management

Reduced productivity of forests and lowered food security as a result of climate change may increase the threat to natural forests for livelihoods, and sustainable management and protection of forests through community participation as a key strategy of the FD may improve the forest condition while improving the living standards of forest dwellers.A comprehensive research continues to study the effect of community participation in forest management on the change in forest structure towards conservation (Alawathugoda and Balharrie, 2016).

Bioenergy production

Increased use of bioenergy helps in both reducing GHG emissions from fossil fuel burns, while removing emissions from atmosphere during its growing phase.A research is continuing to study the efficient utilization of available resources for industrial bioenergy production. A study is initiated to assess the production and fuel value of local and underutilized tree species for bioenergy production.

Carbon sequestration

Carbon sequestration helps in valuing ecosystems for making policy decisions in conservation and land-use change options.Further, Forest Reference Levels have to be established for Carbon Trading options. A comprehensive study has been done on Carbon estimation of mangrove ecosystems (Alawathugoda and Premakantha, in preparation) and some case studies have also been done in individual forests by various scientists, for example, inBadagamuwaConservation Forest (Alawathugoda*et al*., in preparation).

Tree volume and biomass estimation

Species specific and general allometric equationsof tree volume and biomass help in estimating Carbon stocks and sequestration rates by various ecosystems as well as forest plantations. Species-specific volume equations have been produced for some exotic and local tree species, for example, *Tectonagrandis* (Subasingha and Guneratna, 2008), *Eucalyptus grandis* (Sivananthawerl, 2008), *Toonaciliata,Micheliachampaca* (Sivananthawerl and Premakantha, 2011),*Gmelinaarborea* (Sivananthawerl and Pushpakumara, 2011),*Azadirachtaindica, Berryacordifolia, Chloroxylonswietenia* (Sivananthawerl and Premakantha, 2012) and Trees Outside Forests (Premakantha*et al*. 2012).

Control of aggressive weeds in forest plantations

Severe weed growth is a main cause of low survival and growth of forest plantations particularly guinea grass (*Panicum maximum*)predominantly in the dry zone. Therefore various mechanical methodssuch as uprooting, cutting, pressing of grasses etc. have been tested for weed control in commercial forest plantations as well as in degraded forest areas with limited success (personal observations).Spread of *Ochlandrastridula* (*bata*) in the undergrowth is a severe problem in forest plantation establishment in the wet zone, and it is considered as a main reason for failure of plantations with current forest management practices. A research finding shows that with high input intensive management system including removal of *bata* clumps repeatedly for about 3 years or covering of cut stumps with black polythene sheets for several months will reduce the growth of *bata* significantly (Bandumala, personal communication).

Water conservation methods in plantation establishment

Another main factor of failure of forest tree planting in the dry zone is water scarcity in young stage of plantations due to changes in rainfall pattern. Therefore various water conservation techniques in plantation establishment such as trenching, burying coconut husk, mulching, use of salvinia along with irrigation are being tested.

Invasive plant species management and utilization

Spread of invasive species is regarded as a result of climate change, and it affects floral diversity and leads to the habitat destruction of wildlife and loss of their feeding grounds. Research continues to identify and control invasive species through management and utilization. For example,*Acacia mangium* is a highly invaded exotic tree species in the wet zone forest plantations disturbing the growth of local tree species, but *A. mangium* is a good source of fuelwood on the other hand. Therefore a research study continues to assess the existing resource and its sustainability as a source of bioenergy and wood chips for furniture manufacturing.

GAP ANALYSIS OF CLIMATE CHANGE RELATED FORESTRY RESEARCH

Although forestry research has addressed most pressing problems related to climate change, there are many areas yet to study in detail.

