# Landscaping Agroecosystems: A Way Forward for Natural Resource Utilization

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**Text by:** R. Wimalasekera, W.M.T.P. Ariyaratne, A.J. Mohotti, K.M. Mohotti, G. Hitinayake, L. Wariyapola, S.A.C.N. Perera, M.R. Wijesinghe, H.D.D. Bandupriya, R.H.G. Ranil, D.K.N.G. Pushpakumara, P.C.G. Bandaranayake, D.S.A. Wijesundara, R.M.S.R. Chamara, J.P. Eeswara. H.I.U. Caldera, D. Halwathura

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**Institute of Biology Sri Lanka (IOBSL)**
'Vidya Mandiraya',
120/10, Wijerama Road, Colombo 07.
Email: iobslcouncil@gmail.com
Web: http://www.iobsl.org/

# Landscaping Agroecosystems: A Way Forward for Natural Resource Utilization

## Authors

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# PREFACE

Institute of Biology of Sri Lanka (IOBSL) is the leading professional body of biologists in Sri Lanka, formulated for the advancement of the interests in biology in academia, research, education and industry. It was formulated in 1981 and became an incorporated organization by the Act of Parliament No. 22 in 1984. The IOBSL council gives priority in publishing books in timely relevant themes in applications of biology for the purpose of promoting, dissemination and interchange of biological knowledge among fellow stakeholders as one of the main activities amongst other science promotional programs.

The agricultural sector is very important to Sri Lanka and practical application of biological sciences is necessary to ascertain its sustainability and to ensure balance in maintaining environment, ecosystems and livelihood dependence. Currently, agriculture in local and global context experiences many challenges. In trying to achieve high production targets, agriculture has greatly intensified with use of high, and sometimes excessive use of inputs and mechanization etc. Although with inequitable access, these achieve satisfactory levels of food production. However, agricultural intensification has focused almost exclusively on yield increase on ensuring ‘food security’, while largely neglecting the uncompensatory cost of detrimental effects on broader ecosystem service provisioning. Hence, the ill impacts on environment, climate, human and food health remain to be resolved. It could be argued that the future of this planet lies in the hands of agriculturists and the use of concepts in biology would be the key in this endeavor.

In this sense, the theme for the year 2018/19 declared by IOBSL as ‘Ecophysiological applications on agricultural landscapes’ was quite justifiable and timely relevant. The chapters in this book are a collection of reviews to discuss relevant and appropriate aspects of proposals and recommendations in line with the theme.

We hope that the information in this book will be valuable to academics, researchers, students, industrialists and policymakers in the field of biology and allied disciplines and wish that the Sri Lankan agricultural landscapes are realigned to ensure balance in maintaining healthy environments, ecosystem services and assured livelihood dependence.

Dr S.A.C.N. Perera
Dr A.J. Mohotti
(Technical Editors)
27th September, 2019

# REVIEWERS

Chapter 1: **Dr. M.A. Wijerathne**, Principal Research Officer, Tea Research Institute of Sri Lanka, Thalawakele.

Chapter 2: **Prof. H.P.M. Gunasena**, Department of Crop Science, Faculty of Agriculture, University of Peradeniya. Peradeniya.

Chapter 3: **Dr. L. Rankoth**, Senior Lecturer, Department of Crop Science, Faculty of Agriculture, University of Peradeniya, Peradeniya.

Chapter 4: **Prof. R.O. Thattil**, Department of Crop Science, Faculty of Agriculture, University of Peradeniya. Peradeniya.

Chapter 5: **Prof. N. Dassanayaka**, Department of Botany, Faculty of Science, University of Sri Jayawardenepura, Nugegoda

Chapter 6: **Prof. B. Marambe**, Department of Crop Science, Faculty of Agriculture, University of Peradeniya, Peradeniya.

Chapter 7: **Prof. J.P. Eeswara**, Department of Crop Science, Faculty of Agriculture, University of Peradeniya, Peradeniya.

Chapter 8: **Dr. G. Samarasinghe**, Director, Horticultural Crops Research Institute, Department of Agriculture, Peradeniya.

Chapter 9: **Dr. K.W.L.K. Weerasinghe**, Senior Lecturer, Department of Crop Science, Faculty of Agriculture, University of Peradeniya, Peradeniya.

Chapter 10: **Dr. E. Lokupitiya,** Senior Lecturer, Department of Zoology and Environmental Sciences, Faculty of Science, University of Colombo.

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## CHAPTER 01

# Climate-Smart Crop Production Systems for Food Security Under Climate Change

**R. Wimalasekera***

*Department of Botany, Faculty of Applied Sciences, University of Sri Jayewardenepura, Gangodawila, Nugegoda*

## Abstract

Crop production is extremely vulnerable to the climate change, threatening the global food security. Intensified crop production contributes largely to greenhouse gas emissions leading to climate change. The climate-smart crop production system is one of the approaches that jointly address food security and climate change. Climate-smart crop production systems ensure more efficient and sustainable use of resources where land, water, soil nutrients, energy and genetic resources are managed sustainably, increasing agricultural land productivity and they are more resilient to climate variability. However, climate-smart crop production practices and technologies cannot be applied universally. It requires site-specific assessments to identify most suitable production technologies and practices. To achieve the targeted changes, profits and increased systemic resilience, it is essential to have appropriate policies, institutions, financial investments and access to the required knowledge at all the levels. Climate-smart strategies also overcome the inefficiencies that are responsible for yield and productivity gaps. Sustainable intensification of crop production, a climate smart crop production strategy, leads to reduce poverty, food insecurity and malnutrition and thereby improves livelihoods of people especially more vulnerable to climate change.

**Keywords:** climate change, crop production, environment, food security, sustainability

*rinukshi@sci.sjp.ac.lk

## Introduction

Climate change is defined as the long-term alteration of temperature and normal weather patterns in a particular location or in the planet as a whole (www.nationalgeographic.org). Climate change, as evident by prolonged droughts, catastrophic flooding and temperature rise is taking place in an unprecedented scale. In this industrial era, more than the natural causes, human activities such as emissions of greenhouse gases from fossil fuel combustion, deforestation, increased livestock farming and land-use change are the main causes of the climate changes. Climate change is a global challenge that has no borders and impacts of climate change are apparent across many sectors adversely affecting population all over the world. The impact of global climate change is predicted to be intensified in the future. The most well-known effect of climate change is global warming (Singh and Singh, 2012). Some of the agriculture-related consequences of climate change are reduced crop production, scarcity of water, desertification, insufficient energy and emergence of new diseases finally threatening all dimensions of food security. Recent projections indicate that in order to cater future population growth, food production has to be doubled (FAO, 2016). Hence, there is an urgent need to enhance crop production while addressing the threat of climate change by profound transformation of production systems worldwide. Climate-Smart crop production is an approach to manage agricultural systems responding effectively to climate change by sustainably increasing productivity, adapting to climate change by better integration into complex ecological processes and reduce emission of greenhouse gases.

## Climate Change and Crop Production

Agriculture sector is one of the most vulnerable sectors for climate change. Climate change affects crop production and at the same time, crop production especially intensive agriculture has a considerable impact on climatic change indicating a deep interconnectivity between them.

Changes in temperature, precipitation, atmospheric concentrations of $CO_2$ and $O_3$ and soil quality largely affect the crop productivity which in turn influences the future food security (Lobell and Gourdji, 2012). Rising temperatures under climate change shorten crop duration and decrease photosynthetic rates reducing overall plant productivity. With temperature increases above the optimum growth temperature of crop species, yields of the major crop species can decrease by 5-10% (Hatfield and Prueger, 2015). About 80% of the crop cultivated area producing 60% of crop yield is rainfed (Tubiello *et al*., 2007). Changes in precipitation timing and intensity and the frequency and length of droughts are critical to crop productivity (Kang *et al*., 2009). When the change of precipitation pattern is combined with temperature alterations, impact on crop yield is severe. Further, crop production can be affected by extreme wet weather conditions resulting from heavy rains, storms and flooding. Climate change during the last few years has been rapid and as a result, the extreme weather events increased in many agricultural regions in the world (FAO, 2016). Climatic factors have variable impacts on crop production around the world. Crop yield and climate impact assessments clearly indicate the implications of climatic change on the reduction of yield in major food crops such as wheat, rice, maize and soybean. According to the climate change projections, up to 30% reduction of maize production in Southern Africa, up to 10% reduction of rice and more than 10% reduction of millet and maize yield in South Asia are expected by 2030 (Lobell *et al*., 2008). Low crop production is a key issue for future food security, risk of undernourishment and livelihood of billions of farmers.

In Sri Lanka, crop production accounts generally 75-78% contribution to GDP from agriculture. Over the past few years, increase in mean annual temperature and decrease in annual rainfall is reported from all the agro-ecological zones of Sri Lanka (De Costa, 2008). Rice cultivation is mostly rainfed and significant yield reduction has been observed during the periods of prolonged droughts and delayed monsoon rains (Central Bank of Sri Lanka, 2018). The productivity of plantation sector which comprises mainly of tea, rubber, coconut and sugar cane is vulnerable to floods, droughts, changes in rainfall patterns and landslides. Analysis based on climate projections 2031-2060, indicate US$ 183.12 per acre reduction per year of net revenue due to changes in temperature and rainfall (Climate Change Vulnerability, 2011). Reduction in crop yield has serious repercussions on the national food security and foreign exchange earnings while causing substantial socio-economic damage to large number of families.

Enhancing crop production under changing climate is a great challenge and there is a timely requirement for reorientation of crop production from conventional practices to sustainable and environment friendly practices.

Climate-smart crop production is an approach for developing agricultural strategies to secure sustainable food security under climate change (FAO, 2013). Climate-smart crop production also reduces food waste globally and minimizes exploitation of natural resources.

## Climate-Smart Crop Production Strategies

Climate-smart crop production aims at sustainable increase of agricultural productivity and incomes, adapting and building resilience to climate change and reducing greenhouse gas emissions (FAO, 2013). Further, crop production strategies should address the efficient use of resources and reduction of food and system waste while minimizing the carbon footprint and emission of greenhouse gases to ensure the environmental sustainability. The climate-smart crop production strategies encompasses agricultural technologies and practices such as different methods of crop establishment and diversification, use of improved seeds and other planting material that are adapted to climate change, efficient nutrient management, improved methods of rainwater harvesting, irrigation and water management, residue management, strengthened processing facilities and establishment of information and communication technologies based advisory and insurance schemes.

## Soil and land management

A diverse range of lands are being utilized worldwide to produce an array of products. Over the years, a large extent of land being deforested and grasslands were converted into agricultural lands contributing to increase of greenhouse gas emission and associated climatic problems (FAO, 2013). Soil has become one of the most vulnerable resources affected by land degradation, climate change and diminished biodiversity (FAO and ITPS, 2015).

Land degradation in terms of soil degradation is caused by human activities and by natural causes like climatic changes has a great impact on sustainable crop production. Degradation varies by nation and by climatic region, for example in India about 144 million hectares of land are affected by wind and water erosion (Kumar and Pani, 2013). The 12 million hectares of agricultural areas in the European Union that suffer from severe erosion are estimated to lose around 0.43% of their crop productivity annually (Panagos *et al*., 2018).

Continuous cultivation without sufficient replenishment of extracted nutrients and associated soil erosion are the major drivers of soil fertility degradation. Physical properties of soil are easily affected by erratic and extreme rainfall events such as severe drought and floods. Proper soil and crop management practices need to be adopted in order to supply water and nutrients to plants adequately, sequester carbon and reduce greenhouse gas emissions. Hence, sustainable soil and land management practices in a given agricultural production system and socio-economic condition can strengthen climate change adaptation and mitigation and build the resilience of the agricultural ecosystem (Lal, 2013).

Systematic assessments of land and soil properties are fundamental for the identification of potential land resources suitable for specific crops. It is crucial to carryout on-site soil visual assessments, laboratory analysis of soil physical, chemical and biological properties, soil surveys across a range of vegetation types, and/or agro-ecological zones and mapping for sustainable management of soil that can contribute to climate-smart land use. Soil quality test kits, various conventional and digital mapping tools and visual soil assessment field guides have been developed by FAO for annual crops such as olive orchards, vineyards and wheat (FAO, 2008). These are valuable tools for farmers and land managers that are helpful to assess the condition of their soils and the suitability for growing crops, and to make informed decisions that will lead to sustainable land and environmental management. To get high crop yields and maintain optimal growing conditions, it is essential to adopt appropriate soil management practices (FAO, 2013).

Use of conservation tillage practices help to protect the soil surface, reducing water runoff and soil erosion, improves soil trafficability and optimize sowing time and increases biodiversity of microorganisms. Soil organic carbon (SOC) is one of the main indicators of soil health and changes in SOC largely depend on the land-use system and land management practices (Mohawesh *et al*., 2015). Increasing the soil organic matter and preserving existing soil carbon stocks are important in sustainable soil and land management. Preventing and mitigating land degradation especially by soil erosion is equally important in increasing soil organic matter. Land degradation is accelerated by the climate change and it is also a major cause of climate change (Scherr and Sthapit, 2009). A key component of smart crop production includes maintaining soil health through increasing organic carbon stocks. Climate-smart crop production practices such as minimal tillage, residue management, crop diversification and regeneration of trees by frequent lopping in farming systems significantly improve SOC and soil biological quality (Entry *et al*., 2002; Blanco-Canqui and Lal, 2009; Lal, 2010). Studies on rice-wheat system in Indo-Gangetic plains of India (Jat *et al*., 2019) and maize, millet and sorghum cultivation in West Africa (Bayala *et al*., 2012) highlighted suitable management practices restoring SOC in agricultural soils and turning soils into carbon sinks (carbon sequestration) by increasing organic matter content which is seen as a promising way of mitigating climate change. Digital soil mapping, Infrared spectroscopy, data bases of soil information services and organic resources and related decision-support system for organic material management resources facilitate improved use of organic resources in soil management and making practical recommendations for appropriate use of organic matter (Palm *et al*., 2001; 2014).

It is also necessary to measure and monitor the multiple benefits of agricultural landscapes that contain the elements of interaction between environmental features, land-use patterns, provision of environmental services for farmers and society (FAO, 2013). Different landscapes will require different approaches and participatory planning and management of land irrespective of the land size is useful in improving crop yield successfully. Hence, climate-smart soil and land management practices could enhance climate change adaptation and mitigation.

## Water management

Worldwide annual crop production is adversely affected by variability of rainfall mainly reduction in rainfall, reduction in the number of rainy days, increase in drought periods and extreme precipitation. Hence, irrigation has become vital in agriculture. According to the FAO, agriculture accounts for 70% of water withdrawals and 93% of water consumption worldwide (FAOSTAT, 2012). It is predicted that irrigation water demand will be increased by 13.6% by 2025 (Rosegrant and Cai, 2002). Major problems associated with irrigation are the uncertainty of water supply and low application efficiency accounting to only about 55% of water being used by the crop (Chartzoulakis and Bertaki, 2015). Therefore, it is necessary to divert from traditional high-water demanding cultivation practices to new cropping and irrigation practices with improved technologies.

Sustainable management of water is an important strategy in climate smart crop production. It generally aims at balancing water availability and water needs in quantity and quality in space and time mainly by irrigation scheduling and changing irrigation methods (FAO, 2016). Localized irrigation by trickle or drip irrigation and micro-sprayers is considered as an efficient method of watering crops which aims at application of water directly into the root system minimizing water losses (Keller and Blienser, 1990). Water use efficiency is dramatically increased in this method boosting crop yield. Several studies done using different crop species have shown that drip irrigation reduces water use by 30-70% (Postel *et al*., 2001). In water scarce regions, irrigation scheduling is very important as it determines when to irrigate crops with optimal amount of water. Soil-water holding capacity, infiltration rate, crop response to water, climatic factors such as evaporative demand, rainfall and temperature, method of irrigation and availability of water are some of the factors to be considered for improved performance and sustainability of irrigation (Chartzoulakis and Bertaki, 2015).

In many countries, rainwater harvesting and storage by primary and simple methods are being practiced especially for household usage. Development of surface runoff rainwater harvesting and roof top rainwater harvesting techniques and integration of rainwater harvesting systems with the existing water supply system is important to overcome the increasing demand of water in an era of intensive climate change (Pendey *et al*., 2003). The captured rainwater can be diverted, stored and utilized for crop irrigation. Some regions especially in Arabian Peninsular, efficient methods to harvest rainwater have been developed to recharge the groundwater and impounding structures for agricultural production (Dabour, 2006).

Measurement of crop related parameters such as leaf water potential, stem/fruit diameter, and sap flow are also useful in determining irrigation time and irrigation depths (Itier *et al*.,1993). Access to soil water estimates and measurements, predictions on soil-water balance and information on plant stress factors through technical support systems and extension programmes will be important for sustainable farming practices.

Fertigation, the application of fertilizers through irrigation water is a common practice in irrigated agriculture. It reduces the cost of fertilizer application and improves nutrient use efficiency. Regulated deficit irrigation (RDI) method is practiced to increase the water use efficiency of crops while having only a little impact on yield. RDI can be implemented through the approaches of growth stage-based deficit irrigation, partial root-zone irrigation and subsurface dripper irrigation (Chai *et al*., 2016). Before implementing RDI it is necessary to have the information on crop yield response to water. Partial root-zone irrigation is popular and has been practiced effectively in wheat, rice and cotton with minimal impact on crop yield and saving irrigation water by about 20-30% (Jarvis, 2011). A number of studies have shown that crops with RDI can increase nutrient use efficiency through the promotion of nutrient recovery after a short period of water stress (Jarvis, 2011; Li *et al*., 2007). The reallocation of water resources and modification of irrigation systems can play a major role in increasing crop productivity by improving water use (Homayounfar *et al*., 2014).

## Intensified and integrated crop production systems

Integral components of crop production/farming system include processes from land preparation through planting and delivery of products. Since the domestication of crop species, world's crop production increased significantly especially with the Green Revolution. However, epochs of intensive cropping has caused longstanding problems; degraded fertile land, depleted groundwater, polluted water and soil and triggered upsurge in pests and diseases (FAO, 2011a). Sustainable crop production intensification (SCPI) aimed at conserving and enhancing natural resources by capitalizing on natural and biological inputs processes are helpful to enhance crop production under climate change while reducing negative impacts on the environment (FAO, 2011a; 2016). A crop production practice of SCPI is inherently climate smart and risks arising from climate change are also addressed. SCPI is achieved through eco-friendly agricultural production systems and good management practices such as managing soil-related ecosystems (water and fertilizer), using quality seeds and planting materials, high yielding varieties, and integrated management of pests, diseases and weeds. Biological nitrogen fixation (BNF) contributes to nitrogen nutrition in agricultural lands which can be enhanced by introducing legumes as cover crops, intercropping and inoculations of rhizobia.

Integrated agricultural production strategies such as establishment of greater on-farm diversity of plants, more perennial cultivation, crop-livestock systems, rice-fish systems and agroforestry can minimize the need of energy, water, chemical fertilizers, pesticides and other management intermediation providing opportunities for mitigating climate change. Maintaining a greater biodiversity is essential for sustainable functions of the ecosystems and reducing risk and adapting to climate change. Biodiversity has the potential to enhance ecosystem carbon sequestration by elevating the processes of carbon inputs particularly belowground carbon inputs and increasing diversity of soil microbial community and activity suppressing carbon losses from decomposition processes such as microbial decomposition (Diaz *et al*., 2009). Tree diversity, relative abundance and the spatial arrangement of species influence the amount of carbon stored in a particular ecosystem. Many studies all over the world is being done to understand how biodiversity can enhance the potential of climate change mitigation initiatives based on carbon sequestration. Conservation and enhancement of biodiversity in cropping systems is an important aspect in climate smart crop production (FAO, 2016).

Global crop production is highly dependent on pollination services provided mainly by insects. The global economic value of pollination services is estimated to be US$ 214 billion per year (Gallai *et al*., 2009). Pollinators are very sensitive to climatic changes and hence crop yield can be affected in years to come. When moving towards climate smart crop production strategies, a special emphasis should be given to adopt the pollinator-friendly management practices, for example maintaining cropping systems with flower-rich field margins, buffer zones, cultivating shade trees, preserving wild habitat and reducing application of pesticides in order to ensure enhanced yield, quality, diversity and resilience of crops (Kjøhl *et al*., 2011). All of these approaches result in natural resource conservation, management of the resilience of ecosystems, stakeholder involvement and simultaneous achievement of multiple objectives.

## Management of energy

There is a close relationship between agriculture and energy and over the last few years, energy consumption by agriculture has significantly increased, especially because of increased dependency of agriculture on chemical fertilizers, irrigation and machinery (FAO, 2011b).  One of the challenges that agriculture sector faces today is to minimize energy consumption with reduced greenhouse gas emissions while ensuring food security. Energy-smart strategies include introduction of energy-efficient measures in all the stages of food production chain and use of diverse energy sources including renewable energy and bioenergy. Use of renewable energy is aimed at low-carbon emission which minimizes global warming. However, its dependence on climatic conditions also makes it susceptible to climate change. On-farm energy generation is another approach that can be adopted in agriculture. Level of energy input can also be reduced by minimizing the degree of mechanization in small local production systems (FAO, 2013). Enhancement of crop production in a climate-smart manner can be accomplished through increased use of renewable energy and adoption of measures to increase energy efficiency. A combination of appropriate energy technologies, diverse energy portfolio, equipment and facilities in farming communities is necessary to make the gradual shift towards energy-smart crop production systems.

## Sustainable use of genetic resources

Crop genetic resources are the basis for sustainable agriculture. Selection and domestication over centuries have led to the development of several varieties of crops. The rich genetic diversity has allowed people all over the world to sustain their livelihoods and continued functioning of ecosystems under diverse climatic conditions (Lin, 2011). Genetic diversity is lost at an alarming rate mainly because of climate change and shrinking of consumer choice. Climate change has also altered species distribution, population sizes, community composition and ecosystem dynamics. Even though there are numerous species of crops, it is estimated that currently only 30 crops provide over 90% of human food energy needs (FAO, 2009).  Of them, rice, wheat, maize, millet and sorghum provide about 60% of the energy intake of the world’s population (FAO, 2010a).

There is a great potential to select and cultivate most suitable crop species across many different regions and under varying environmental conditions.

In this strategy, the traits namely drought and temperature tolerance, resistance to diseases and pests and water and nutrient use efficiency are to be considered. Information required for the most appropriate use of those genetic resources, whether scientific, traditional or indigenous should be made available for the users. Another important strategy is to promote use of genetically diverse varieties in order to improve resilience of agroecosystems and to reduce genetic erosion (Asfaw and Lipper, 2011) under climate change. Traditional crop production systems are believed to be of high diversity of genetic resources and more resilient to changing environments. In the modern-era, these systems can be further improved by introducing more specific techniques for ensuring their optimal use. Easy accessibility of plant genetic diversity should be ensured for vulnerable farmers especially in Africa and South East Asia. For the climate-smart production processes, there is a necessity for continuous breeding activities and generating continuous knowledge on characterization, selection and reproduction. Although not widely practiced, assisted migration of crop species is an important concept that can be applied for some regions where the predicted climate is suitable for particular species. Thus, conserving and using genetic diversity is essential for coping with climate change and generating high yields (FAO, 2010a). Moreover, combination of *ex situ* and *in situ* techniques in genetic resource conservation is critical for the development of climate-smart agriculture.

## Policies and Capacity Development

Transformation to climate-smart crop production is successful only if diverse sectors dealing with climate change, agricultural development and food security are well coordinated, integrated and mainstreamed into government policies and planning (FAO, 2013). Climate-smart crop production policies must contribute to economic growth, sustainable developmental growth, better management of agricultural production and ecosystem services. Special attention has to be paid for introducing policies and interventions to ensure that the most vulnerable communities are benefitted (IFAD, 2011). Presence of disaster risk reduction and management legislations policies is also important to support climate-smart production systems. There is emerging need for access to financial support for implementation of climate-smart crop production programs especially for the developing countries that are projected to be more vulnerable to climate change (FAO, 2010b). Climate-smart crop production and management systems are knowledge-intensive processes that require specific technical skills for diverse strategies and sound assessments abilities showing the importance in capacity development.

## Conclusion and Future Directions

In the face of climate change, climate-smart crop production addresses sustainable and integrated practices for improved food security, increased resilience, and low-emissions development conserving the environment. Social and environmental impacts associated with the strategies and practices should not be undervalued. For the success of the climate-smart practices, the skills, tools and methods related to strategies, policies, institutions and plans have to be made available and easily accessible for all the stakeholders concerned.  Climate-smart crop production practices cannot be applied universally and all the approaches require site-specific assessments to identify suitable agricultural production technologies and practices.

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# CHAPTER 02

# Technology for the Productivity Enhancement of Agricultural Systems

**W.M.T.P. Ariyaratne***

*Department of Crop Science, Faculty of Agriculture, University of Peradeniya 20400, Sri Lanka*

## Abstract

The Food and Agriculture Organization predicts that the global population will reach 9.2 billion by 2050, and there will be high demand for a large quantity of foods. With limited farming land and freshwater resources, traditional systems cannot cater to the increasing demand. Adaptation of modern technology is one of the alternatives that can be used by the farmers to increase their production in a sustainable manner. However, the poor knowledge on the modern technology is one of the limitations for technology adoption. Therefore, the main purpose of this chapter is to introduce modern technologies that can be used in the farming to improve the productivity and sustainability of the agricultural production. Technologies developed in the last century have created to huge improvement in land preparation, crop management, harvesting and breeding. Modern technologies like nano technology, sensor technology, molecular markers, remote sensing, wireless sensor networks, geographic information system (GIS), Global Positioning System (GPS), drones, photovoltaic technology, and information and communication technology etc are discussed in this chapter.

**Keywords:** Agriculture, drones, molecular markers, nano technology, sensors

*mojith@cropsci.pdn.ac.lk

## Introduction

The Food and Agriculture Organization of the UN(FAO) predicts that the global population will reach 9.2 billion by 2050, and food requirement will increase drastically (Fig 1). The income distribution in the world is uneven and hugely divided. In one part of the world, prosperity exists, and there is always demand for high-quality food. While in another part of the world, hunger and war exist, and there is always demand for a large quantity of foods. With limited farming land and freshwater resources, this quality and quantity crisis in food can only be addressed by the application of technology in agriculture.

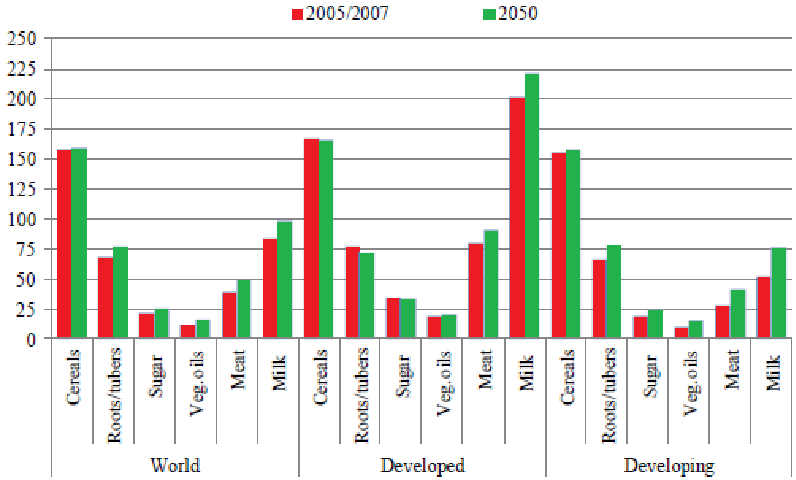

**Fig 1**. Food consumption per capita, major commodities (kg/person/year)
Source: Nikos *et al.*, (2012)

Both small- and large-scale farming can benefit from introducing technologies like ICT (information and communication technology) into the agriculture value chain, having their productivity increased, quality improved, services extended, and costs reduced. Furthermore, ICT facilitates information- and knowledge-based approach rather than only focusing on input-intensive agriculture. As a result, agriculture becomes more networked, and decision-making and resource utilization could significantly be leveraged. Modern agriculture is hugely automated, controlled, and constantly monitored. Sensors are the heart of ICT, and various sensing devices (Fig. 2) used for this purpose generate a large volume of data continuously. It provides insights into various issues in the agriculture like weather prediction, crop and livestock disease, irrigation management, and supply and demand of agriculture inputs and outputs and helps in solving those problems. It can also provide valuable information for optimum resource utilization and production boosting.

Further to the ICT, biotechnology is another modern approach that can be used to solve productivity related problems in agriculture. DNA is the key in biotechnology and based on its understanding scientists have developed solutions to increase agricultural productivity. Starting from the ability to identify genes that may confer advantages on certain crops, and the ability to work with such characteristics very precisely, biotechnology enhances breeders’ ability to make improvements in crops and livestock. Biotechnology enables improvements that are not possible with traditional crossing of related species alone and also it shortens the time required to develop new variety. Foods developed with biotechnology are as safe as those developed with conventional practices.

## Image Processing for Agriculture

Imaging techniques with different spectrum such as Infrared, hyper spectral imaging, X-ray were useful in determining the vegetation indices, canopy measurement, irrigated land mapping etc. with greater accuracies. Weed classification, which affects the yield, can be correctly classified with the image processing algorithms. The accuracy of classification varies from 85%- 96% depending on the algorithms and limitations of image acquisition. Thus with such great accurate classification farmers can apply herbicides in correct form. This approach helps to save the environment and reduce the cost. In case of fruit, grading systems the segmentation and classification can also be achieved with great accuracy as the case with weed detection. In this case also the classification accuracy can be obtained up to 96% with correct imaging techniques (Vibhute *et al.*, 2012).

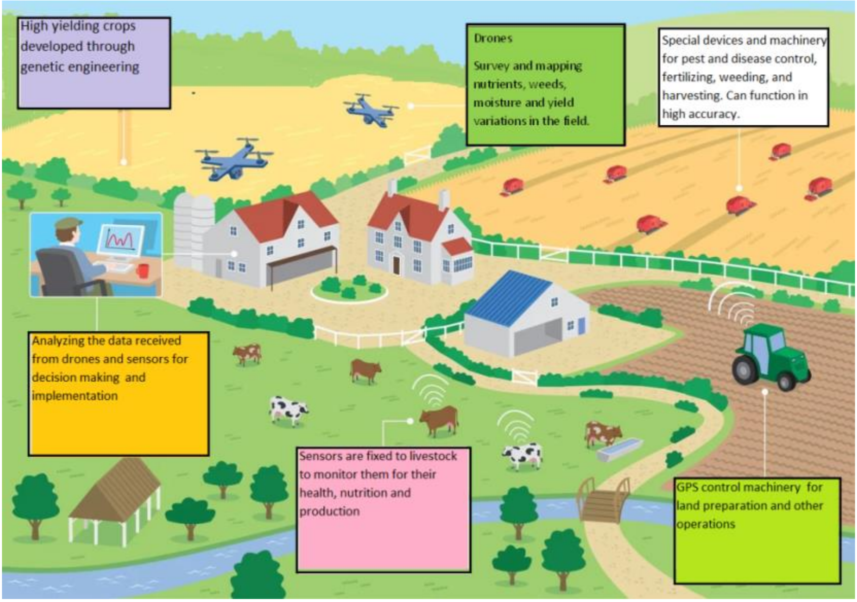

**Fig.2**. A diagram of different technologies used in agriculture

## Crop, Soil and Climate Monitoring for Crop Selection

There are many systems, which provide the functionality of the crop selection depending on the data monitored by Wireless Sensor Networks (WSN) of different related sensors. Chaudhary *et al*. (2011) proposed a novel technique to monitor and control various parameters of green house with the utilization of programmable system-on-chip (PSOC), technology as a part of Wireless Sensor Networks (WSN). Further, with the help of environmental sensors such as temperature sensor, humidity sensor, $CO_2$ sensor the farmer can easily record the environment conditions of the area. Such monitored data will be sent to a central Decision Support System (DSS) for taking the crop selection decision and select crops accordingly (Patil *et al*., 2016).

## Use of Photovoltaic Technology

Solar photovoltaic (PV) cells were invented at Bell Labs in the United States in 1954. In this technology, solar rays collected *via* small plates that are semiconductor photovoltaic, are converted into electricity. Photovoltaic cells can be built in two ways; concentrator and flat panel. Solar cells are the most common type of flat panels where the light is immediately brought to semiconductor and is converted to electricity (Shams *et al*., 2012). Electricity generated using the solar panels can be applied to a wide range of applications; most important ones include irrigation, refrigeration of agricultural products, milling of grains, electric fencing, poultry lightning etc. Although the application of solar PV system is limited to apparatus with smaller energy inputs, it will help you cut the dependency on electricity.

Further, the excessive sunlight irradiating greenhouses could be useful to provide an electrical energy source for theoperation of environment-control equipment after conversion into electricity using photovoltaic (PV) modules. Past PV greenhouse studies commonly used conventional flat hard or planar flexible PV modules. However, recent progress in PV technologies has provided additional possibilities for solar cell applications in greenhouses. A spherical solar microcell is one such candidate that is notable for its small size and its isotropic ability for photoreception (Biancardo *et al*., 2007). Although roof and wall orientations differ among greenhouses, spherical cells have no directional preference. For this reason, the cell is expected to produce constant quantities of electricity over widely varying sunlight incident angles. Therefore, they are suitable for greenhouse roof and greenhouse wall embedded applications.

Wavelength selective photovoltaic systems (WSPVs) that feature narrow photovoltaic strips embedded in a “bright magenta luminescent dye” that can absorb some of the sunlight’s blue and green wavelengths while converting some of the green light into red light, which has the highest efficiency for photosynthesis in plants. These transparent panels contain a low density of silicon photovoltaic (PV) strips arranged periodically on a panel of glass, allowing light to transmit between the strips. A thin layer of luminescent material is adhered to the backside of the glass, enhancing light quality by converting green light to red light. The optimized light spectrum enhances power production and facilitates plant growth.

## Nano Technology

Nano, the term derived from Greek word “nannos”, meaning “dwarf” means extremely small and denotes one billionth part of a specified unit indicating the factor $10^{-9}$. It can also be called ‘‘Nanotech’’, which is the study of manipulating matter up to atomic and molecular scale (Agrawal and Rathore, 2014). The term nanotechnology is a branch of science that deals with the manipulation and engineering of nano-scale materials up to 1-100 nm to be precise in size (Dudo *et al*., 2011; Ehsani *et al*., 2012). Nano technology is the manipulation of individual atoms, molecules or molecular clusters into structures to create materials devices with new or vastly different properties. Nanotechnology has a wide range of applications in agriculture, medicine, chemistry, physics, food industry, energy, telecommunications, textiles, electronics, sporting goods, construction industry, energy and automotive industry and so on (Qureshi *et al*., 2009; Bradley *et al*., 2011; Zambrano-Zaragoza *et al*., 2011; Rai and Ingle 2012; Fakruddin *et al*., 2012). Nanotechnology have many potentiality to agriculture and the ambition of the nanotech in agriculture is to diminish the amount of hazard chemicals, minimize nutrient losses in fertilization and increased yield through pest and nutrient management (Prasad *et al.,* 2017). Day by day, the application and the importance of nanotechnology in the agricultural sectors is increasing all over the world. Some of the nono technological approaches used in the agriculture are listed below.

## Nanotechnology in Seeds

Nanotechnology can be used to harness the full potential of seeds. Without improving the seed science through the nanotech it will be difficult to reach the desire yield. Technologies such as nanopriming, nanobiosensors, coating seed are used in seed science. Nanopriming accelerates seed germination, seedling growth, enhances starch metabolism and hydrogenase activity (Mahakham *et al*., 2017). Seed production is a tedious process especially in wind pollinated crops. Detecting pollen load that will cause contamination is a sure method to ensure genetic purity. Use of bionanosensors specific to contaminating pollen can help alert the possible contamination and reduce contamination. Nanocoating of seeds using elemental forms of Zn, Mn, Pa, Pt, Au, Ag etc. will not only protect seeds but used in far less quantities than done today. Quantum dots (QDs) is another nanotech which will be useful to separate unviable and infected seeds (Su and Li, 2004). Coating seeds with nano membrane, which senses the availability of water and allow seeds to imbibe only when time is right for germination. The use of carbon nanotube improves the seed germination percentage through better permeation of moisture (Khodakovskaya *et al*., 2009).