Productivity Improvement through adaptation

Forest plantations and restoration efforts in degraded forests are often unsuccessful due to various reasons, mainly fire risk, animal damage, drought, heavy weed growth etc. Further, restoration efforts are very challenging in harsh site conditions. Therefore, further studies in alternative planting techniques will be needed to successfully establish the plants particularly slow growing local tree species,along withimproved practices for production of seedlings with appropriatestandards.Restoration and domestication of local tree species in the upcountry areas has not been adequately addressed and therefore needs attention. Integrated management of aggressive weeds is essential to improve the status of plantations.Novel concepts for water conservation in the dry zone planting have to be introduced.

Efficient utilization of resources to maximize mitigation

Alternative tree species are to be identified to produce bioenergy with multiple benefits, and use of invasive species for productive purposes has to be explored.Integration of forest plantations and degraded forests with commercial crops have not been studied.

Forest health

Sensitivity of different species to climate change impacts are not adequately studied. Forest die back incidences are mounting in various forest ecosystems. Reason for forest dieback in different areas are not completely understood.

Fire control

Although recent severe fire incidences damaged large areas of important forests and plantations, studies on assessment of fire risk and in minimizing fire damage have not been conducted.General operations implemented for fire control are establishing fire lines by clean weeding a strip of land around the young plantations. This technique is very time consuming and costly, and not feasible in protecting large areas of forests. Research on fire control methods either in plantations or natural forest are minimal. Information is lacking on the interactions between fire and other climate related factors.

Carbon and non-carbon benefits

Market-based mechanisms are lackingto encourage service providersfor forest conservation.Carbon estimations of different ecosystems are not available and technical tools in estimating Carbon stocks have to be developed.

FUTURE RESEARCH NEEDS RELATED TO CLIMATE CHANGE IN FORESTRY

Following studyareas are proposed for further research related to climate change in forestry sector.

Predictions of climate change impacts

Projections on climate effects on disturbances in different ecosystems will help understanding and planning of future adaptation measures. Risk assessments of fire incidence related to climate change predictions are needed to manage fire damage.The fundamental mechanisms underlying tree survival and mortality during drought should be studied.Research should identify herbivores and pathogens that are likely to be key agents of forest disturbance in the future.

Establishment technologies of forest plantations and restoration

With severe dry and infertile soil conditions in planting sites, innovative technologies for tree planting have to be studied involvingsimple and effective techniques for hilly areas. Research on suitable light-weight, water-retaining potting medium in biodegradable containers for seedling establishment helps in minimizing environmental impacts.Vulnerability of local tree species to severe drought and pest and diseases need to be analyzed.Suitability of commercial crops,for example spices, for inter-planting with forest plantations has to be tested.

Ecosystem conservation

Species specific allometric equations and general equations at ecosystem level for carbon estimation should be made available. Total carbon stocks have to be assessed in all important ecosystems for policy decisions on land use changes. Systems for Payment for Ecosystem Services (PES) should be developed to encourage community groups to secure conservation of ecosystems.Forest plantation management should be based on ecosystem approach with multiple benefits.

Weed control

Innovative approaches in utilizing grass weeds for productive purposes such as compost making, mushroom production, biodegradable materials, etc. are to be tested as a measure of control. Possibilities of using mulching material to control weed can be explored. Present legislations must be reassessed for allowing controlled grazing in forest plantations. Combined research on efficient use of grass with the animal production sector will improve mutual benefits for both sectors.

Water conservation

New technologies for soil amalgamation with water absorbing and slow releasing materials should be studied for tree planting.Use of efficient irrigation technologies for forest plantations have to be explored.

Fire control

Interactions among fire, and biological disturbances (such as insects, pathogens, and introduced species) should be studied to improve long-term predictions about forest succession and ecosystem dynamics that would lead to better prediction of affecting conditions.Effective methods to minimize fire risk should be studied:for example, controlled burning, close spacing planting, species mixing etc.Testing of fast growing, fire resistant tree species suitable for green fire belt establishment should be continued.

Forest health

Research is needed to determine the status and trends of forest stress and mortality in relation to climate change, as well as to understand ecosystem responses after dieback events.Studying the sensitivity of different types of pests and diseases to environmental change and the potential for increased outbreaks of insects and pathogens at the margins of their existing ranges would be important to manage forest health.

Bioenergy production

Research should focus on utilization of invasive and less-utilized tree species for bioenergy production, and search for desirable wild tree species for liquid biofuel production. Studies on use of wood waste from forestry operations such as harvesting, logging, sawing in bio energy production can protect the existing forests.

Proceedings of the Workshop on Present Status of Research Activities on Climate Change Adaptations (Ed. B. Marambe),. Sri Lanka Council for Agricultural Research Policy, Colombo.

CONCLUSION

Although climate change wasnot mentioned among the priority research areas within the FD in the past, forestry sector itself primarily address the issues related to climate change mitigation and adaptation in its usual programs.Any measures to improve forest conservation are climate change mitigation practices and most activities to tackle the issues in improving forest resources are related to climate change adaptation, as most of the difficulties are created by climate change impacts such as drought, fire, weeds, pest and diseases. However, climate effects on forest disturbances and the interactions among different disturbances are not adequately understood. Therefore, projections on climate effects, risk assessments, and underlying fundamental mechanisms of disturbances are crucial factors for further research in planning future adaptation measures.

Adaptation measures related to drought, weeds and invasive species have been addressed to some extent in the present FD research agenda, but forest health and fire issues are not adequately studied.Assessment of potential and effects of extensive climate-induced forest dieback is highly important.
Utilization of alternative tree species for bioenergy production and other purposes, and incorporation of commercial crops and non-timber forest products will ensure efficient resource utilization and maximize mitigation efforts.Estimating climate change mitigation values (air regulation) and approaches in market-based mechanisms for environmental services would ensure policy decisions on land use changes towards forest conservation.

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Climate Change Impacts on Agrarian Sector and Adaptation

H.J.C. Jayasooriya and W.H.A. Shantha
Environmental and Water Resources Management Division, Hector Kobbekaduwa Agrarian Research and Training Institute, Colombo, Sri Lanka

ABSTRACT: The agrarian and rural sector has been experiencing theadverse impacts of climate change over the last decades,especially due to increasedfrequency of occurrence of extreme events such as prolonged dry spells, droughts, floods and landslides. The damage caused to the agricultural sector and rural agrarian community is much serious and multi-faceted. The Hector Kobbekaduwa Agrarian Research and Training Institute (HARTI) has been providing ample space in its research and training schedules for timely important issues related to climate change impacts on agrarian communities, climate adaptation and climate resilience of farm households. Presently, the research and training focus of the HARTI in the sub-themes under climate change include climate vulnerability of different crop production systems, water management issues in selected drought stricken areas, high sedimentation of tanksand impact of abandoned village tanks in aggravating the climate change impacts. Further, research areas in participatory forest management, expanding potential agroforestry-based home gardens in rural and semi-urban areas, climate change impacts on food security and heath of the farm households, identifying potentials for rain water harvesting, implications of ground water extraction for intensive perennial fruit crop cultivation have been identified as the future needs.

Keywords: Adaptation,,Agrarian sector, Climate change, Resilience, Vulnerability

INTRODUCTION

Climate change is “a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer” (IPCC, 2007), which is the long-term significant changes in average climate conditions of a particular area. “Climate Change” has become a critical scenario in the present day context, where it has taken the attention of the scientist across many sectors and has universally being recognized as the fundamental human development challenge of the 21stcentury. Almost all nations are affected by the impacts of climate change, where, developing nations are more vulnerable as they are deficient in resources leading to increase in the sensitivity and also in adaptive capacity to cope up the challenges of climate change.

Evidence-based research has proven that climate change has considerable amount of negative impacts on all sectors including agricultural/agrarian sector.The impacts of climate change could affect many aspects of a country’s economy such as food and nutrition security, access to water, sanitation, shelter, health, labor productivity and human development and etc. Therefore, the impacts of climate change could threaten the significant achievements of country's economic development, including poverty reduction. As a result, climate change can disturb the anticipated achievements pertainingtothe development of a country. Hence, an understanding on the level of impacts/vulnerability and the possible strategies to overcome adverse impacts of climate change could make the decision-makingprocesses in many areas including local level climate actions to national level policy formulation, more effective.