## Nano Fertilizer

Application of large amount of fertilizer is harmful for environment. Besides much of the fertilizers are unavailable to plants as they are lost as run-off leaching causing pollution. Proper application method of optimum quantities of fertilizer maximized nutrient uptake and reduced pollution. Advances in nanotechnology offer significant advantages to minimize these negative effects of fertilizers. The fertilizer carriers, which are called as smart fertilizers, or the nanosized materials as the tools of controlled release increase the effectiveness of fertilizer used and hence reduce the amount significantly. In this way, the pollution from fertilizers is minimized in soil, water resources and in food products. Due to the high surface to volume ratio, which is one of the most important features of nano-materials, plants can easily take the nano-fertilizers. Reduction of the frequency and amount of fertilizer application has economic benefits because of the decreased fertilizer and labor costs. The fertilizer loss caused by elution and evaporation in the soil system is minimized with the use of nano-sized materials. The nutrients retain their activity in the soil longer due to nano-fertilizers (de Rosa *et al.*, 2010; Naderi *et al.*, 2013; Ditta *et al*., 2015).

## Nano Pesticides

Pesticides are substances or mixtures of substances widely used to eliminate and control the harmful organisms, causing significant economic losses in agricultural production. Secondary metabolites (alkaloids, phenolics and terpenoids) secreted by plant as self-preservation mechanism of nature provide defense and protective function against insects. In traditional pest control methods, producers excessively use pesticides, which pose significant increase of cost of production (Sharon, 2010). Although there are some benefits of pesticide use, it can cause major problems in terms of environment, animal and human health due to potential toxicity.

Nano-pesticides offer advantages to producers to achieve economic benefits. The longevity of biological activities of the nano-pesticides compared to other pesticides reduces the amounts to be used. Their high surface to volume ratio provide a better contact with the target organism and exhibit lethal effects in a shorter time. They eliminate the necessity of flammable solvents in the used in conventional pesticides, and increase safety of users. In addition, reducing the loss of pesticides induced by environmental factors (vaporizing, sunlight) is possible with the use of nano-pesticides. Reduction of pesticide exposure of plant growers, reduction of accumulation of pesticides in the environment are among the other advantages provided by nano-pesticides (Peshin *et al.,* 2009; Jo *et al.,* 2009; Goswami *et al.,* 2010; Teodoro *et al.,* 2010).

## Nano-herbicides

Weeds cause significant economic losses in crop yields, posing a serious problem in agriculture. The chemicals used by producers for chemical weed control in the agriculture industry are called herbicides in general. However, despite the benefits of herbicide use, there are very harmful consequences for humans, animals and the environment. It is possible to get rid of weeds by an environmentally friendly and low-cost approach by using the nano-herbicides, which is one of the products of the groundbreaking nanotechnology revolution all over the world (Pérez-de-Luque and Rubiales 2009). The amount of herbicides used will be lower when the active ingredient to be employed for controlling weeds is modified by a “smart” carrier system. The high surface to volume ratio provided by the nano scale dimensions, provide a higher interaction with soil particles in the applied area. Although the conventional herbicides are effective on the above ground parts of weeds, they are not effective on the parts below ground (tubers etc.). Thus, the remaining parts of the plant below-ground may become a source for the weeds in the next season. The specific receptors of weeds under the ground are targeted by modifying a herbicide molecule with encapsulated nano particles. In this way, less weeds will require a control in the next season.

## Nano-arrays in Agriculture

Another application of nanotechnology in the agriculture industry is the reduction of the microarray analysis of plants down to the nanoscale. Microarray analysis allows mRNA analysis simultaneously for large number of genes (Aharoni and Vorst, 2002). Plant physiological processes can be evaluated on the basis of DNA, through these analyses (Schena *et al.,* 1998). Reduction of microarrays down to nano scale in the light of the nano technological developments is highly advantageous since it reduces the required sample volume and the amount of analyze. In addition, nanotechnology can be used to increase the efficiency of the microarrays, through the development of signaling and mobilization strategies of microarrays. Using this strategy, the target DNA molecules can be fixed at concentrations as low as $8\times10^{-13}$ M (Zhao *et al.,* 2003; Yan *et al.,* 2007; Kumari and Yadav 2014).

## Drones

One of the latest developments is the increase in the use of small, unmanned aerial vehicles (UAVs), commonly known as drones for agriculture. Drones are remote controlled aircraft with no human pilot on-board. These have a huge potential in agriculture in supporting evidence-based planning and in spatial data collection. Despite some inherent limitations, these tools and technologies can provide valuable data that can be used to influence policies and decisions. The use of drones in agriculture is extending at a brisk pace in crop production, early warning systems, disaster risk reduction, forestry, fisheries, as well as in wildlife conservation. At the most basic level, UAV permit farmers to obtain a birds-eye-view of their crops, allowing them to detect subtle changes that cannot be readily identified by “crop scouts” at ground level. UAVs equipped with special sensors can collect multispectral images that are stitched to generate spectral reflectance bands. These bands allow users to calculate indexes such as a Normalized Difference Vegetation Index (NDVI), Leaf Area Index (LAI) or Photochemical Reflectance Index (PRI), allowing farmers to view crop changes or stress conditions that are otherwise invisible to the human eye. Drones, which are fitted with infrared, multispectral and hyperspectral sensors, can analyze crop health and soil conditions precisely and accurately.

## Use of Sensors in Agriculture

Sensor is a device that measures/detects a real world condition such as motion, heat or light and converts the condition into analog or digital representation. The advantages of sensors are their robustness, reduced size, versatility, and low mass-production costs. They are simple devices, compared with other analytical techniques such as chromatography or spectroscopy, and they offer the possibility of designing *in-situ* analysis systems. These devices can be used in agriculture because current agriculture demands continuous *in-situ* information of soil physical and chemical parameters, such as macro- and micronutrients, owing to modulation of the amounts of fertilizers to be added. Some of the different types of sensors used in agriculture are given below:

## Optical Sensors

These sensors measure the type and intensity of the reflected light wavelengths to evaluate crop and soil conditions. The reflected green light wavelength can be used to measure chlorophyll in leaves and evaluate conditions causing the reduction in green color such as nitrogen status, sulfur and iron deficiency. Optical sensors are also used to predict clay, organic matter, and moisture content in soil.

## Mechanical Sensors

Mechanical sensors measure soil mechanical resistance, often related to level of soil compaction. Compacted soil, which can be caused by the heavy weight of field equipment or just the natural soil forming processes, can lead to soil degradation and affect crop production negatively.

## Electromagnetic Sensors

Due to low cost, high durability and rapid response, these sensors are commonly used for on-the-go soil mapping. Electromagnetic properties of soil are measured by its capability to conduct or accumulate electrical charge and are influenced by soil texture, organic matter or total carbon content, moisture content, salinity, residual nitrate content and other soil attributes.

## Electrochemical Sensors

These sensors have been successfully used to evaluate soil fertility by measuring the soil's chemistry through tests such as nutrient content and pH level. Two commonly used electrochemical sensors are ion-selective electrodes (ISE) and ion-selective field effect transistor (ISFET). They measure the activity of selected ions ($H^+$, $K^+$, $Na^+$, etc.) in the soil as well as the uptake of these ions by plants. Monitoring ion concentrations in plants helps farmers to design fertilization strategies that optimize production.

## Security Surveillance Systems

Security is one of the important issues for farmers. It is also important to detect and secure valuable items in the farm. The main objective for the surveillance is to secure the farm in absence of the farmer. For that detection of theft and animal interference in the farm should be avoided, and this can be done by security and surveillance system. For this, different technologies such as PIR sensor, CCTV and alert system are used which not only provide the security but also provides alert messages too.

## Global Positioning System (GPS)

GPS is a navigation system based on a network of satellites that helps users to record positional information (latitude, longitude and elevation) with an accuracy of between 100 and 0.01 m (Lang, 1992). This information is provided in real time, meaning that continuous position information is provided while in motion. Having precise location information at any time allows soil and crop measurements to be mapped. GPS receivers, either carried to the field or mounted on implements allow users to return to specific locations to sample or treat those areas. When collecting soil samples, GPS is used to precisely locate the sample points from a predefined grid. When GPS is integrated with an aerial guidance system, the field sprayer can be guided through a moving map display. Based on the sprayer's location, the system will apply the chemicals at the right spots, with minimal overlap, and automatically adjust their rate. This, in addition to increasing productivity, ensures that chemicals and fuel are used efficiently.

## Geographic Information System (GIS)

The use of GIS began in 1960. This system comprises hardware, software and procedures designed to support the compilation, storage, retrieval and analysis of feature attributes and location data to produce maps. GIS links information in one place so that it can be extrapolated when needed. Computerized GIS maps are different from conventional maps and contain various layers of information (e.g. yield, soil survey maps, rainfall, crops, soil nutrient levels and pests). GIS helps convert digital information to a form that can be recognized and used. Digital images are analyzed to produce a digital information map of the land use and vegetation cover. GIS is a kind of computerized map, but its real role is using statistics and spatial methods to analyze characters and geography. A farming GIS database can provide information on filed topography, soil types, surface drainage, subsurface drainage, soil testing, irrigation, chemical application rates and crop yield. Once analyzed, this information is used to understand the relationships between the various elements affecting a crop on a specific site.

## Remote Sensing

Remote sensing is becoming a useful tool for precision farming. In here scanners on aircraft or satellites are used to monitor changes in wavelengths of light from fields and growing crops. Satellite imagery is also useful in more precise mapping of field boundaries and location of tile drainage lines, for example, and is often most effective when used in conjunction with field scouting ("ground truth observations") to help identify the reasons for variability. The data collected can be mapped and analyzed with the help of GIS tools, to provide additional data layers for GIS analysis and management decisions. Remote sensing helps to define the extent of problems identified in field scouting by recognizing similar patterns. It is used to document such issues as pest problems, weather factors, nutrient management issues, and more. While it has taken several years to develop remote sensing technology to the point of providing dependable, cost effective products and services in a timely fashion, there are now such services available to add to the toolbox to aid farmers and their advisors in making crop management decisions.

## Robots

Self-steering tractors have existed for some time, as John Deere equipment works like a plane on autopilot. The tractor does most of the work, with the farmer stepping in for emergencies. Technology is advancing towards driverless machinery programmed by GPS to spread fertilizer or plow land. Other innovations include a solar powered machine that identifies weeds and precisely kills them with a dose of herbicide or lasers. Agricultural robots, also known as AgBots, already exist, but advanced harvesting robots are being developed to identify ripe fruits, adjust to their shape and size, and carefully pluck them from branches.

Companies are using automation and robotics to help farmers find more efficient ways to protect their crops from weeds. Blue River Technology has developed a robot called *See & Spray* which reportedly leverages computer vision to monitor and precisely spray weeds on cotton plants. Precision spraying can help prevent herbicide resistance.

## Applications of DNA Technologies in Agriculture

### Transgenic Plants

Transgenic plants are plants that have had their genomes modified through genetic engineering techniques either by the addition of a foreign gene or removal of a certain detrimental gene (Jhansi *et al*., 2013). A foreign gene inserted into a plant can be of a different species or even kingdom. The first transgenic plant was developed through the insertion of nptII bacterial antibiotic resistance gene into tobacco (de Framond *et al*., 1983). Since then, with the rapid development in plant molecular biology and genetic engineering technology, a wide variety of transgenic plants with important agronomic traits such as pest resistance and drought tolerance have been developed, ranging from dicots to monocots that are amenable to genetic modifications. The main purpose in the production of transgenic plants is to produce crops, which have ideal traits, quality, and high yield. Besides being beneficial to the agriculture sector, the plants are found to be able to act as the factory for pharmaceutical protein production (Lai *et al*., 2012).

Some transgenic plants are enriched with nutrients to reduce the malnutrition children in developing countries. ‘Protato’, which is genetically engineered potato in India produces about one-third to one-half more protein than usual, it also has substantial amounts of all the essential amino acids such as lysine and methionine (Coghlan, 2003) helping Indians to obtain more protein from potato. Similarly, Golden rice has been genetically engineered to produce beta-carotene, the precursor to vitamin A. So, it can be used to recover the vision problem caused by Vitamin A deficiency (Ye *et al*., 2000). In addition, using genetically engineering techniques, scientists have developed crops for drought resistance (Khan and Khan, 2010), as animal feeds (MacKenzie and McLean, 2002), herbicide-tolerance (James, 2002) and pest and herbicide resistance (Fernandez-Cornejo *et al*., 2000).

## Genetic Markers

Genetic markers are important developments in the field of plant breeding (Kebriyaee *et al*., 2012). The genetic marker is a gene or DNA sequence with a known chromosome location controlling a particular gene or trait. Genetic markers are closely related with the target gene and they act as sign or flags (Collard *et al*., 2005). Genetic markers are broadly grouped into two categories: classical markers and DNA/molecular markers. Morphological, cytological and biochemical markers are types of classical markers and some examples of DNA markers are restriction fragment length polymorphism (RFLP), amplified fragment length polymorphism (AFLP), simple sequence repeats (SSRs), single-nucleotide polymorphism (SNP) and diversity arrays technology (DArT) markers, Inter simple sequence repeat (ISSR) and Randomly amplified polymorphic DNA (RAPD). Table 1 gives some basic characters of molecular markers.

### *Marker Assisted Backcross Selection*

Marker assisted selection (MAS) is an indirect process where selection is carried out on the basis of a marker instead of the trait itself. The successful application of MAS relies on the tight association between the marker and the major gene or QTL responsible for the trait. As we have described before, the new genomic tools accelerate the identification of markers tightly linked to target genomic regions. On the other hand, the new dense genotyping platforms available today accelerate the genotyping of large amounts of samples during the MAS process in a rapid and economically feasible manner. MAS can take benefit from these technologies, speeding up the release of new varieties.

### *Heterosis Prediction*

Heterosis prediction is important to improve breeding efficiency and shorten the breeding process. By DNA marker technology, we can detect the positive markers or positive locus related to heterosis in any period or organ, and then predicts the heterosis based on the heterozygosity of these loci. This technique overcomes the deviation of genetic distance-based heterosis prediction.

Table 1. Comparison of some basic characteristics of the commonly used molecular markers

| Characteristics | AFLP | RAPD | RFLP | ISSR | SSR | SNP | DArT |
|---|---|---|---|---|---|---|---|
| Co-dominant/Dominant | Dominant | Dominant | Co-dominant | Dominant | Co-dominant | Co-dominant | Dominant |
| Polymorphism level | High | very high | Medium | High | High | High | High |
| Reproducibility | Intermediate | High | High | Medium–High | High | High | High |
| Genome abundance | Very high | Very high | High | Medium | Medium | Very high | Very high |
| Required DNA quantity | Low | Medium | High | Low | Low | Low | Low |
| Required DNA quality | High | High | High | Low | Low | High | High |
| Sequencing | No | No | Yes | No | Yes | Yes | Yes |
| PCR requirement | Yes | Yes | No | Yes | Yes | Yes | No |
| Cost | High | Less | High | High | High | Variable | Cheapest |
| Visualization | Agarose gel | Agarose gel | Radioactive | Agarose gel | Agarose gel | SNP-VISTA | Microarray |

*Source:* Muhammad *et al.* (2018)

### *Construction of Genetic Map*

In recent years, with the rapid development of molecular marker technology, the genetic maps for most crops have been drawn. Cui *et al.* (2012) constructed the high-density genetic linkage map of wheat (average genetic distance is 4.42) using DArT markers, and Blenda *et al.* (2012) constructed the high density genetic linkage map of cotton (average genetic distance is 4.3) using SSR marker. Most of the field and economic crops have finished the construction of high density and even saturated genetic linkage maps, and this will be of great help to understand the information of genomic composition and structure, and will finally benefit to the breeding practice.

## Mutation Breeding for Crop Improvement

The utilization of induced mutation in crop improvement is called mutation breeding. Most of the mutant varieties (around 89 %) have been developed using physical mutagens (X-rays, gamma rays, thermal and fast neutrons), with gamma rays alone accounting for the development of 60 % of the mutant varieties. A wide range of characters which have been improved through mutation breeding include plant architecture, yield, flowering and maturity duration, quality and tolerance to biotic and abiotic stresses (Kharkwal *et al.*, 2004).

The variability generated through induced mutations are either released as new varieties or used as parents for subsequent hybridization programmes. Mutation breeding programme should be clearly planned and should be large enough with sufficient facilities to screen large populations (Wani *et al*., 2017; Raina *et al*., 2016).

Mutation breeding is known to induce genetic variability in the crops that show higher yield and wider adaptability (Khursheed *et al.*, 2016). Mutation breeding technique has played a major role in generation of climate smart varieties. These crop varieties have been shown to withstand wide range of environmental fluctuation. Globally millions of hectares of cultivated lands have been devoted for the cultivation of mutant crop varieties and billons of revenue have been generated (Jain, 2010). The main objective of mutation breeding is to increase food production and provide sustainable nutrition (Goyal and Khan, 2009; Wani *et al*., 2011)

## Machinery Used in Agriculture

Farming is perhaps one of the world's oldest and most necessary trades, and up until recently, it has continued on with the same tools. Modern engineering along with tractors and new machinery has shifted the farming industry to one of efficiency and mass production. Farming is no longer a small scale production, but rather one that takes place with massive machines over thousands of hectares. This efficiency boost means that the world has access to any food it wants at any time.

## GPS Based Variable Rate Granular Fertilizer Applicator

A GPS Based variable rate granular fertilizers (NPK) applicator has been developed to ensure ideal application of fertilizers. It consists of a differential global positioning system (DGPS), micro-processor, micro-controller, DC motor actuator, power supply, threaded screw arrangement and fluted roller fitted metering mechanism. The fertilizer application rate is changed according to the prescribed application rate at the identified grid.

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# CHAPTER 03

# Ecosystem Services of Plantation Agroforestry Landscapes in Sri Lanka

**A.J. Mohotti[1]* and K.M. Mohotti[2]**

[1] *Department of Crop Science, Faculty of Agriculture, University of Peradeniya, Peradeniya 20400, Sri Lanka*

[2] *Tea Research Institute, Talawakelle, Sri Lanka*

## Abstract

At present, there are many challenges ahead of agriculture in view of population increase, land fragmentation, limitation and competition for resources, environmental degradation, climate change and its consequences, etc. In a given crop land, it is imperative that maximum returns are obtained from each unit of land while ensuring environmental and ecological sustenance. However, improper land use, misuse and indiscriminate use of agro inputs and over exploitation of natural resources etc. tend to disrupt the balance of agro eco systems. Agroforestry can be considered as one such age-old approach where multiple benefits are obtained. Amongst, plantation crops provide such benefits even though maintained as monocultures. The features and ecosystem benefits of plantation agroforestry landscapes in Sri Lanka are discussed in this communication. Conversion of existing systems into efficient, sustainable and climate-smart landscapes is proposed by carrying out landscape-scale planning, designing, policy and land management.