Sri Lanka, being a developing island nation, which depends on tropical climate patterns, is considered as a highly vulnerable country to climate change impacts (MOE, 2011). Punyawardena (2012) and MOE (2011) identified occurrence of extreme events such as droughts, intensive rains and floods and landslides as adverse impacts of climate change in the context of Sri Lanka and frequency of occurrence of these extreme events has drastically increased during recent decades.

The 'Sri Lanka's National Climate Change Policy'(CCS, 2012) has identified addressing the climate change vulnerability, ensuring climate change adaption at national level and promoting research towards the same as the most prioritized areas where immediate policy changes are needed. Both climate mitigation and adaptation have been incorporated to this national policy suggesting the need for conducting periodical assessment of the socio-economic and environmental vulnerability of different sectors to climate change, in order to empower the particularsectors and different stakeholders concerned.

Sri Lanka also has developed the National Climate Change Adaptation Strategy (CCS, 2015) and the National Adaptation Plan (CCS, 2016) mainstreaming climate change adaptation into national planning and conducting research on climate change impacts and adaptive measures in different sectors including agriculture, livestock and fisheries. In these circumstances, being one of the key sectors in Sri Lanka's economy by involving approximately one third of the country's active labour force, the agricultural and agrarian sectorsshould be given high priority in national climate planning. In formulating strategies in combating climate change impacts on agriculture at national level through to implementing climate actions at the grassroot level where the increased climate resilience and adaptation is much needed for securing livelihoods of farm households, the present situation and future needs of these sectors should thoroughly be taken into consideration. Studying such effects and impacts on those agrarian communities is vital in designing and implementing climate actions in mitigating climate change impacts, promoting climate adaptation and increasing climate resilience. Being the pioneer national level organization in socio-economic research in the agrarian and rural sector, the

Hector Kobbekaduwa Agrarian Research and Training Institute (HARTI), over the last few decades, have given due attention to the climate change impacts on agrarian community. In designing and executing research studies, training activities and action-research on village/agrarian community development, socio-economic impacts of climate variation on agrarian communities living in different parts of the country and climate adaptation by such communities have necessarily been considered.

The HARTI has initiated research and training activities related to climate change impacts on agrarian communities over the past several years focusing on water and irrigation management, efficient practice of rainwater harvesting, land degradation in watershed areas, crop diversification as a strategy for combatting climate change impacts, leaving paddy lands in wet zone uncultivated and unlawful paddy land fillings. In this paper, we briefly review the research and training activities currently being conducted and planned for coming fiscal years (2018 and 2019) by HARTI, with reference to climate change impacts on agrarian and rural sector of Sri Lanka. Furthermore, initiatives and approaches that linked with climate change impacts, climate mitigation, adaptation and climate resilience related to agrarian communities, taken in participatory rural development programs of HARTI are also discussed.

PRESENT STATUS OF RESEARCH AND DEVELOPMENT ACTIVITIES RELATED TO CLIMATE CHANGE

Rainfed upland farming is considered as highly vulnerable to climate change. A recent study by Jayasooriya(2016)attempted to understand the comparative level of vulnerability of rainfedupland farmers in different locations across the dry zone and potential ways for achieving increased resilience for coping up with the prolonged drought periods. As farmers operating under rainfed systems are comparatively lack of livelihood assets (*i.e.* natural assets, financial assets, physical assets, social assets and human resource assets) they are more vulnerable to adverse effects of drought. The results, which are being finalized at present, would lead to identification of vulnerability of the rainfed agricultural communities to climate change (especially focusing on drought) influenced by other socio-economic factors including status of poverty, insecure land tenure, resource endowed, level of education, institutional supporting framework and government policies.