**Keywords:** Agroforestry, ecosystem services, plantations

*mohottij@yahoo.com

## Introduction

Population in the world, and in Sri Lanka, is ever increasing. The estimated population in Sri Lanka in 2018 was 21.7 million (Department of Census and Statistics, 2019). The land use systems in Sri Lanka at present are greatly challenged by the population pressure for various needs and pressure of economic development in addition to mounting concerns of environment (Pushpakumara *et al*., 2012). Concerns on climate change, soil degradation, and environmental pollution further aggravate the situation. Thus, the land use systems today have to be planned based on their ability to maximize the productivity and sustainability, and not only on the ability to fulfil one objective.

On the other hand, land fragmentation due to demands in parallel to the population increase is also inevitable. Consequently, many crops that were traditionally grown as plantation crops now are grown in smallholder lands. The increased contribution of tea production from smallholders of Sri Lanka against the corporate sector in the recent past can be considered as a good example where the share of smallholding sector in total tea production in Sri Lanka was above 70% during the period 2010-2012 (Premaratne *et al*., 2018) which is approximately 76% at present.

Agroforestry can be considered as a mean of maximizing land productivity in a sustainable manner with multitudinal benefits. It is an integrated approach of using the interactive benefits from combining trees and shrubs with crops and/or livestock (Ameer and Kuraisiya, 2014). Here, the agricultural and forestry technologies are combined to create more diverse, productive, profitable, healthy and sustainable land-use systems. Currently 1.2 million people worldwide are known to practice agroforestry (Seneviratne *et al*., 2015).

Many agroforestry systems in the world integrate various intensities of traditional agricultural practices in combination with modern low-cost technologies. The subcategories of agroforestry include agro-silviculture (growing trees with crops), agro-silvopasture (growing trees with pasture), agro-horticulture, shifting cultivation and home gardens (Seneviratne *et al*., 2015). There are both ecological and economic interactions between woody and non-woody components in agroforestry, and it has an important role to play in food and wood security and the conservation of the environment (Ameer and Kuraisiya, 2014).

Chapter 3

# Agroforestry Systems in Sri Lanka

Agroforestry is an integrated approach of using the interactive benefits from combining trees and other plant species/ crops and/or livestock to create more diverse, productive, profitable, healthy and sustainable land-use systems. The integrations can be either in a spatial mixture or in a temporal sequence. By integrating tree growing with crop production, the problems of poor agricultural production, worsening wood shortages and environmental degradation can be addressed. Furthermore, Agroforestry technologies/ practices are seen as an opportunity to take pressure off the remaining natural forests and to increase the diversity of vegetation on existing farms (Ameer and Kuraisiya, 2014).

Agroforestry systems have been an integral part of Sri Lankan landscapes from ancient times. They are considered as sustainable resource management systems. Tree-crop-other plant species systems are the most common in Sri Lanka. The common agroforestry systems in Sri Lanka are: Traditional systems (i.e. Shifting cultivation, homegardens, Kandyan forest gardens); Plantations (i.e. tea, rubber, coconut, taungya systems); Silvopastoral systems; Conservation farming and alley cropping; and Participatory or community forestry (Liyanage *et al*., 1986; Ranasinghe and Newman, 1993). Many of these systems are present in different elevations/ agro climatic regions in the country. Shifting cultivation is more common in drier and lower elevations, and in more rural areas of the country, while in the wetter parts of the country, most common systems are the homegardens, Kandyan forest gardens, plantations and forestry. Only the plantations will be considered, and tree-animal integration will not be considered in this communication.

## Plantation Agroforestry Systems

The main plantation crops grown in Sri Lanka are tea, rubber and coconut. In addition, export agricultural crops such as pepper, cardamom, cloves, nutmeg, coffee, arecanut, oil palm and palmyra are also important as plantation crops. All these crops are either grown as mono crops, or in combination in agroforestry systems in Sri Lanka.

## Tea as an Agroforestry System

Tea in Sri Lanka is grown as plantations in large and medium estates and as smallholdings. Majority of large and medium lands are mono crop models while smallholdings constitute of a mixture of trees and crops depicting vertical and horizontal vegetation arrangements and in some instances, lowland crops and animal husbandry are also embedded (Plates 1, 2 and 3). However, some tea smallholder lands are managed as monocultures or mixed gardens as well (Abeywickrama *et al*., 1999). The tea smallholder contribution is quite important at present with respect to total extent as well as their contribution in production. For example, in 2018, smallholders contributed to 75.5% of the total tea production in the country (Ministry of Plantation Industry, 2018).

Tea is a shade loving plant, hence benefits when grown in association with trees (Mohotti and Lawlor, 2002). Tea in smallholder lands is usually grown in association with many tree species, which may have various purposes such as food, timber, shade etc. In many smallholder lands, tea can be seen to be intimately mixed with homegardens. High shade trees consisting of forest trees and perennial crops are an integral component in tea lands which is analogous to natural forest conditions. In southern part of the country where smallholders dominate, coconut, jak, mahogany, arecanut and lunumidella are the dominant high shade tree species in tea small holdings with land extents less than 0.25 ha, while albizia dominate in the holdings larger than 0.5 ha (Abeywickrama *et al*., 1999).

The large plantations on the other hand comprise of large land areas planted with tea, and normally with a lesser number of shade tree species. Two kinds of shade trees are being used in tea plantations in Sri Lanka: medium and high shade (Ekanayake, 2008). High shade trees are planted at a 40 m x 40 m final spacing, and regularly pollarded to a maximum height of 20 m to induce lateral growth of branches in order to provide shade for the tea plants. As high shade trees, *Grevillea robusta* L. and *Falcataria moluccana* (Miq.) Barneby & J.W. Grimes (syn. *Albizzia moluccana* Miq.) are grown in medium-high and low-medium elevations respectively. As medium shade trees (depending on the location), one or more of the following species: *Erythrina lithosperma, Gliricidia sepium, Calliandra calothrysus, Acacia pruinosa, A. decurrens* are grown in between the high shade trees at a final spacing of 6 m x 6 m and they are lopped 2-3 times a year in order to regulate the shade (Ekanayake, 2008).

## Intercropping Under Coconut and Rubber

Intercropping under coconut can be practiced when the palms are 0-5 or 25-50 years old (Ranasinghe and Newman, 1993). Crop types such as tuber crops (i.e. manioc, sweet potato, *Colocasia* spp., *Diascorea* spp.), cereals (i.e. finger millet, maize, sorghum), legumes (cowpea, green gram, groundnut, soybean, winged bean), fruit crops (i.e. banana, citrus, papaya, passion fruit, pineapple, pomegranate), spices and condiments (arecanut, betel leaves, chillies, ginger, turmeric), cash crops (black pepper, cocoa, cinnamon, clove, coffee, nutmeg), sesame and pastures (*Brachiaria milliformis*) can be intercropped with coconut successfully. Intercropping of coconut tends to increase coconut yields by associated changes in improved management of the ground between trees such as weed control and indirect fertilization, whilst minimum effects are observed on the understory growth (Liyanage *et al*., 1986).

Intercropping with rubber has been experimented with two spacings, i.e. 2.4 x 9.1 m and 3.7 x 6.1 m, where the latter is considered as more appropriate for agroforestry. However, intercropping is known to be possible only during the first 5-7 years at these spacings (Ranasinghe and Newman, 1993). Any sun loving crop such as banana, pineapple, passion fruit and sugarcane could be grown with rubber during this immature phase, (Rodrigo *et al*., 2004). Perennial plants that can tolerate shade such as coffee, cocoa and tea could be grown when the rubber is still young and does not impart much root competition. Intercropped rubber reached the tappable girth 4-6 months earlier than the sole cropped rubber, and also, the amount of latex obtained was greater in intercropped rubber compared to sole cropped rubber due to increased growth (Rodrigo *et al*., 2004).

## Ecosystem Services

The dominant ecosystems in Sri Lanka discussed above provide many benefits to humans, which may be considered as ecosystem services. Key ecosystem services may be conceptualized as provisioning, regulating, cultural, and supporting services (Mohri *et al*., 2013). Provisioning services are those resources supplied by homegardens to human communities, which include food products, timber for construction, fuel in the form of wood and charcoal, and natural medicines and other raw materials for plants, animals, fungi and micro-organisms. Regulating services include functions such as sequestration of carbon from the atmosphere, soil erosion regulation, waste treatment, water purification, pest regulation and pollination, all of which help in maintaining a sustainable supply of many provisioning services provided by homegardens (Plate 1). Supporting services include the system in a sustainable approach to improve soil fertility by nutrient cycling and maintaining organic matter, carbon content, and soil structure (Mohri *et al.*, 2013). Apart from above services or goods, a vast array of cultural services like recreation and a sense of place also can be considered as important. Such ecosystem services in the plantation and homegarden agroforestry systems are summarized below.

## Ecosystem Services of Plantations

Tea forests integrate all provisioning, regulatory, cultural and supporting services (TEEBcase, 2013). Shade trees also can be considered as important agents in facilitating various ecosystem services. Tea, coconut and many species used in the agroforestry systems of tea, rubber and coconut (i.e. cocoa and spices such as nutmeg in rubber intercropping, spices, masticatory crops such as betel in coconut) are used for human consumption. Further, the tree species planted in smallholdings may serve multi-purposes, such as providing food/ fruits [e.g. mango (*Mangifera indica*), avocado (*Persea americana*), jak (*Artocarpus heterophyllus*), Citrus, etc.), timber [e.g. mango, jak, toona (*Toona ciliata*), mahogany (*Swietenia macrophylla*), etc.], fuelwood (e.g. gliricidia), medicine [e.g. neem (*Azadirachta indica*) etc.], cash crops [e.g. cloves (*Syzygium aromaticum*), nutmeg (*Myristica fragrans*) etc.], and wood for other purposes such as fencing etc. in addition to providing shade and green manure (Plates 1 and 2).

In a study conducted in coffee plantations across six agroforestry and tree cover transition sites spanning in tropical/subtropical forest zones in three continents, the absence of shade trees resulted in loss of native earthworm populations, which in turn caused a reduction of 76% of soil macroporosity. Increased tree cover has contributed to 53% increase in tea crop yield, maintained 93% of crop pollinators found in the natural forest and nearby forest fragments and contributed to as much as 86% lower incidence of coffee berry borer (Barrios *et al*. 2017). In a study carried out in Yunnan, China, where tea is traditionally grown under forest, biodiversity, soil and water conservation, natural pest regulation, climate regulation, contribution to carbon storage in trees etc. were proven to be significantly high in comparison with modern tea terraces (TEEBcase, 2013).

In another study, tea, when grown under seven shade tree species, the microclimatic conditions were improved favouring tea where both atmospheric and soil temperature were lowered by 2 to 3 °C compared to a non-shaded open condition, RH values were increased by 3 to 9% within the shade, net radiation varied from 108 to 178.94 Wm-2, and photosynthetically active radiation from 188 to 339 1/4 E m-2s-1 (Mukherjee *et al*., 2008). Incorporation of contour hedgerows in tea lands had the potential to regenerate soil fertility and sustain tea yields on sloping terrains in Sri Lanka, when prunings were added as mulch. The amounts of nutrients added through hedgerow prunings exceeded the recommended K requirement of tea (De Costa *et al*., 2005).

When plantation tree species are grown in highlands, it is held responsible for erosion control, minimizing silting in down streams and reservoirs, serving as wind breaks, improving ventilation and cool climates and providing shelter for wild animals etc. In Sri Lanka, majority of rivers, streams, reservoirs and dams are fed through tea plantations which also provide shelter for important fauna like giant bees, bats, birds, rabbits etc.

Rubber and coconut, and common shade tree species such as *Grevillea robusta* L. and *Falcataria moluccana* and many other species have a wood value. Firewood also is an important use of these trees. In a study conducted using 14 species, *Gliricidia* was the best in many locations due to a high wood yield, high rate of leaf decomposition, ability to tolerate frequent harvesting with less mortality, easy establishment with vegetative propagation, easy handling due to uniform size of branching and multiple use (animal fodder, green manure etc). On average, *Gliricidia* and *Acacia* yielded 24 mT and 18 mT per ha respectively, grown at the density of 10,000 trees/ha. *Gliricidia* also improved soil fertility and the microclimate

(Gunathilake *et al*., 2005). The lopping of shade trees and leaf fall provides large quantities of organic matter, which improves the physical, chemical and biological properties of soil (Ekanayake 2008).

The plantation agroforestry systems are considered to be quite beneficial in terms of carbon sequestration. For example, the low country, mid country and up country tea growing regions have the potential of sequestering 2.81, 1.03 and 0.37 million MT of CO2 equivalents per year respectively (Wijeratne *et al*., 2014). In another study carried out in up country of Sri Lanka, total organic carbon stocks calculated were 5.61 kg ha-1 in tea plantations and 4.21 kg ha-1 in Eucalyptus plantation at a 0-15 cm?? soil depth (Weerakoon, 2014). The C stock of the coconut plantation ecosystems varied between 32 and 72 Mg C ha-1 whilst the net carbon balance varied between 0.4 and 1.9 Mg C ha-1 month-1 under different growth conditions (Ranasinghe and Thimothias, 2012). On the other hand, mature rubber is capable of sequestering 81 MT of CO2 per hectare annually and, within the 24 years of mature phase, 1296 MT of CO2 would be sequestered in a hectare of rubber (Munasinghe *et al*., 2011). However, many studies have considered monocultures of plantation crops, and studies conducted on C sequestration capacity as a whole agroforestry system are lacking.

Agroforestry systems increase the diversity. In general, the diversity in the smallholder lands can be considered to be higher than in large monocultures. Many studies have indicated a strong connection between biodiversity and ecosystem services and strongly emphasize the importance of biodiversity conservation for enhanced ecosystem services (Udawatta *et al*., 2019). In addition to diversity of flora, these agroforestry systems provide unique niches and habitats and support maintenance of natural faunal diversity including many globally and nationally threatened species. For example, in a study carried out in a tea plantation in the upcountry of Sri Lanka, highest avifaunal species count of 62% was recorded in homegarden habitat where Shannon index (H') = 3.03 and Evenness (J) = 0.46. Species diversity and the evenness of the secondary forest were comparable to tea field indicating H'= 2.86 and J = 0.43; H' = 2.77 and J = 0.46 respectively. One globally threatened species; Kashmir Flycatcher (*Ficedula subrubra*) and 12 nationally threatened species were also observed in this study (Kottawa-Arachchi *et al*., 2010).

## Agroforestry Systems as Climate-Smart Models

Considering the present-day challenges for agriculture, it is important that the agricultural landscapes need re-examining for reaping maximum benefits. It is well proven that agroforestry systems have multitudinal benefits, and that they can provide quite diversified products and services. These landscapes need revisiting by following agroforestry principles and adding values to these ecosystems as in climate-smart agriculture (CSA) landscape models. The CSA has been considered for many sectors in Sri Lanka (World Bank; CIAT 2015), and such models have also been discussed and implemented elsewhere (Milder *et al*. 2015). In CSA, integrated landscape management principles are applied to incorporate climate change adaptation and mitigation goals into multifunctionality in rural landscapes. It includes widely used many field- and farm-scale agricultural practices, such as agroforestry, crop residue management, water harvesting and irrigation, indigenous crop and agrobiodiversity conservation and use etc. This is achieved by carrying out landscape-scale planning, policy, land management, support activities, improving coordination and alignment of activities, policies, and investments among sectors and scales. In many agricultural systems in Sri Lanka, many of these aspects are already in place. Hence, it will be a matter of proper planning which will add much values to the existing systems.

Plate 1. A typical example of a Sri Lankan homegarden with upland crops including tea, rubber, coconut, areaunut, spices, fruits, timber and fuel wood tree species and paddy fields

Plate 2. A large tea plantation ecosystem strengthened with high and medium shade tree, green manure, fencing and fuel wood tree species responsive in providing safe water, air and facilitation for aerial and aquatic fauna and flora

Plate 3. A broader tea landscape assuring wider benefits to water resources, downstream floral and faunal habitats and food for humans and animals

## Conclusions and Way Forward

Being a country based on agriculture, appropriate management and utilization of resources for maximizing benefits are of paramount importance. The socio-economic and political dependence on such ecosystems are equally important as ecological services and positive impacts to the country. At present day, there are many challenges ahead of agriculture in view of the ever-changing needs of humans, rising populations, land fragmentation, limitation and competition for resources, environmental degradation, climate change and its consequences, etc. Over exploitation of lands, underutilization and misuse of natural resources and inability to maintain higher land use efficiencies in plantation crop landscapes are highlighted besides difficulties in managing larger landscapes and units and climate change etc. Land degradation, soil erosion, water pollution, threats to aerial and aquatic biodiversity habitats, weakening biodiversity hot spots and niches etc. are already been experienced. Therefore, a collective effort is urgently sought to restrain and remunerate the lost wealth of resources in the country.

In parallel, many crop landscapes have been converted to smaller units from large monoculture units. Further, with increasing contribution to the national production by smallholders of crops who maintain their lands with many tree species in combination, it is more appropriate to consider these systems as agroforestry systems. With these challenges ahead, such landscapes need revisiting by reorienting the landscape designing using agroforestry principles and paying attention to better harnessing of natural resources in an effective manner. It will add values as in climate-smart agriculture landscape models as well as ensure sustenance with equal sharing of resources with the grower, practitioner and the nature as the way forward.

Taking the ideal smallholder as the model, with all components in place, country-and region-specific CSA models may have to be developed in the future. This will require proper planning, government policy level interventions, land management, and support activities such as development of knowledge management systems. Further, in depth eco system analyses, impact assessments and multi benefit estimations of such landscapes are essential.

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# CHAPTER 04

# Ecoagriculture Approach for Sustaining Ecosystem Services in Fast Changing Landscapes in Sri Lanka: The case of Rattota, Matale

**G. Hitinayake[1*] and L. Wariyapola[2]**

*[1]Department of Crop Science, Faculty of Agriculture, University of Peradeniya, Peradeniya*

*[2]Postgraduate Institute of Agriculture, University of Peradeniya, Peradeniya*

## Abstract

The present study was conducted to understand the landuse changes that are taking place at landscape level in the ecologically sensitive areas in Sri Lanka. Rattota, a semi-rural area in the Matale district was selected for the study and land use changes taken place during a 16-year period (2001-2017) was assessed. It is clear from the study that the landscape of the area is fast changing. The trend shows that predominantly plantation crop based landscape is changing towards a homesteads based one. However, the agroecology of the area has made them ecologically sound tree gardens compromising agricultural productivity and biodiversity conservation. In this regard adopting ecoagricultural approach is vital to sustain the ecosystem services in the long-run. This requires use of ecological knowledge wisely, including local knowledge and developing an institutional mechanism to organize the work to get the project off the ground.