Water management is a key area that should be thoroughly reviewed in formulating strategies and actions for minimizing climate change impacts on agricultural and agrarian sectors, particularly in the dry zone areas where the prolonged dry spells and severe droughts occur frequently. The ancient Sri Lankan irrigation systems are highly praised for their unmatchable technology in water storage, releasing system and distribution network for crop cultivation. There are lots of lessons to be learnt from such efficient irrigation systems for designing the most suitable water management system to meet the present day challenges from climate change impacts. With the objective of conceptualizing an integrated water resources management a research study to understand ancient Sri Lankan water management techniques for the development of integrated water resource management concept is being undertaken by the Institute.

Climate change, its consequences and anticipated effects on food production systems are well documented at different levels of organizations such as regional, continental and global (Reidsma,2007). Planning vulnerability assessment is a useful tool that can improve the evidence-based decision making procedures at policy and concept formulating levels as well as at designing of climateprojectsandprogrammes. This tool is further of great importance to the formulation of rational and effective adaptation strategies at different institutional/organizational levels. (Mallari, 2016; Tao, 2011). Vulnerability analysis ranges from local or household level to the global level. Though the choice of scale is dictated by the objectives, methodologies and data availability, the most appropriate scale to understand impacts and adaptation, assessment should consider different levels of organization preferably the lowest administrative unit, such as district or even a village within a district to target interventions more precisely (Deressa*et al*., 2008; Reidsma*et al*., 2010; Niranjan*et al*., 2013).In Sri Lanka, many studies have focused on vulnerability and adaptive capacity of different sectors such as agriculture, water resources, industrial, health, etc., and within the agricultural sector focusing on climate change impacts on specific crop sectors such as plantation crops, paddy, other field crops, etc. (De Costa, 2010; Weerakoon and De Costa, 2009;Malawiarachchi*et al*., 2009; Nugaliyadde, 2009).

In different farm types, the kinds of vulnerability issues as well as management/coping strategies thatthese farm types will adapt will be different (Reidsma, 2007). Similarly, it is reasonable to assume that crop production systems operating based on a common water source (*i.e.*rainfed, ground water) will have more or less similar issues as water resources are among the most affected from climate change and is one of the key factors in agricultural production. However, information on climate change impacts on area specific crop production system/s based on particular water source in Sri Lanka is limited in scientific literature. Therefore, HARTI has initiated research focusing the climate vulnerability and adaptive capacity of different crop production systems across the dry zone. The study covers almost all the geographical areas of the dry zone by taking approximately about 10 crop production systems based on different sources of water.

Northern Province falls within the dry zone Sri Lanka has been identified as one of the hot spots in the sense of climate vulnerability. Jaffna district,in particular, is separately situated from the other four districts of the province and from the main land mass of the island possess its own climate-ecological features reflected by the unique agricultural system in the peninsula. Without having direct access to water sources from the other districts, the agricultural water requirement of the peninsula has to be met by the limited water resources available within the area. The severe drought condition that periodically experienced by the peninsula has been detrimental. Even though, scientific evidence has not been recorded on salt water intrusion to the artesian wells, which are mainly used for irrigation in the Jaffna peninsula, it has also been considered as a growing issue in the agricultural sector. No studies on water management issues in this part of the country has been conducted by the HARTI or other relevant agencies in the recent past. Hence, the HARTI has designed a study to be initiated in 2018 to fill the existing knowledge gap in this particular area of study.

The cascade irrigation tank systems are mostly found in dry and intermediate zones of Sri Lanka, and have been recognized as an efficient water use/management and water conservation system. Negligence of these sustainable irrigation and water management systems over the centuries has been one of the reasons for frequent failures in crop cultivation systems in drought-stricken areas of the country. Abandoning of small and medium level village tanks arranged in cascade system has occurred largely owing to damaged tank bunds and sedimentation or siltation of tank beds. Inappropriate human activities including agricultural practices particularly in the catchments close to the tanks have been the major causes of the origin of sediment loads into highly vulnerable tanks.

The land use pattern close to the village tanks has drastically changed in favour of accelerated soil erosion that generate excessive sediment loads into the cascade system. Disregarding of traditional concepts and technologies meant for conservation and management of village tank systems to intercept excessive sediments from upper areas of the tanks has resulted in high sedimentation of tank beds. Reduction of capacity of the tank/s has directly affected the crop cultivation in the command area of these tank/s. Apart from crop cultivation, livestock and inland fisheries are other main livelihood assets that have direct impacts of tank sedimentation. In addition, village tanks are largely used by rural community for their bathing and washing purposes as well as other domestic purposes. Thus, tank sedimentation aggravates the climate change impacts on agriculture and agrarian communities. In this background, with the view of assessing the impacts of tank sedimentation on agricultural production and farm livelihoods in dry zone, a study has been initiated in two cascades in *Mee-Oya* and *Malwathu-Oya* basins in Anuradhapura and Kurunegala districts, respectively, to study the sedimentation of tank beds due to human activities and its impacts on agriculture. The findings of the study would certainly be an important input for developing better strategies for sustainable cascade system as a means for combatting climate change impacts on agricultural and agrarian sectors.

Good agricultural practices have gained recognition in different aspects such as environmental, health, labor productivity and welfare, social equity and etc. in many parts of the globe. Many practices related to good agricultural practices (GAP) such as resource conservation practices, organic material application, minimum disturbance of the soil, precise use of irrigation water are directly contributing to tackle the adverse impacts of climate change. Adoption GAP by majority of the farming community,especially in the subsistence agricultural sector, however, has still been at a minimum level. A research study aiming to investigate the determinants for low adoption of GAPs by subsistence farmers has been designed to be carried out in year 2018.

Inappropriate anthropogenic activities in the upper watershed areas have been recognized as the major cause for watershed degradation and its subsequent on-site and off-site effects on different sectors. These adverse effects have directly further aggravated the climate change impacts. The degradation of watershed areas has direct impacts on irrigation systems in the drier parts of the country,which has been extensively researched and discussed during the past few decades. However, due attention on the agricultural water management issues in the areas immediately below (belong to the intermediate and dry zones) the upper watershed areas have not attracted attention of researchers in the recentpasr.The eastern slopes of the upper watershed area of the country, which is the rain shadow of the south-western monsoon, has been undergoing periodical water shortages for agricultural activities, drinking and other domestic purposes. The century-old villages with agricultural background located in this region are experiencing severe socio-economic issues as other livelihood opportunities are limited. Intercepting and excessive utilization of limited water available in natural streams for the newly established up-country crop cultivations on marginalized, abandoned tea estates by the estate communities living in the most upper parts of the slopes has made this situation further volatile. Frequent disputes for water sharing have also been observed among these communities.. Taking this dire situation into accounts, HARTI has designed a research study to find ways for sustainable water management in this region.

The HARTI has a long history in contributing to the development of agrarian and rural community through its research and training activities and by conducting action research coupled with participatory rural development strategies. Sustainable Development Village Program, initiatives with the *'Gamaneguma"* programof the government of Sri Lanka are such prominent rural development activities where the HARTI has immensely contributed along with the line ministries. Apart from those country-wide programs the HARTI alone has carried out a number of village development activities in different parts of the country. Stretching this tradition further, the HARTI has planned to conduct a model village development initiative in 2018. Integrating strategies to meet the challenges posed by climate change is one of the important aspects of the planned village development initiative. Soil and water conservation, application of micro-irrigation systems, promoting no-tillage and minimum tillage concepts and rain water harvesting techniques, and shifting cropping season to be in-line with the onset of rainfall, would be some of the actions to be incorporated in proposed village development program.

In terms of training,the HARTI is providing a considerable focus on subject areas such as climate change impacts on agriculture, adaptation and resilience in the training schedules. The threats posed by adverse impacts on climate change on household food security in agrarian communities are highly discussed in training programs and the farming community, especially elder female members of the farm families are made aware and empowered to meet such challenges. Promoting agro-forestry based home gardening systems to cater to part of the household's food requirement is also a key subject area of the training programs of the HARTI.