**Key words:** Landuse changes, changing agricultural landscapes, Ecoagriculture approach

*gaminisbh@gmail.com

## Introduction

Sustaining ecosystem services will be a challenge when landscapes are changing rapidly. Landscapes are mosaics of natural and human-modified ecosystems. They provide multiple benefits, such as food, rural livelihoods and well-being, energy, fiber and building materials, medicines, ecosystem services and biodiversity. In a more formal sense "a landscape is a socio-ecological system that consists of natural and/or human-modified ecosystems, and which is influenced by distinct ecological, historical, economic and socio-cultural processes and activities" (Ecoagriculture Partners, 2019).

Ecoagriculture refers to a relatively novel approach to managing landscapes specifically to meet three goals, conserve biodiversity and ecosystem services, provide agricultural products, and support viable livelihoods for local people (Scherr and McNeely, 2001). This is also interpreted as the wise use of ecological knowledge in planning and developing agricultural landscapes. In the past, the goals of ecoagriculture were often perceived to be in conflict, but many integrated landscape initiatives practicing ecoagriculture have shown how conservation, agriculture and development can co-exist or even positively affect each other (Denier *et al.*, 2015). This process requires collaboration or coordination between diverse stakeholders who are collectively responsible for managing key components of a landscape (Denier *et al.*, 2015). This process must reinforce the synergies between different initiatives.

The present study was conducted at the Rattota Divisional Secretary's Division. The reason for conducting this study at Rattota is not because it is the most threatened landscape in Sri Lanka, but it is one of environmentally sensitive, ecologically and socio-culturally diverse areas in Sri Lanka. It has got most features common to landscapes in central highland ecosystems of Sri Lanka. The central highlands are often identified as the "Geographical heartland of Sri Lanka" (Gunasekera, 2006) given its transboundary effects on ecosystems as far as dry zone areas of Sri Lanka.

The objective of this study was to evaluate the landscape changes that are taking place in central highlands of Sri Lanka and whether ecoagriculture approach could be used to understand synergies between different initiatives and suggest ways and means to manage those changes to sustain ecosystem services. The landuse maps in 2011 and 2017 were used to evaluate the changes in landuse. Ground truthing was done in 2017 to interpret the results and understand the causes for landuse changes.

## Ecological Setting

Rattota Divisional Secretary's Division (DSD) is situated between northern latitude 7.25-7.33 and eastern longitude 80.36-80.45 and 305-1524m above mean sea level. Rattota administratively falls within the Matale District and Central Province of Sri Lanka. Rattota Divisional Secretary's Division consists of 205 villages covered by 54 *Grama Niladhari* Divisions and that total population is 60,464. This division became a populous area during the past two decades. This is because Rattota division is situated near Matale.

Some parts of the division are covered with mountains, hills and inaccessible places. Especially the Southern and Eastern boundaries are covered by the Hunnasgiri Mountain and Knuckles Conservation Area which has been recognized as a world heritage. Rattota DSD traverse through Upcountry Intermediate Zone (IU1), Midcountry Wet zone. (WM3b) and Mid Country Intermediate Zone (IM3a) (Table 1). Heavy and well distributed rainfall is received by the Rattota ranging from 1400-2400mm per year. Highest rainfall is received during the December-January period whereas July and August are considered as dry months in Rattota. This shows that rainfall is mainly received during the north east monsoon period and less in the South West monsoon period. A number of small water streams that starts from Knuckles and Hunnasgiriya Mountain ranges, namely, Daliwala Oya, Dankanda Oya, Moragulu Oya and Nikal Oya flows through the division and connect with Suduganga.

Soil erosion is high in the area as landform is Mountainous, steeply dissected, hilly and rolling in the IU1, rolling and undulating in the WM3b and steeply dissected, hilly and rolling in IM3a. The average temperature of the Rattota area ranges from $24^0$C to $30^0$C. The hottest month is August and January is the coldest. The climate of the area is highly suitable for high value perennial crops such as Tea, Rubber, Coconut, Cardamom, Cocoa, Coffee and Pepper.

Table 1. Agro-ecology of Rattota.

| **Agro-ecological region (AER)** | **Proportion of the Rattota DSD** | **Rainfall (mm)** | **Soil type** | **Major landuse** |
|---|---|---|---|---|
| IM3a | 30% | >1400 | RBL, IBL, LHG | HGs, Rubber, coconut, Rice |
| IU1 | 24% | >2400 | RYP, Mountain regasols, Lithosols | Forest / Cardamom, Pathana grasslands, Tea |
| WM3b | 46% | >1400 | RBL, IBL, LHG | Tea, KHGs, Rice, Vegetable |

**Source**: Punyawardena, (2008)

**Key**: DSD-Divisional Secretary's Division, RBL-Reddish Brown Latasolic, IBL-Immature Brown Loam, LHG-Low Humic Gley, RYP-Red Yellow Podzolic, HG-Homegardens, KHG-Kandyan Homegardens, EAC-Export Agriculture Crops.

## Ecoagriculture Practices in the Rattota Area.

The ecological and economic setting in the Rattota has provided the basis for a unique set of ecoagriculture practices. Ecoagriculture includes a wide range of systems and practices that integrate productivity goals (for crops, livestock, fish, trees and forests) with provision of ecosystem services including biodiversity and watershed services at a landscape scale. The status (in the year 2017) of major ecoagricultural practices recorded from Rattota is explained below.

## Social Forestry Plantations (Taungya):

Establishing tree plantations with the participation of local people where local people are allowed to grow and harvest annual crops for a few years to match their contribution towards planting and tending of tree plantations. Forest department has created many such plantations in the area with the assistance of local communities. One such example was reported from the area through an initiative of the Renuka Group of Companies Ltd. The Viharagama Estate owned by the company has provided local farmers to establish *Tectona grandis* (Teak) and *Khaya senegalensis* (African mahogany) through a three-year contract agreement. Farmers were allowed to grow annual crops as intercrops for a period of three years. They have planted banana, ginger, passion fruit, papaya, pineapple, sesame and many vegetable crops as intercrops in these forest plantations.

## Sloping Agricultural Land Technology (SALT)

SALT otherwise known as contour hedgerow intercropping where tree or shrub species are planted along contour lines thus creating a living barrier that traps sediments and gradually transforms the sloping land to terraced land. Establishment of Gliricidia hedgerows was observed in some tea, rubber and coconut plantations growing in the Kabaragala, Banadrapola, Hapuwida, Kandenuwara, Muwandeniya, Yatawatta and Udatenna areas.

## Trees in Soil Conservation and Reclamation:

This is high density planting of trees and tree crops to control soil erosion and also to reclaim lands that were degraded due to annual cropping on steep slopes. These plantations are managed like natural forest. Thinning and pruning is not done and uncontrolled natural regeneration have made these plantations very thick and dense. Best use of such plantations for soil conservation were seen in Kabaragala, Midlands, Yatawatta, Kelebokka, Kandenuwara, Muwandeniya, Uda Hapuwida and Elkaduwa areas.

## Multilayer Tree Gardens, Multilayer Homegardens and Homegardens with Animals

Multilayered mixed tree gardens and multilayer (mixed) homegardens are one of the most dominant land uses in the area. Raring animals in the homegardens is rare. Small scale dairy cattle and chicken units were recorded in 5% of the homegardens in the area. Multilayered gardens especially homegardens were found planted with a wide range of tree and tree crop species used as timber, fruit, spices, beverage and multipurpose plants as shown below: *Artocarpus heterophyllus* (Jak), *Swietenia* *macrophylla* (Mahogany ), *Michelia champaca* (Gini-sapu), *Alstonia macrophylla* (Hawari nuga), *Melia dubia* (Lunumidella), *Tectona grandis* (teak), *Berrya cordifolia* (halmilla)**,** *Hevea brasiliensis* (Rubber), *Areca catechu* (Puwak), *Cocos nucifera* (Coconut), *Garcinia gummi-gutta* (Gorka), *Myristica fragrans* (Nutmeg), *Caryota urens* (kithul), *Garcinia mangostana* (Mangosteen), *Durio zibethinus* (durian), *Artocarpus incisus* (Del), *Terminalia catappa* (Kottamba), *Aegle marmelos* (beli), *Thespesia populnea* (Gansooriya), *Syzygium aromaticum* (Cloves), *Piper nigrum* (Pepper), *Coffea arabica* (Coffee), *Theobroma cacao* (Cocoa), *Elettaria* (Cardamom), *Curcuma longa* (Turmeric), *Zingiber officinale* (Ginger), *Gliricidia sepium* (Gliricidia) and *Paraserianthes falcataria* (Albizia).

## Plantation Crops

The study found that 72% tea, 23% rubber and 07% of coconut plantations were found established as single cash crop plantations. However, in case of tea as usual they were found integrated with shade trees namely, *Gliricidia sepium, Grevillea robusta* and *Paraserianthes falcataria*. Hence they can be classified as agroforestry. It is the same with rubber plantations, as they were under planted with the cover crop *Pueraria phaseoloides*. Only 7% coconut plantations were found growing as single crop (non-agroforestry) plantations.

## Plantation Crop Combinations

The study found that 28% tea, 77% rubber and 93% of coconut plantations were found intercropped with other perennial cash crops. This is a strategy adopted by the farmers to maximize the productivity and minimize the risk of price failure. The mixtures such as Rubber with cocoa, coffee, vanilla, ginger and turmeric; Coconut with Export Agricultural Crops, fruit trees, forest trees, tuber crops; Mixed gardens: Pepper, clove, nutmeg, forest trees, fruit trees, multipurpose trees, vegetables. The best development of this system was recorded from Revesten, Kabaragala, Yatawatta, Gammaduwa, Bandarapola, Polwattakanda, Muwandeniya, Viharagama, Midlands, Neluwakanda, Weragama, Rattota, Kelebokka and Kandenuwara West.

## Plantation Crops with Pastures and Animals

This system is very rare but reported from a few locations including Keula, Muwandeniya and Neluwakanda. e.g. In Kiula a farm with 45 cattle and 18 buffaloes were recorded. They are kept in a 35-acre coconut plantation under planted with pasture.

## Ecoagricultural Practices in the Landscape

The land use maps (Figure 1 and 2) clearly shows that tea, rubber, coconut, mixed homegardens / tree gardens, and rice paddy are the dominant agricultural land use in the area whereas forest, scrub forest and pathana grasslands forms the natural landuse. The North, North East and Eastern edges of the Rattota is bordered by the evergreen forest of the Knuckles Conservation area. A large proportion of the forest area (over 550ha) have been under planted with Cardamom which is an important cash crop for the local communities. Forest areas do not make a mosaic with agricultural land uses in Rattota. Further Pathana grasslands are found in the Western Part and scrublands (Secondary forests and Savanah type vegetation) in the Northern and South Western parts of Rattota.

## Landuse Changes (2001-2017) and Ecoagricultural Practices

The study clearly shows that Rattota landscape is dominated by the ecoagriculture practices. Considering the characteristics, Tea, Rubber, Coconut, Forest, Scrub forest and Multilayer homesteads / gardens can be classified as ecoagriculture or agroforestry practices. Their proportion in Rattota according to landuse maps of 2001 and 2017 (Fig. 1 and 2) are 82.7% and 87%, respectively. Land use changes during 2001-2017 period is summarized in the Table 2. The major change is with the extents of three main plantation crops especially tea. Further there is a major increase in the extent of homegarden / tree garden category. Tea, rubber and coconut growing areas have reduced at least by 62%, 62% and 38%, respectively, during the period. Proportionately new planting areas related to these crops have to be added to the above figures to get the exact reduction in growing areas. 217% increase in homegarden / tree gardens and 313% increase in scrub forest are the biggest changes in the landuse. This can be attributed to use of abandoned tea plantations for village expansion (i.e. setting up homestead gardens) and abandoned tea plantations developing into scrub forests. Rice growing area has reduced by 19%, which is a common phenomenon observed in most parts of the country.

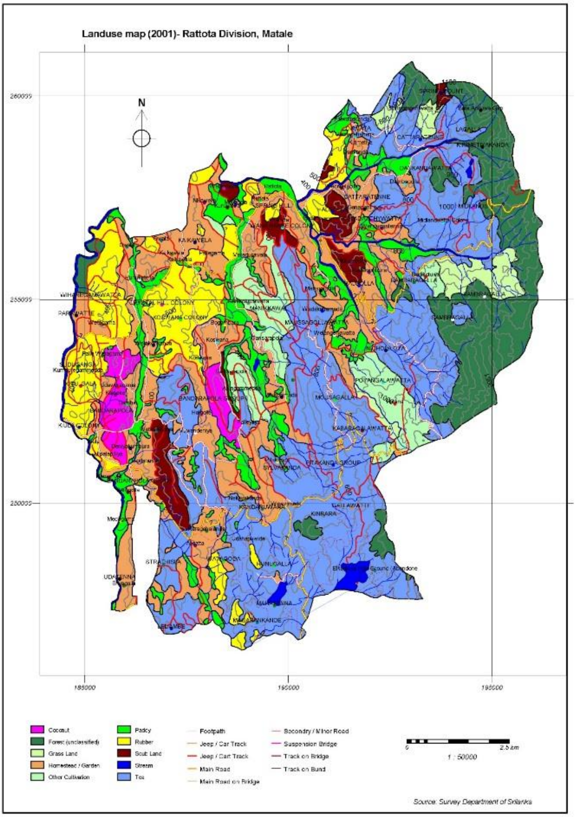

Fig. 1. Land use map: Rattota Divisional Secretary’s Division for the year 2001.

(Source: Survey Department of Sri Lanka)

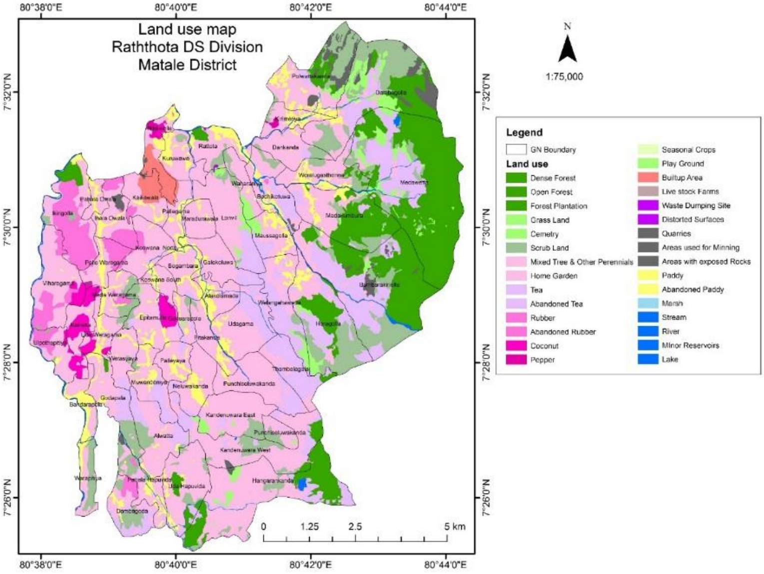

Fig. 2. Land use: Rattota Divisional Secretary's Division for the year 2017 (Source: Land Use Policy Planning Department, Ministry of Lands and Mahaweli Development, Sri Lanka).

Table 2. Land use changes in the Rattota Divisional Secretary's Division during 2001-2017 period.

| **Landuse category** | **2001** | | **2017** | |
|---|---|---|---|---|
| | **Extent (ha)** | **Percentage (%)** | **Extent (ha)** | **Percentage (%)** |
| **Tea** | 3,744 | 35.6 | 1410 | 13.4 |
| **Rubber** | 1,030 | 9.8 | 391 | 3.7 |
| **Coconut** | 245 | 2.3 | 151 | 1.4 |
| **Forest (unclassified)** | 1,211 | 11.5 | 1508 | 14.3 |
| **Scrub forest** | 339 | 3.2 | 1062 | 10.1 |
| *Pathana* grasslands | 258 | 2.4 | 260 | 2.5 |
| Multilayer homesteads & Multilayer tree gardens | 2,139 | 20.3 | 4641 | 44.1[1] |
| Other Cultivations | 594 | 5.7 | 2 | - |
| Paddy | 870 | 8.3 | 705 | 6.7 |
| Stream | 85 | 0.8 | 88 | 0.8 |
| Tank Boundaries | 7 | 0.1 | 6 | 0.1 |
| Water hole Boundary | 1 | - | - | - |
| Other (Built up areas, rocky outcrops) | - | - | 300 | 2.9 |
| **Total** | **10,523** | **100** | **10524** | **100** |

**Key**: Ecoagricultural practices are identified by the bold etters;

[1] Multilayer homesteads, other homesteads & Multilayer tree gardens.

## Applying Ecoagriculture Approach

The study identified the trend in the landuse changes taking place in the Rattota. Most probably this trend will continue and homegardens will continue to dominate the landuse. The homegarden system can provide wide range ecosystem services provided that their structural diversity and complexity is unharmed during these changes (Hitinayake and Ekanayake, 2000; Mohri *et al,* 2013). Hence it is important to be conscious about these changes and take possible actions to sustain the ecosystem services. In this regard strategies and actions must be identified to address the three pillars of ecoagriculture, conserving biodiversity, enhancing agricultural production and improving livelihoods.

However, mainstreaming of ecoagriculture approaches will be crucially dependent upon mobilizing local communities to become leaders in ecoagriculture or ecosystem partners. Their knowledge, traditions, land use practices, and resource-management institutions are essential to the development of viable ecoagriculture systems for their landscapes. In this regard the following land management suggestions can be made to improve the situation at Rattota:

- Plan and manage protected areas with the participation of local people: Provide alternative income generating opportunities for communities who depend on Knuckles and *Hunnasgiriya* conservation areas, develop community forestry with local communities living adjacent to Knuckles and *Hunnasgiriya* conservation areas.
- Use of community-conserved areas on lands owned by farmers can be used for ecosystem-wide management of biodiversity e.g. Conserving riparian forests, gallery forests in rice fields and *wanatha* areas near rice fields.
- Link unfarmed areas, forest fragments, and wetlands within agricultural landscapes to develop habitat networks and corridors that support and expand the range of wild species. This approach is particularly useful to migratory species, which can include pollinators and natural enemies of agricultural pests.
- Reduce the conversion of natural areas to agricultural areas by improving the productivity of currently utilized agricultural, forestry and grazing lands. e.g. Improving productivity and sustainability of uplands by promoting regenerative agricultural technologies and providing secure land tenure.
- Modify farming systems so they mimic natural vegetation and ecological processes. Integrating trees, shrubs, and grasses into

agricultural production systems to improve ecosystem services across the whole landscape (i.e. Promoting agroforestry practices).