IDENTIFIED GAPS AND FUTURE RESEARCH NEEDS

The studies on climate change impacts on different agrarian communities conducted by the HARTI in many parts of the country have mostly been limited to micro level. Therefore, the findings and results of such studies are based on data, information and observation from a few number of villages. However, the level and magnitude of climate change impacts on different parts of the country is mostly different from one another owing to many climatic, bio-physical and socio-economic characteristics. Therefore, it is a timely need that the research studies should be focused on the 'bigger picture' of the climate change impacts on agricultural and agrarian sectors.

As the water resource is the most affected agricultural input by climate change particularly in the dry zone Sri Lanka, the efficient water management initiatives should further be studied to tackle this situation. A number of studies are being conducted focusing surface water management and thus, there is a real need of undertaking research on use of ground water for agricultural purposes and its sustainable use for combatting long-term threats from climate change. Ground water extractionis undertaken in different forms (tube wells, ground wells, artesian well, etc.)in different areas of the island. The recent significant growth and expansion of perennial fruit crop cultivation under agro/tube wells has remarkably contributed to increase in the production of fruits. Un-disturbed flow of ground water as the main irrigation source has ensured further expansion of this sector. However, the long-term effects of these practices on aggravating the climate change impacts in the drier parts of the country should further be studied.

The possibility, capacity and the potential for diversifying rural and semi-urban home gardens into agroforestry-based multi-functioning home gardensto increase the climate resilience of farm households is high. Though, different blanket projects and programs have been implemented to popularize food crop cultivation in home gardens, the most appropriate and area-specific comprehensive approaches to make this materialized have not been taken. Therefore, it is suggested to design and trial some models to promote home gardening concept as a mean of combatting climate change impacts on agrarian communities. Knowledge and experience of such successful models should be disseminated through the training and awareness programs regularly conducted by the HARTI.

Practicing participatory forest management concepts is a widely accepted strategy for ensuring sustainability of forest resources while reaping the benefits from the forests for increased climate resilience of the communities living closer to the forest reserves. Novel and additional livelihood opportunities that can be generated through participatory forest management approaches could further be enhanced as coping up strategies for climate change impacts. However, research studies focusing on existing participatory forest management projects and programs are not currently being undertaken. Furthermore, the attention on such concepts in the training programs extremely low. Therefore, it is suggested to undertake studies to identify the potential areas in sustainable forest resource utilization to tackle the climate change impacts through making livelihood opportunities based on forest resources. Awareness and attitude changing programs for forest-dependent rural communities in environmental-friendly resource extraction and utilization would minimize the malpractices and illegal activities within forest reserves.

The HARTI has conducted several research studies on rain water harvesting (RWH) for agricultural activities as well as drinking and domestic purposes in the remote areas where the mean annual rainfall is relatively low and year around secured irrigation facilities are not available. Studies on surface (soil) water collection mechanisms mainly meant for agricultural and livestock activities as well as roof-rain water harvesting for drinking and domestic purposes conducted in recent past have indicated the appropriateness, usefulness, farmers' attitude towards RWH, practical limitations and constraints pertaining to the RWH methods promoted by different agencies. However, possibility of promoting RWH with appropriate techniques and designs as a promising solution for climate change impacts of the drought-affected areas have not been thoroughly studied. Therefore, the actual need and proper establishment of RWH structures and their designs for the rural community should be identified and examined.

Studies on adverse socio-economic impacts by climate change on farm households have been limited to the estimation of parameters that can be reflected in monetary terms, such as reduction in land area cultivated and yield loss, and loss of on-farm income. Climate change has direct impacted agricultural employments and food security, health and education of school-aged children in farm households. Furthermore, with the temporary out-migration of males has direct gender related issues within thefarm household as the female members are further pushed into the receiving end of the other issues such as food security. Therefore, studies to examine the impacts of climate change on farm households should further be expanded in order to capture the issues such as, food security, health, education and other gender related issues. In such studies, food security should be given utmost priority as it has immediate impacts on other issues such as health, and children's education as well as gender related issues in the households.