- Use of non-chemical approaches in farming activities e.g. Promoting organic crop production with tea and other plantation crops (i.e. Moving from “input-intensive” to ‘knowledge-intensive’ agricultural practices).
- Encourage soil, water, and vegetation management strategies that limit negative impacts on surrounding ecosystems.

The implementation of above actions requires institutionalizing this approach. As a starting point creating awareness among the relevant stakeholder is necessary to make them understand, appreciate and take it up as a policy.

## Conclusions

In addition to landuse changes, abandoning cultivations and neglect of land management were seen all across Rattota. The push and pull factors for the above scenario was identified. In case of many people farming is no more the main livelihood activity. It is has become a supplementary source income for many people. Availability of other employment opportunities (Pull factor), poor social status attributed to farming (Push factor) and low profits from farming (Push factor) were the main underlying causes. Urbanization and increase of population density causing land fragmentation and use of agricultural land for establishing homesteads were also seen (Push factors) across the study area. Wild animal damage also was identified as an issue causing low agricultural productivity and pushing people to other employment.

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# CHAPTER 05

# Genetic Improvement of Crops for Agricultural Sustainability

**S.A.C.N. Perera***

*Department of Agricultural Biology, Faculty of Agriculture, University of Peradeniya, Peradeniya, 20400. Sri Lanka*

## Abstract

Crop production worldwide is challenged with biotic and abiotic stresses which are aggravated due to global climate change. Despite the challenges on production and productivity the demand for food is more than ever to feed the nine billion human population estimated to inhabit the planet earth in a few decades. While the demand for food is increasing the challenges for agricultural sustainability also is rising aggravating the problem. During the last century, the improvement in agricultural production has been mainly due to increase in the area cultivated, increased use of inputs and genetic improvement of plants for yield through classical approaches. However, the increase of cultivated area and agricultural inputs are no longer practical and would not relate to sustainability of agriculture. Genetic improvement of plants for resistance/tolerance to biotic and abiotic stresses is one of the most viable and sustainable options for increasing the crop production. In this context, the conventional 'genetics' approaches should be coupled with the modern 'genomics' approaches for the breeding programs to be more efficient and more targeted. This chapter focuses on the present status and the future of plant breeding research in satisfying the increasing demand for food while maintaining agricultural sustainability.

**Keywords:** Biotic and abiotic stresses, climate change, genomics, precision breeding

***chandrikaperera2003@yahoo.com**

## Introduction

Before the dawn of agriculture, hunger was appeased by the hunter–gatherer system and it supported a global population of about 4 million (Cohen, 1995). Modern agriculture now feeds nearly 7,000 million people and to accommodate this the world cereal production has doubled in the past 40 years. This increase in the yields has mainly resulted from greater inputs of fertilizer, water, pesticides, new crop cultivars and the technological advances (Tilman *et al*., 2001; Briggs, 1998). The human population on planet earth is predicted to increase from the current 7 billion to 9 billion by 2050. To meet the demand for food the world agricultural production is needed to increase by 50% by 2030 (Royal Society 2009). However, the extent of arable land is limited and much of the land extent is lost to agriculture due to urbanization, salinization, desertification, and environmental degradation etc (Waggoner, 1995). Therefore, the increase of agricultural production in future should be via the increase of productivity by breeding crop plants coupled with improved agronomic practices. Advances in plant genetics delivered the new knowledge and the technologies required for the genetic improvement of crops for desirable traits. Plant genetics still remains to be a key component of global food security and millions of lives do and will depend on the crop genetic improvement for the supply of quality food in adequate quantities amidst the crises of reduced resources for agriculture. The fundamental technologies of plant genetic improvement are thus expected to play a crucial role in meeting the ever increasing demands for global food security. Under such situations, however, the use of traditional plant breeding methods alone may not be sufficient to produce enough staple food grains to the growing world population (Barret, 2010; Green *et al*., 2005, Ronald, 2014) especially in the context of global climate change (Godfray *et al*., 2010). This means that the conventional plant breeding practices may not able to achieve the sustainability in today’s agriculture. The answer would lie in coupling the conventional ‘genetics’ approaches of crop improvement with the advanced ‘genomics’ approaches where the linkage of genes to specific traits will lead to more efficient and more targeted crop breeding programmes.

Chapter 5

# Brief History of Crop Production and Plant Breeding

Plant breeding, initiating from its basic principle of selection, started 10,000 years ago along with the beginning of agriculture. The changing or 'improving' of the genetic make-up of plants was first through the primitive domestication and for about the last 3 centuries using more sophisticated or scientific approaches.

There has been a significant improvement in production and productivity of important cereal crops globally as a consequence of basically, the "Green Revolution" and other initiatives (The Royal Society, 2009). Production of hybrids has been one of the most important introductions in increasing the food production in the 20th century. Hybrids inherit desirable and agriculturally useful traits, such as high yield, disease resistance, and environmental stress tolerance, from two genetically distinct parents. The first hybrid seeds were commercialized in 1920s, and there has been a very high demand for hybrid seeds ever since due to their superior characters. However, the seeds from hybrid plants, although can be planted, the resultant progeny will not have the same combination of beneficial traits as their hybrid parents due to segregation. Therefore, only those farmers who could afford hybrid seeds each season were benefitted, while the others had to depend on other seed sources which were most often inferior to hybrid seeds at least in terms of yield.

In addition to hybrid breeding the conventional approaches of crop improvement included mutagenesis, either by chemicals or radiation, and Inter-breeding of related species. Citrus varieties, such as orange, lemon, lime, and grapefruit are some examples for crops improved through interspecific hybridization. The use of wild species as donors of agronomically important traits has also been important to the success of conventional breeding approaches (Mc Couch *et al.*, 2013). Currently, almost all our food is produced from seeds that have been genetically altered in one way or another using these well-established approaches of genetic improvement.

Chapter 5

# Factors Challenging Food Security and Modern Day Plant Breeding

A broad range of improvements in the chain of food supply will be needed to fulfil the food and nutritional requirement of the growing world population. In addition to the growing demand, the agricultural production is hindered by several factors causing reduction in crop yields (Lobell *et al.,* 2008). The crop production is affected by a severe deficit in water resulting in drought (Vorosmarty *et al.*, 2000) (Fig. 1) and the increased food production must take place on the limited land area available while using less water. The most recent challenges for agricultural production are mainly due to the predicted effects of climate change (Lobell *et al*., 2008). With the rise of sea levels and the melting of glaciers, low lying croplands will be submerged increasing the incidences of flooding. The temperature is another crucial factor as it imposes heat stress on plants and lead to drought stress as well resulting in a drastic reduction in yields of most of the important food, feed, and fiber crops (Schlenker *et al.*, 2009).

Fig 1: The effects of drought on a perennial crop: coconut

In addition to the abiotic or environmental stresses the incidence of biotic stresses and the resulting crop losses are also expected to increase. Even today, there is about 30-60% yield reduction due to such biotic and abiotic stresses and if the status quo prevails this proportion will be even higher (Gustavsson *et al,* 2011). Most of the biotic and abiotic stresses are imposed on the crops when the plants are fully grown at a stage where most or all of the land and water required to grow a crop has been invested (Dhlamini *et al*., 2005). Therefore, breeding crops only for higher yield will no longer be a solution for food security in future. The plant breeding goals should thus heavily focus on improving the crop plants which are adaptable, tolerant or resistant to increasing temperatures, decreased water availability, flooding, increased salinity and the evolving and newly emerging pathogen and insect threats. As such it will be essential to develop a new generation of agricultural crops possessing the genetic capacity to survive and produce yields amidst the biotic and abiotic stresses which are expected to be integral component of agricultural systems in future (Somerville and Briscoe, 2001).

## Plant Breeding for Sustainable Agriculture

The genetically improved cultivars, bred using the genetic principles is only part of the solution for the demand of food. Such improved cultivars must be integrated into ecology based farming systems where their performances should be in parallel with the environmental, economic, and social factors for agriculture to be sustainable. Sustainable agriculture, basically refers to efficient agricultural production while maintaining the environment, farm profitability and prosperity of farming communities. Accordingly, the goal of agricultural sciences would be to increase crop productivity while maintaining the environment (Briggs, 1998) and therefore the growing concern for food security is necessarily linked with the sustainability of agriculture (Godfray *et al*., 2010).

Sustainable agriculture is a major component in sustainable development and it is essential to the future well-being of the human and the planet earth. Sustainable agriculture is a system of agricultural production that will satisfy human food, feed and fibre needs, while enhancing the environmental quality and the natural resources used in agriculture (Bharadwaj, 2016). It is further associated with efficient utilization of technologies available, the integration of natural biological cycles, sustaining the economic viability of farm operations and enhancing the quality of life for farmers and society as a whole. Accordingly, there are various components of sustainable agriculture, which include technological interventions and environmental and socio-economic factors.

One misconception associated with sustainable agriculture is the belief of a necessity for going back to past techniques/farm practices which were originally used by our ancestors. Such wisdom from the past will essentially benefit the sustainable agriculture, but they should be combined with the judicious use of current technology, including the vast array of information technologies now available. Today, the world has reached a situation where the traditional methods of crop improvement alone will not be sufficient to provide adequate amounts of the required quality staple food to the constantly growing world population (Green *et al*., 2005). In order to ensure sustainability in agriculture, it is important to adopt innovative technologies which can increase the efficiency of selection with greater precision in plant breeding (Tester and Langridge, 2010). The recently developed novel molecular approaches including modern genomics and genetic engineering technologies have emerged as very useful tools to assure rapid and precise selection for economically important crop traits of interest.

## Novel Approaches for Increased Crop Production

In the view of the global food shortage and the concerns of sustainability of agricultural produce, the advances in plant genetics and genomics research have opened a new era in plant breeding. This involves more precise linkage of genes to specific traits leading to efficient and predictable breeding programmes. It is now evident that genomics will be an integral part of the plant breeding programmes in future for improving crop productivity for food security and the sustainability of agricultural systems.

## Genetics and Genomics

The early day plant breeding theories were based on the theory of genetics which investigated the identification and transmission of one or only a few genes at a time. Today with the novel approaches of genomics, the whole genome can be scanned in a single experiment to search for desirable genes and alleles of crops. Plant genomics has emerged as a rapidly developing field, which is radically improving the understanding of plant biology by making available novel tools for the improvement of plant properties relevant to sustainable agricultural production. Recent advances in high throughput genomics technologies including the next generation sequencing and high throughput genotyping have helped the understanding of the functions and regulation of genes in crop plants (Varshney *et al*., 2009). Plant genomics technologies have thus become immensely useful in today's agriculture for better understanding of how plants function, and how they respond to the environment. This understanding is vital for achieving the set objectives of breeding programs to improve the performance and productivity of crops.

Such recent advances in molecular biology coupled with bioinformatics offer significant opportunities for improving the success of classical plant breeding approaches. The use of such tools in crop improvement will enable the genetic analysis of a high numbers of crosses precisely and simultaneously at the early seedling stage. This approach is known as 'genomics-assisted breeding' and through this approach, both the phenotype and the genotype of new varieties can be analyzed thereby facilitating the predication of the performance of new specific introgressed traits. Successful utilization of genomics-assisted breeding approach in a crop requires certain pre-requisites such as a set of high throughput informative molecular markers and genetic maps etc. (Pawan *et al*., 2011). The genomics is necessarily associated with phenomics, i.e. high throughput and accurate phenotyping platforms for developing marker trait associations. Genomics associated with high throughput phenotyping has facilitated 'precision breeding' in comparison to 'chance breeding' which was the result of conventional breeding approaches. The objectives of integrating such molecular technologies in classical breeding should be to create genotype-to-phenotype trait knowledge and to use this knowledge in product development for the benefit of the resource poor farmer and thus both the conventional or classical breeding should be coupled with the novel molecular breeding technologies in assuring food security and achieving sustainability in agriculture.

## Molecular Markers and Genome Sequencing

The ever-increasing availability of genome sequences in crop plants have facilitated the development of genomic resources that will allow understanding the important biological functions and basic processes relevant to crop production leading to sustainable agriculture. The DNA based molecular markers have facilitated more efficient and more targeted crop breeding by enabling the selection for desired traits at an early growth stage without the need for waiting until the specific characters are expressed. This also has led to a reduction in the extensive field selection.

In addition to early selection, the molecular DNA markers can be effectively used for the conservation and characterization of crop genetic resources leading to effective use of them in plant breeding avoiding the random crossing of gene pool resources. There is a wide array of molecular markers, such as Restriction Fragment Length Polymorphism (RFLP), Randomly Amplified Polymorphic DNA (RAPD), Microsatellite or Simple Sequence Repeats (SSR), Amplified Fragment Length Polymorphism (AFLP), Single Nucleotide Polymorphism (SNP) and Diversity Array markers which have been developed in most of the important crop species. Out of them SSR and SNP markers have been chosen in many programmes (Gupta and Varshney, 2000) due to the feasibility of them with the advent and the improvement of sequencing technologies and the feasibility for operation in high-throughput genotyping platforms. Research of major cereal crops especially rice, maize, wheat, barley are being highly benefitted with the availability of genomic resources and the genome sequences have already become available for several crop species including rice, sorghum and maize. Recent investments coupled with advances in genomics technologies have contributed towards developing a good resource of genomic tools in legumes as well (Patterson *et al*., 2009) and with the later improvement in sequencing technologies the whole genome sequencing of individuals have become a much easier and a faster task.

## Some Modern Breeding Approaches

The availability of genomic resources should be matched with the information on pedigrees and high throughput precise phenotyping to facilitate the genomics-assisted crop improvement (Varshney *et al*., 2005). Some examples for such integrated approaches used in the crop breeding are, Marker-Assisted Selection (MAS), Advanced-Backcross QTL analysis, Marker-Assisted Recurrent Selection and Genomic Selection which are being used in several important crops, mainly cereals (Philips, 2010).

### ***Marker-assisted Selection (MAS)***

MAS involves three major steps, namely, identification of molecular marker(s) associated with trait(s) of interest, validation of identified marker(s) in the genetic background of the targeted genotypes to be improved and marker-assisted backcrossing to transfer the QTL/gene from the donor genotype into the targeted genotype (Pawan *et al*., 2011). Linkage mapping approaches have been extensively used to develop genome maps of important crop species including cereals, legumes and horticultural crops, to develop marker-trait associations (Pawan *et al*, 2011). Although much effort has been invested on genome mapping only a very few studies have led to further validation of the maps for marker assisted breeding. The identification of only a few genes having small-effect on the phenotype, non-validation of markers in elite genotypes and slow adoption of molecular markers by practical field plant breeders are the most possible reasons for this slow rate of adoption of genetic linkage maps in practical plant breeding. The more recent discovery, association mapping concept which is based on linkage disequilibrium is expected yield more precise information and more opportunities for MAS to be a practical reality.

Association mapping is an alternative strategy to linkage mapping to identify marker-trait associations. Association mapping differs from linkage mapping due to the feasibility of using natural populations for gene identification in contrast to the need of having especially developed structured segregating populations for linkage mapping. Association mapping studies have been extensively used in humans and animals because the development of structured populations is not feasible in them. Association mapping is advantageous compared to linkage mapping due to increased map resolution (Gupta *et al*., 2005). Association mapping involves the study of natural populations rather than the offspring of crosses, and associations in natural populations are generally more precise due to the involvement of many historical recombination events (Buckler *et al*, 2007). Over the years a reduction of costs involved in genotyping has been observed and hence more projects on association mapping is expected for MAS in future.

The identification of genes by linkage mapping or association mapping should follow the marker assisted backcross breeding to incorporate the important genes into elite genetic stocks. MAS can be effectively utilized even for traits with low heritability, for gene pyramiding and the selection can be made at seedling stage. The most important advantage of MAS is the lack of issues related to transgenic crops. Use of molecular markers and MAS is common in breeding programs in the private sector in the developed countries such as USA, Europe and Australia in crops such as barley, wheat, rice, maize, soybean etc. In these attempts MAS has been successfully utilized to develop superior lines/ varieties/ hybrids for improved quality, resistance to diseases and tolerance to abiotic stresses (Gupta and Varshney, 2000). Introgression of the FR13A Sub1 locus conferring resistance against submergence upto two weeks, into an Asian rice cultivar, Swarna (Xu *et al*., 2006) is a success story of MAS in South Asia.

### *Advanced-backcross QTL (AB-QTL) Analysis*

Despite been quite successful, plant breeders have observed certain limitations in MAS especially associated with linkage drag. In the genetic improvement of crop species via MAS, the identification of the QTL/gene and the development of improved cultivars are two separate processes. This hinders the application and the use of the genetic potential of the wild or untapped crop germplasm in breeding programs. As a solution to this problem, Tanksley and Nelson (1996) introduced the Advanced Backcross QTL (AB-QTL) analysis. AB QTL analysis facilitates the simultaneous detection of QTL and its transfer from the wild species to an elite cultivar for improvement of a trait. This is achieved by crossing the superior cultivar with a wild species to develop a backcross population and the use of molecular markers to monitor the transfer of QTLs in advanced backcross generations. This advanced backcross method has been successfully demonstrated and applied in various crops including tomato, rice, barley and wheat (Pawan *et al*., 2011).

### *Marker-assisted Recurrent Selection (MARS)*

A majority of economically important traits of crop plants are governed by many QTLs with minor individual effects. Such minor QTLs show spatial and temporal inconsistencies in their phenotypic expression. Incorporation of such QTL into desired genotypes is practically very difficult due to the need for larger numbers of progenies to select appropriate lines possessing the minor QTL. Marker-assisted recurrent selection is useful in such situations for pyramiding of superior alleles at different loci/QTLs in a single genotype. MARS has been successfully applied in the breeding of sweet corn, soybean (Ribaut *et al*., 2010), chick pea and cowpea *etc*. mainly to pyramid favourable alleles against the abiotic stress, drought.

### *Genome-wide or Genomic Selection (GS)*

Genomic Selection is another useful approach to pyramid favourable alleles with minor QTL effects at the whole genome (Meuwissen, 2001). Genomic selection uses high-density marker scores and calculates the marker effects across the entire genome, explaining the entire phenotypic variation of lines. Genome-wide selection refers to marker based selection but without significance testing and without identifying a subset of markers which are associated with the trait. The genome wide data of the progeny lines at marker loci (haplotypes) are used to calculate genomic estimated breeding values as the sum of the effects of all QTLs across the genome. Genomic selection thus exploits the entirety of genetic variance available for a trait and is calculated for each individual in the progeny based on genotyping data of a population having both phenotyping and genotyping data. Therefore, one major advantage of genomic selection is the possibility for selection of an individual lacking phenotypic data by the use of a model to predict the breeding value (Meuwissen, 2001).

## Challenges for the Adoption of Genomic Technologies

Sustainable agriculture is the key for the simultaneous catering to the food needs of the increasing population while maintaining and conserving the agricultural ecosystems. However, there are barriers for adopting novel technology mainly resulting from misconceptions of the technologies. In addition to the predicted ill-effects of climate change, many of the present day agricultural systems are responsible for the release of hazardous agrochemicals into the environment.

The promising biotechnology tools, mainly the transgenic approaches which were recently introduced do offer certain solutions to some of the agriculture related environmental issues. However, there is strict oppositions on the adoption of such technologies especially in the developing countries preventing the development and cultivation of such crops. Yet, the current methods of food production, in developing countries and also in the developed countries, are not sufficient or sustainable (Charlafti, 2003) to feed the global community while protecting the agricultural ecosystems.

Although the success of the genomic tools in genetically improving the crops of interest have been adequately demonstrated, the use of the genomic information that has already being generated is at a low level (Ribaut *et al.,* 2010). Possible reasons for this may be the shortage of expertise, lack of facilities for high throughput genotyping, the lack of phenotyping infrastructure, inadequate facilities for bioinformatics systems and above all the lack of experience in integrating these new technologies with traditional breeding (Ribaut *et al*., 2010).

## Conclusion and Future Perspectives

Integration of modern genomics in combination with the traditional breeding methodologies is believed to be the key in addressing the need for food supply and solving the global issues related to sustainable agriculture. Under such circumstances, the above mentioned genomic approaches will play a major role in predicting the phenotype, with higher precision and efficiency, based on the genotype. The genomics interventions may be inadequate to solve all the problems related to agricultural production, but they possess the potential to be integrated with the current or the conventional approaches to improve crop breeding programmes. They would help overcome the hesitation of the early conventional plant breeders to utilize the wild germplasm in commercial breeding mainly because of the long time period taken to recover the desired phenotype from the initial cross. Now that the sequencing technologies have become low cost and high throughput they will be the key for utilization and improving crop genetic resources for sustainable agriculture. By such approaches it will be possible to associate the genome variation with the phenotype facilitating the development of the ideotype based on the haplotype of the crop species concerned. The judicious use of science-and-need based technologies will facilitate the exploitation of genetic resources in order to breed for desirable crop plants for the food security for global population and ensure the sustainability of the agricultural landscapes.

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# CHAPTER 06

# Conserving Biodiversity in Agricultural Landscapes: A perspective on Sri Lanka

**M.R. Wijesinghe***

*Department of Zoology and Environment Sciences, University of Colombo, Sri Lanka.*

## Abstract

Agricultural development, worldwide, is a major cause for the loss of natural forest and, consequently, of the planet's biodiversity. In Sri Lanka, a globally recognized biodiversity hotspot, what amounts to over half of its natural forest cover was lost during the last century, and this was largely due to agricultural expansion (including raising commercial crops). Hence agricultural expansion is generally seen to be in conflict with conserving biodiversity. On the other hand, the benefits to agriculture from natural forests through their role in providing ecosystem services should be recognized – pollination, pest control, nutrient cycling, soil enrichment, water conservation. Moreover, the natural forest is a store house of genetic material that would in the future prove to be extremely valuable in the fields of agriculture and medicine. In this context, agriculture and food production and maintaining its link to conservation of biodiversity call for approaches in which agricultural systems are designed and managed giving due consideration to the conservation of biodiversity. In Sri Lanka there are several measures that could be adopted. Establishing "habitat corridors" across agricultural landscapes is important for maintaining habitat connectivity between isolated forests; this is particularly important in Sri Lanka where much of the natural forest in many parts of the country has been broken up into separate patches. The paper also goes on to describe a range of practices that can be adopted within agricultural landscapes for promoting biodiversity conservation.

**Keywords:** Biodiversity, sustainable agriculture, Sri Lanka

*mayuri@sci.cmb.ac.lk

## Sri Lanka’s Biotic Wealth

Sri Lanka, with a total extent of 65 610 km$^2$, is a tropical island endowed with rich biodiversity. Speciation has been driven by the island’s climatic and topographic heterogeneity, resulting in the creation of a mosaic of landscapes dominated by forest ecosystems supporting a wealth of biodiversity. Much of Sri Lanka’s biodiversity is concentrated in the wet humid forests in the south-western part of the island, covering approximately 1/5 of its land area. A high proportion of the species are endemic. Sri Lanka harbours 3771 flowering plants of which 28 % are endemic. Among the 930 vertebrate species 30 % are endemic to the island (Gunatilleke *et al.*, 2017). Although small in extent, the island has the highest species density for many taxonomic groups in the Asian region (NARESA 1991). The country’s biodiversity is thus significantly important both on a regional and global scale. The high demand for land for settlement, industry and agriculture has caused forest loss and fragmentation, exerting immense pressure on the country’s biodiversity. In recognition of its exceptionally high levels of biodiversity and endemism that also face exceptional levels of threat, Sri Lanka, together with the Western Ghats of India, has been named as one of 25 globally recognized biodiversity hotspots (Cincotta *et al.*, 2000). Myers *et al.* (2000) and Brooks *et al.* (2002) reiterate that wise conservation investments in these eco-regions are critically needed for minimizing future extinctions.

## Agricultural Expansion: A Contributor to Forest Habitat Depletion

Deforestation is the conversion of forests to other forms of land use (Allen and Barnes, 1985), while forest degradation is a process leading to a temporary or permanent deterioration of the quality of the forest (Grainger, 1993). Forest degradation does not necessarily result in a reduction of the forest area, but, rather, leads to quality decline in the forests so affected (Lanly, 2003). Forest fragmentation is where, owing to deforestation, a large contiguous forest is broken down into a number of patches (Fahrig, 2003). Often these processes have detrimental effects on biodiversity.

Sri Lanka’s forest cover was estimated at 70 % of its total area at the commencement of the 20th century, and it has since plummeted to 29.7 % (Forest Department, 2009). The loss of forest cover was largely due to the opening up of land for agriculture (including raising plantation crops) and for village and urban expansion. With about 35 % of the total area of the country being under cultivation, agriculture is one of the dominant forms of land use in Sri Lanka (Forest Department, 2009). Differences are seen across the country. In the wet and intermediate climatic zones in southwest Sri Lanka, from the lowlands to highland areas, forests have been cleared for the establishment of large-scale commercial plantations – earlier for coffee and subsequently for tea, and for rubber and coconut (Mattsson *et al.*, 2012). Also, small-holder plantation agriculture, accelerated by illegal encroachers extending their cultivations into bordering forests, continues to create a constant pressure on the few existing forests. In the dry zone, since ancient times, forests were cleared for cultivating paddy (rice) or using the land for growing a variety of other food crops in a system called shifting cultivation. Furthermore, in recent times, colonization schemes and large-scale irrigation development projects have led to widespread deforestation.

## Transition from Ancient Agroecosystems to Present Day Agriculture

*Chena* cultivation (i.e. slash and burn agriculture or shifting cultivation) is one of the earliest forms of agriculture practiced in Sri Lanka for the sustenance of the people – the forest is cleared in the dry season and the cuttings and other debris burnt, and with the onset of rains the land, called a *chena*, is sown with food crops. After harvesting, the land is left fallow until the next planting season. With the decline in the fertility of the *chena*, a fresh plot of forest is opened up, hence the term shifting cultivation. In ancient times the *chena* plot was only lightly cleared, and after the food crop was harvested re-growth of the forest trees was prolific (Abeywickrama, 1970). This ancient form of agriculture persisted until recent times. Besides *chena* cultivation, in ancient times, a semi-permanent and, by modern standards, what may even be described as an ecologically sustainable system of land use was practiced in Sri Lanka in conjunction with village irrigation tanks that were constructed throughout the dry zone. Here a village irrigation tank supported agriculture, animal husbandry, and human settlements, while on higher ground, in what would be a micro-catchment, the forest was left intact. A village tank, an animal husbandry unit, crop cultivation, a human settlement, and the forest, all intricately linked and working harmoniously, brought about a multitude of benefits. Crop refuse was used to feed the cattle, while dung enriched the plantations; the tank provided water for the crops and for the people's needs, while rural communities also consumed fish; buffaloes ploughed the crop fields and rested in the forests during the heat of the day enriching the soil with dung; and forests harboured natural enemies which kept the pest populations in crop fields at bay. Environmental sustainability was achieved in this manner.

With expansion of the human population more land was opened up for extensive and intensive agriculture, and the sustainable agro-ecosystems that had been developed fell apart – large extents of forest were cleared for cultivation, irrigation and settlements, and crop cycles became shorter with reduced fallow periods. Intensification of agriculture led to the use of synthetic fertilizers in place of organic manure, and the role of natural enemies was taken by synthetic pesticides. These actions led to a large scale loss of biodiversity-rich habitats. Globally, agricultural expansion and intensification has been identified as being among the leading causes of habitat and species loss (Scherr and McNeely, 2008).

## Links Between Agriculture and Biodiversity Conservation

Recognizing that many biological species are facing an imminent threat of extinction and that there is a pressing need to conserve the planet's biodiversity, the United Nations adopted the Convention on Biological Diversity at the Earth Summit on Environment and Development held in Brazil in 1992. The convention stresses on the "intrinsic value of biological diversity and on the ecological, genetic, social, economic, scientific, educational, cultural, recreational and aesthetic values of biological diversity and its components", and emphasizes "the importance of biological diversity for evolution and for maintaining life sustaining systems of the biosphere". Nearly all countries of the world, endorsing the urgent need for action to protect the Earth's biodiversity, have now ratified the convention.

Links between agriculture and biodiversity are indisputable. It is from the world's storehouse of biodiversity that mankind has selected the plant and animal species that serve as the source of food. A range of plant species are cultivated as food crops in Sri Lanka (Gunatilleke *et al.*, 2017). Although the species that provide the bulk of mankind's food are few in number, there are myriad other species that serve mankind in many ways such as providing supplementary food items, medicinal products, and a whole range of household products. The beneficiaries are mainly the rural people in agricultural landscapes. Biodiversity also plays an important role in the provision of ecosystem services, including those that are essential for sustainable agricultural production. Many ecological functions and processes important for improving agricultural productivity such as pollination, pest control, nutrient cycling, soil enrichment and water conservation are facilitated by native biotic communities. Such benefits, in the long-term, decrease the demand for external and often hazardous inputs, and increase the resilience and adaptive capacity of agricultural production systems facing locally occurring disturbances and climate change. It should also be noted that genetic improvement of agricultural species often relies on input of genetic material from wild species in natural ecosystems.

## Managing Agricultural Landscapes to Sustain Biodiversity

In recent decades, trends in agricultural expansion and intensification have had negative impacts on biodiversity while adversely affecting the agricultural systems. In the global context, Tilman *et al*. (2001) predicted that feeding a population of 9 billion using current methods could result in converting another one billion hectares of natural habitat to agricultural production, and this would be primarily in the developing world, and that concurrently there could be up to a tripling of nitrogen and phosphorous inputs and a threefold increase in pesticide use. Against this backdrop, there arises the need to explore as to how agro-ecosystems could be designed and managed so as to circumvent adverse impacts on biodiversity whilst deriving benefits from its conservation.

Agriculture and food production and maintaining its links to conservation of biodiversity call for approaches in which agricultural systems are designed and managed giving due consideration to the conservation of naturally occurring genetic resources, species and ecosystems. To make agricultural landscapes more congenial for biotic conservation, while also deriving benefits for agriculture, one needs to understand the limitations that agricultural systems impose on naturally occurring plant and animal populations.

As a result of deforestation for agricultural development, village expansion, opening of colonization schemes and many other development activities, much of what remains of Sri Lanka’s natural forests now comprises several isolated forest fragments. The breaking up of large contiguous forests into small fragments leads to the isolation of populations hampering many of the natural processes that occur within a forest. One of the results is reduced rates of dispersal between adjacent patches which in turn affects gene flow and leads to inbreeding depression and lowering of genetic diversity within the remnant populations. Small populations have been shown to suffer increased susceptibility to diseases and decreased fitness (Markert *et al.* 2010). To ensure long term survival, populations must be kept above the critical threshold i.e. minimum viable population (MVP) size (Reed *et al.,* 2003).

One of the ways of addressing the problem of isolation of forest fragments is to establish habitat connectivity between isolated forests by establishing what are referred to as ‘habitat corridors’ (see Fig. 1). Such corridors would facilitate the movement of fauna from one forest patch to another so increasing the effective population size. These corridors could be established within agricultural landscapes. A few pilot projects have been undertaken in Sri Lanka to establish such corridors in tea plantations. Despite the challenges posed by habitat corridors by sometimes functioning as ecological traps (Robertson and Hutto, 2006), they provide the best avenue for wildlife movement. Habitat corridors are particularly essential for species with a meta population structure (Opdam 1991) and for predator species. Human-leopard encounters are increasingly reported from the highland areas of Sri Lanka where forested areas have been cleared for tea plantations and village expansion. Cattle, poultry and domestic pets are easy targets of the leopards that are trapped within small patches of remnant forests. Also, when the forest cover is reduced, there is increased human accessibility thereby resulting in illegal hunting of the leopards. Under these circumstances, one of the most important means of survival for such apex predators outside protected areas would be to establish suitable habitat corridors which are broad and densely vegetated (Morrison and Boyce 2009; Kittle *et al.,* 2014). Habitat corridors providing an underpass across highway routes have been set up in the USA (Gagnon *et al.*, 2011), but such corridors may not be feasible for extensive agricultural landscapes in Sri Lanka.

Fig. 1. Aerial photograph of habitat corridors in USA. (Source: Conservation Corridor Planning at the Landscape Level Handbook, USDA / NRCS 2004).

Besides facilitating animal movement, habitat corridors, which provide ecosystem continuity between isolated areas of natural forest within vast agricultural landscapes, would serve as refuge sites particularly for indigenous herbaceous plant species, small mammals, herpetofauna and invertebrates. Apart from habitat corridors, in an agricultural setting, if patches of land are left uncultivated and in a natural or semi-natural state, they would function as stepping stones for species as they move across the landscape. This practice was prevalent in ancient times in Sri Lanka, where an unharvested plot – dubbed a *Kurulu paluwa* – was set aside for birds and insects in rice cultivations (Marambe *et al.*, 2012). This is not practiced today. Small plots of land, preferably in juxtaposition with natural ecosystems, if left uncultivated, would provide a refuge particularly for many small-bodied faunal species. Uncultivated hedgerows in croplands would serve the same function, and wild relatives of crop species may also be found here. Components of wild biodiversity present in agricultural and associated landscapes provide essential ecosystem services such as pollination, biological pest control, and nutrient cycling (MoMD&E,

2016). These benefits, in the long term, would go some way towards compensating the farmer for losses incurred in terms of yield. Motivating farmers to set aside small plots of land in their natural state, even by providing incentives, would enrich biodiversity in agricultural landscapes.

Often, the margins between crop plantations and the forest are clear cut. This renders the forest edges unusable by many species due to edge effects. Forest edges are characterized by high levels of light intensity, low relative humidity, high wind velocity, high levels of agrochemicals, and increased predation – all imposing negative impacts on forest inhabitants (Laurance *et al.,* 2007). Having a buffer zone bordering the forest, preferably left in a natural or semi-natural state, would substantially increase the survival of forest biota.

Hedgerows or corridors with food resources and refuge sites for the animals would help to prevent breakup of faunal species populations and promote their survival. Maintaining habitat heterogeneity in such areas, to the extent possible, would cater to the needs of a diverse faunal community. This can be achieved, for example, by propagating selected non-crop indigenous fruit trees and herbaceous plants. Planting canopy trees amidst large extents of exposed crop plantations such as tea and paddy would provide important refuges and perching sites for volant and arboreal species.

Water is a critical element for sustaining agriculture and conserving biodiversity. Streams, tanks and irrigation canals within agricultural lands serve as excellent water sources for animals. Rehabilitation of canals and tanks frequently involve the replacement of earthen banks with concrete or gabion walls which are not suitable for the establishment of floral and faunal communities. Water sources should ideally be bordered by riparian vegetation with overhanging foliage enriching the landscape and benefiting biota. Such green belts would also reduce desiccation or drying out of the water source thus benefiting the crop plantation.

Agricultural landscapes can be designed and managed to host a range of naturally occurring species, which have neutral or even positive impacts on agricultural production and livelihoods of the rural communities. For instance, native plants may be suitable for use as soil erosion barriers, specifically along contours in steep lands. A secondary benefit is the production of organic matter for soil improvement. Crop diversification or crop rotation is also a healthy practice that would promote soil conservation and reduce nutrient depletion.

Land clearance for agriculture and alteration of natural habitats are known to accelerate the spread of invasive species. While causing adverse impacts on agricultural production, they spread into bordering natural habitats posing a threat to indigenous biodiversity. Action has to be taken to control the spread of such invasive species. Some species of agricultural crops, livestock, trees and fishes that have been introduced to a country with the objective of deriving benefits may also turn invasive, spreading beyond their planned range and displacing native species (Matthews and Brand 2004; Mooney *et al.,* 2005).

One of the major issues in present day agriculture is the intensive use of agro-chemicals, both pesticides and fertilizers. These compounds, many of which are hazardous, ultimately accumulate in water bodies thereby imposing toxic impacts on biota (Henegama *et al.,* 2013). Furthermore, these chemicals are non-selective and therefore also act on non-target, beneficial species. Reducing dependence on synthetic agrochemicals and turning to organic fertilizer and traditional pest control methods would bring in added benefits in terms of promoting biodiversity conservation in agricultural landscapes.