CONCLUSION

The HARTI has been providing ample space in its research and training schedules for issues pertaining to the climate change impacts on agrarian communities, climate adaptation and climate resilience of farm households. Furthermore, the HARTI has identifiedand focused on different but important aspects such as participatory forest management, expanding potential agro-forestry practices in home gardens in the rural and semi-urban areas, climate change impacts on fool security and heath of the farm households, potential for RWH methods, implications of ground water extraction for perennial fruit crop cultivation as the future needs in term of research to be conducted in line with climate change related issues.

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.Research Programs related to Climate Change in the Department of National Botanic Gardens of Sri Lanka

S.A. Krishnarajah and S. Ranasinghe
Department of National Botanic Gardens, Peradeniya, Sri Lanka

Extended Abstract

Botanic gardens are a vital resource of plant conservation in the context of world's climate change. A number of individual research projects in various fields dealing with climate change are now ongoing and others are in the 'development stage' (project planning, budgeting etc.). They include sectors of floriculture and biodiversity, with greater emphasis on biodiversity.

Floriculture– Following activities are proposed to be initiated.

- Capacity development for conducting research in tolerant varieties/ breeds and climate resilient growing methods.
- Development and promotion of water-efficient growing methods for flowers and ornamental plants
- Development of tolerant varieties to drought and heat stress, and screen present varieties for such features
- Promotion of commercial cultivation of ornamental flowering plants that can tolerate adverse climatic conditions such as dry and hot weather and low rain fall landscaping and decorative purposes.

National Botanical Survey-through which several actions can be implemented in response to climate change.

- *Ex-situ* collection of native plants that arecollected from the wild to maintain a pool of threatened plants –it is aimed at collecting 40-60% of threatened endemic plants in ex-situ collections in 5 years (by the year 2021).
- Implementation of programs in each botanic gardento introduce suitable native plants for home gardens and floriculture industry to improve the green cover of urban areas with native species. About 50 species are to be selected to make plants available at all botanic gardens for sale by 2020.
- Botanic gardens with their unique expertise on collecting, storing, propagating and cultivatingwild plants, have already started

propagation of threatened plants.These plants propagated in*ex situ* nurseries will be used to conduct research in reintroduction of species in the wild.

Phenology records- selection of suitable native plants that exist in living plant collections at the Botanic Gardens to record phenology.

- Long term monitoring of phenology patternsmay enable the recognition of climatic changes and assist in providing suitable mitigation actions. The Royal Botanic Gardens at Peradeniya, Sri Lanka has initiated a phenology monitoring project in 2011 for 50 selected species in their *ex-situ* collection. Similar phenology recording projects will be implemented in other botanic gardens beginning fromthe year 2018.

Floristic Research- establishment of new collaborative initiatives with and among other local and international botanic gardens and research institutes to conduct floristic research in the native ecosystems

- These research initiatives will be focused on vegetation mapping, understanding sensitive and degraded ecosystems and introduction of suitable forest regeneration programs.
- Introduction of modern molecular biology methods in floristic research such as molecular sequencing for DNA bar-coding, understanding of species boundaries and dating of plant species allow us to understand past vegetation and future directions especially through bioclimatic modeling.
- Research on seed bank conservation and special propagation techniques. Some species may require special propagation techniques, such as micro-propagation *in vitro*, because they do not set seed orbecause their natural populations are extremely diminished in the wild.

Updated database and information system

- Planning for the curation of living collections and herbarium collections to the highest standards ofrecord-keeping is underway. This is toensure that the plants are 'fit for purpose' in dissemination of information and research considering conservation and mitigation of climatic changes.For example, a complete herbarium database can be used to compare the past and present distribution of plants and vegetation type thus, important comments on the effect of climate change on biodiversity would be possible. A network database will be implemented to ensure that the past memory of botanic gardens are stored in a manner that can be effectively utilized for future work.