Effective application of best practices at a landscape level requires the application of scientific knowledge in the formulation of policies that would create a synergy between agricultural practices and biodiversity conservation. Integrating biodiversity conservation concerns into farming requires that economically viable and socially acceptable practices targeted towards safeguarding biodiversity, particularly in biodiversity-rich regions, are adopted. Success would inevitably be tied up with raising awareness among farmers on the advantages of sustaining biodiversity within agricultural landscapes, in order to persuade them to use these biodiversity-friendly practices. Agri-practices must take into consideration local and traditional methods which are often environmentally friendly. Rehabilitation of neglected agricultural land and increasing the productivity of such lands should be the preferred policy instead of clearing forest and opening up new land for agriculture. Moving from annual crops to perennial native crops, where feasible, and reducing the use of synthetic fertilizers and pesticides would reduce agricultural runoff into natural water bodies so benefitting indigenous biodiversity. Also, in agricultural research, more emphasis could be directed towards developing techniques for improving harvest in terms of quality and quantity, so maximizing returns. Many of the options for fostering biodiversity conservation in agricultural landscapes could be implemented if they are incorporated into policies, and governments are seriously committed towards adopting them. Ideally agricultural landscapes should be turned into what could be described as ecoagricultural landscapes with a mosaic of areas in natural/native habitat and areas under agricultural production. Effective ecoagricultural systems rely on maximizing ecological, economic and social synergies, and minimizing conflicts (Scherr and McNeely, 2008).

The conservation of biodiversity in a country is generally associated with forest reserves, wildlife reserves and other protected areas. However, since large areas of forest have been cleared for providing land for agricultural development, the distinctive role of agricultural landscapes in protecting biodiversity should be recognized. As outlined in this article there is a wide range of measures that could be adopted to ensure that agricultural landscapes are managed so as to produce food while simultaneously contributing towards conserving biodiversity.

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# CHAPTER 07

# *In vitro* Approaches for *Ex-situ* Conservation of Plant Genetic Resources

**H.D.D. Bandupriya***

*Department of Plant Sciences, Faculty of Science, University of Colombo, Sri Lanka*

## Abstract

Plant genetic resources provide invaluable assets for global food security by providing raw materials for plant breeders to use in the crop improvement programmes. Preservation of the diversity of plants, both cultivated and wild relatives, is quite essential for the maintenance of plant diversity for their use at any time in future. Plant genetic resources can be conserved in two major ways; either conservation in natural habitats where plants are located (*in situ*) or conservation outside their natural habitats (*ex situ*). *Ex situ* conservation techniques have been recognized as complementary methods which are more efficient than that of *in situ* methods. Plant biotechnology, mainly *in vitro* culture techniques provides important tools for improving germplasm collection, exchange, multiplication and conservation of plant genetic resources of many problematic species. Literature on the subject is reviewed with an emphasis on *in vitro* techniques.

**Keywords:** Cryopreservation, encapsulation-dehydration, slow growth storage, vitrification

**dbandupriya@pts.cmb.ac.lk*

## Introduction

Plants provide food, shelter, clothing, medicine, timber, tools, dyes and many more for mankind, thus considered most essential world’s natural resource. Plant genetic resources (PGR) can be defined as ‘materials considered of systematic importance and applicable in cytogenetic, phylogenetic, evolutionary, physiological, biochemical, pathological and ecological research and plant breeding. They encompass all cultivated crops and those with little or no agricultural value as well as their weedy and wild relatives’ (Ulukan, 2011). Majority of the primitive and conventionally used agricultural plants have been now replaced by new species with improved characters and genetic variability of crop species is getting eroded at an alarming pace due to deforestation, spread of superior varieties and selection pressure.

Climate change is also having an adverse effect on maintaining the genetic diversity of crops. According to the United Nations reports, the world population is expected to reach 9.8 billion in 2050. Each year roughly 83 million people being added to the world’s population increasing the amount of food required in each year. The situation become worst due to the Climate change which force plant breeders to look for new traits to combat the challenges caused by the changing climate. Maintaining the Genetic diversity is essential as a source of novel traits and alleles for crop breeding in order to face the erratic challenges laying ahead due to changing climates (Tester and Langridge, 2010).

Plant genetic resources provide invaluable assets for global food security by providing raw materials for plant breeders to use in the crop improvement programmes. Not only the cultivated crops but also their wild relatives play a significant role in maintaining the diversity and some of the wild relatives may contain genes responsible for significant traits that may be needed to increase yield, disease resistance, drought tolerance, nutritional quality and, taste in future. Preservation of both cultivated and wild relatives is quite essential for the maintenance of plant diversity for their use at any time in future.

Plant genetic resources can be conserved in two major ways; either conservation in natural habitats where plants are located (*in situ*) or conservation outside their natural habitats (*ex situ*). Conservation *in situ* provides the benefits of continuing natural selection. However, there is always a risk for the loss of endangered species due to prevailing habitat destruction and the transformations of the natural environments.

*Ex situ* conservation techniques have been recognized as complementary methods which are more efficient than that of *in situ* methods. Certain rare species that are highly endangered can only be conserved through *ex situ* techniques. *Ex situ* conservation was facilitated internationally by establishing seed gene banks in many countries (Rao, 2004).

Seed gene banks, where desiccated seeds are stored at low temperatures are the most efficient and convenient way to preserve genetic diversity. Various techniques have been developed to sustain the available genetic resources in the form of seed banks. However, this is not applicable for all species specially the species which produce non-orthodox or recalcitrant seeds which are desiccation intolerant. Recalcitrant seeds cannot be stored at low temperatures by desiccating them to low moisture content and exacerbated loss of viability is resulted when drying and freezing conditions are applied attempting to expand the storage longevity (Engelmann, 2011; Reed 2017). A large number of tropical species which are commercially important fall into this category. Furthermore, some tuber crops (cassava, yam, potato, sweet potato), fruits (banana, apple, pear, citrus), spices (pepper, ginger, turmeric) and other miscellaneous crops (vanilla, sugarcane *etc*.) are propagated by vegetative measures in order to maintain clonal genotypes. Seed storage of these crops is not practical in the sense of conservation of true genotypes, due to the heterogeneous nature of the seeds. For these problematic species, germplasms are conserved as field gene banks. However, conservation in the form of field banks are always prone to high labour cost; require large areas, vulnerable to natural disasters as well as pest and disease attacks. Thus, plant biotechnology, mainly *in vitro* culture techniques provides important tools for improving germplasm collection, exchange, multiplication and conservation of plant genetic resources of many problematic species. In the present chapter, the application of *in vitro* techniques towards the progression of PGR conservation is discussed.

## *In vitro* Culture

The ability to regenerate whole plants from single cells *in vitro* is a powerful biotechnological process, which can accelerate plant multiplication in terms of micropropagation, somatic embryogenesis, zygotic embryo culture, and dihaploid plant production. During the plant tissue culture process plant cells, tissues, organs and their components are cultured aseptically under controlled chemical and physical environments. The main application of tissue culture technology is to propagate plants by vegetative means. Production of disease free plants, especially virus free plants, is possible through meristem culture allowing the production of disease free plant stocks not only for germplasm storage but also for the safe international movement of germplasm (Fig. 1). Small size of the plant materials in the *in vitro* environment reduce the demand for space and labour in maintaining germplasm collections. Depending on the requirement, different *in vitro* conservation techniques have been developed for plants which do not produce orthodox seeds which can be stored directly in seed gene banks. *In vitro* culture or tissue culture techniques provide great opportunity for the conservation of many plant species and the technique is applied in different steps during the process of collecting, multiplying and storing of plant genetic resources (Engelmann, 2011). Conservation *in vitro* is considered as an approach to balance the *ex vitro* conservation by going hand on hand with field, seed and pollen gene banks along with *in situ* conservation (Rajasekharan and Sahijram, 2015). Several aspects of *in vitro* culture technology such as *in vitro* seed germination, vegetative multiplication and acclimatization accelerate the production of propagules for short to medium term conservation and also long term conservation through cryopreservation.

## Collection and Exchange of Plant Germplasm

The collection of plant materials is the first step towards the acquisition of plant germplasm and is the most challenging task. This involves the gathering of plant materials from their natural habitats or cultivated fields for the purpose of conservations. Most economical method of sample collection for *ex situ* conservation is in the form of seeds or cuttings of plants. This is not always possible for species which produce recalcitrant seeds or sterile seeds. In the case of species which do not produce seeds and propagated vegetatively, propagules may not be transported easily or they may have short longevity (Engelmann, 2011). Collecting of samples often requires travelling in distant regions for comparatively lengthy periods maybe up to several days or weeks. Therefore, it is essential to maintain the gathered material in good condition before they are placed under ideal conditions for the storage purpose. There is a risk of germinating or declining of the viability of recalcitrant seeds during long collecting periods. Moreover, the size and the volume of certain fruits cause significant problems during sample collection. In certain cases, *in vitro* tissue collection is less invasive than the removal of whole plants particularly the species where there are few individuals exist in the wild. Seasonal patterns in the development sometimes do not allow collecting materials in the traditional approach. *In vitro* methods pave a way to improve the effectiveness of sample collection considerably (Fig. 1).

International Board for Plant Genetic Resources *(*IBPGR*)* in 1984 organized a meeting to review research programmes and enforce guidelines for simple and effective *in vitro* collection procedures for plant materials such as vegetative tissues and embryos of both wild and crop species (Engelmann, 2011). Protocols have been developed for collecting germplasms of problematic species and the technique showed a great potential to facilitate the collection of tropical and subtropical germplasm. For example, coconut (*Cocos nucifera* L.) seed, being the largest seed in the plant kingdom, is difficult to handle during germplasm collections due to the recalcitrant nature and cannot be stored for long periods due to lack of dormancy. Mature zygotic embryo, which is a comparatively a small structure, can be collected in the field instead of seeds (Fig. 1) and transportation of germplasm is facilitated by this method (Assy-Bah *et al*., 1987; Bandupriya *et al*., 2014). Similarly, *in vitro* approaches have been attempted for collecting *Musa* accessions. Approximately 300 Musa accessions have been collected in Papua New Guinea and transported to Australia in order to maintain as a duplicate collection (Withers, 1995). Most importantly, this ensured acting in accordance with the prevailing quarantine regulations that are undertaken to combat with the spreading of diseases such as *Fusarium* wilt (IBPGR, 1988). Rapid decline of cacao (*Theobroma cocoa*) seeds during sample collection and transport was a problem for collecting cacao germplasm from different areas. This has been overcome by introducing a simple *in vitro* culture method using shoot nodes (Yidana *et al*., 1987). Similar *in vitro* methods were developed for species such as coffee, Citrus, grapes, oil palm and some forage grasses (Withers and Engelmann, 1998). At the same time, development of *in vitro* techniques offers significant benefits such as reduced weight and volume which eventually led the procedure to become more economical and enhanced the health conditions of the cultures which ensured the reduction of spreading of diseases (Vollmer *et al*., 2017). *In vitro* cultured tissues (embryos, shoot cultures or microtubers) are usually transported in standard media under aseptic conditions. This simplifies the storage and regeneration of the material at the recipient region/country.

Fig. 1 *In vitro* collection and transportation of coconut germplasm. a. Dissected embryos from mature nuts (12 months after fertilization). b. Embryos prepared for transportation by culturing into individual vials containing water agar. c. *In vitro* raised embryos at the recipient laboratory.

## Plant Germplasm Conservation

Depending on the demand, infrastructure accessibility and the techniques applied, genetic resources are stored short, medium or long durations. Regular sub culturing in four to eight week intervals is adequate for the maintenance of cultures for short durations. Two main approaches, namely slow growth and cryopreservation, are adopted for conserving genetic resources for a longer period of time.

## Short Term and Medium Term Storage Using Slow Growth

Slow growth is applied to hold the plant materials for moderate durations (one to fifteen years) by changing the culture medium and/or the environment. This is possible through periodic sub culturing of the material. The sub culturing interval mainly depends on the plant species (Engelmann, 2011). Organs such as shoot tips or nodes are frequently used for slow growth storage knowing the advantage of their amenability to maintain the true to type nature. In contrast, callus cultures are more vulnerable to induce somaclonal variations during storage. Maintenance of cultures at reduced temperatures is the most commonly used method for slow growth storage which can also be combined with low light intensities or complete dark storage. Cold sensitive tropical species are stored at higher temperatures ranging between 15°C and 20°C depending on the cold sensitivity of the species, while cold-tolerant temperate species are stored at relatively low temperatures between 0°C and 5°C (Engelmann, 2011). In addition, modification of the sugar concentration and/or mineral concentration, the oxygen level, the type and/or concentration of growth regulators and incorporation of osmotic compounds in to the culture media are employed for short term storage of genetic resources (Engelmann, 2011). Parameters such as explants type and its physiology, type of the container, its volume, type of closure of the container and the volume of the culture medium also affect the slow growth storage (Engelmann, 1991). Combinations of physical and chemical features are used frequently to prolong the culture duration. Reduced levels of temperature, mineral and carbohydrate concentration and reduce light intensity are the most common features combined together to achieve maximum success (Cruz-Cruz *et al*., 2013). Slow growth medium term storage is routinely used to conserve several temperate and tropical crop species as well as rare and endangered species (Fay, 1992; Razdan and Cocking, 1997; Sarasan *et al*., 2006). More than 1,500 accessions of banana (edible and wild), which is considered the richest collection of banana germplasm in the world, is hosted at the Katholieke Universiteit, Leuven (KU Leuven), Belgium at 16°C under slow growth conditions. On the contrary, more cold sensitive cassava shoot cultures are conserved at comparatively higher temperatures than 20°C (Roca *et al.*, 1984). The International Potato Center (CIP) conserves approximately 4,700 cultivated landrace accessions of potato under medium-term *in vitro* storage conditions at 6 – 8°C (Vollmer *et al*., 2016). Even though medium term *in vitro* conservation appears as a simple technique, it is essential to customize the technique for any new material before it is being implemented. It is not possible to apply one single protocol for diverse genetic materials. However, once cultures are established, these cultures can act as resources of tissue providers for long-term storage through cryopreservation (Reed *et al.,* 2011).

## Cryopreservation

Plant cryopreservation is the storage of cells, tissues or organs at an extremely low temperature (-196°C) that is in liquid nitrogen (LN). Nitrogen sometimes can be used in its vapour form at -140°C depending on the plant material. All the physical and biochemical reactions are arrested at this temperature thus cells are considered to be in an absolute silence stage. When plant parts are cryopreserved their viability is preserve and conservation time is unlimited. When these cultures are brought back to their standard culture conditions they recover to produce new plants (Fig. 2). First application of cryogenesis to conserve plant material is reported in 1968. Since then cryopreservation has been tested for several plant species and it is an authenticity for the conservation of number of crop species. Freezing of intracellular water molecules during rapid cooling in liquid nitrogen is the major problem faced in cryopreservation and it should be avoided (Engelmann, 2004). Intracellular ice crystal formation is a lethal and non-reversible incident occurs during the exposure of plant cells to ultra-low temperatures. Ice crystals lead to membrane penetration and reduce the semi permeability of the membrane leading to ultimate cell death. Thus plant materials must undergo special treatments prior to the induction of low temperatures in order to reduce the intracellular water content and become sufficiently dehydrated. Based on the physical mechanism applied for water removal, the cryopreservation techniques are classified as conventional and new cryopreservation techniques (Withers and Engelmann,1998).

## Cryopreservation Techniques

### Conventional Cryopreservation Techniques

The conventional cryopreservation techniques were developed in the decades of 1970s and 1980s (Kaviani, 2011). Initial cryopreservation methods for *in vitro* culture were based on slow freezing techniques. In this method, tissues are preserved using cryoprotective solutions such as sugars, dimethyl sulphoxide (DMSO), glycerol and/or proline. The presence of these substances facilitates slow freezing since they removed certain level of water present in the plant cells. The very first attempt on slow freezing on plant cells was described by Quatrano in 1968 where he attempted to freeze cultured flax cells treated with 10% (v/v) DMSO by placing them in a -50°C freezer at a cooling rate of 5-10°C $min^{-1}$. Successful regeneration of plant cells was reported upon culturing the thawed cells at the end of the storage period. Similar attempt was reported by Latta in 1971 for *Daucus carota* cells however there was an additional cryogenic storage step after cooling the cells to -40°C at a cooling rate of 2-4°C $min^{-1}$. The slow freezing technique which then involves a slow cooling of plant tissues to a prior defined freezing temperature which then followed the immersion in liquid nitrogen was optimized for vast number of species (Panis *et al.*, 1990; Salaj *et al.*, 2007; Salaj *et al.*, 2010). Depending upon the rate of cooling and the pre-freezing temperature, different amounts of water will leave the cell before the intracellular contents solidify. A major portion of all freezable intracellular water is removed from the cells at optimum conditions. Undifferentiated callus or suspension cells were quite responsive to this technique and considered suitable for the range of species. However, there were certain plant species which do not show positive response for the slow freezing techniques. Thus new methods were experimented for such unresponsive species.

## New Cryopreservation Techniques

Cryopreservation techniques based on new vitrification procedures are applied by dehydrating the cells prior to freezing. This is achieved either by exposing plant tissues to highly concentrated cryoprotective media and/or by air desiccation. Cells are then rapidly cooled by plunging them in liquid nitrogen. Critical step to achieve the success in these new techniques is the dehydration step but in classical techniques it is considered the freezing step. Several new cryopreservation techniques namely encapsulation /dehydration, vitrification, encapsulation/ vitrification, droplet vitrification have been developed aiming the conservation of vast number of species for future use.

## Encapsulation/ Dehydration

The encapsulation/dehydration is based on the technique designed for the production of artificial seeds and was first reported by Fabre and Dereuddre (1990) where the technique was applied to conserve *Solanum tuberosum* shoot-tips. This technique has been applied to explants such as shoot-tip, zygotic and somatic embryos and suspension cultures of several species of wide range of species including both temperate and tropical origin. During the process, explants are first encapsulated in calcium alginate beads, then pre-grown in sugar or sugar alcohol rich liquid medium for several days, partially desiccated inside a laminar flow cabinet or using silica gel until beads express a water content of 20% on fresh weight basis prior to plunge them in liquid nitrogen (Fig. 2). Alginate matrix including the explant experiences vitrification after exposing it to sugar pre-treatment and dehydration. Growth recovery of cryopreserved explants is rapid and direct without going through a callus phase (Engelmann, 2011). The sensitivity of numerous plant species for elevated levels of sucrose and stress created during dehydration prevent the application of this technology for vast number of species in large scale. Moreover, the technique is laborious and takes several days to complete the whole process until plant materials are stored in liquid nitrogen.

## Vitrification

Vitrification technique is based on dehydration of plant material using highly concentrated vitrification solutions prior to rapid cooling. The technique was developed according to a study reported by Rall and Fahy (1985) where they recorded successful cryopreservation of animal tissues (mouse embryos) after treating them with highly concentrated vitrification solution (Panis, 2018). First report on plant cryopreservation by vitrification was recorded in 1989 by Uragami *et al.* (1989). Upon storing the tissues in liquid nitrogen, rewarming, removal of cryoprotectants and recovery of plant tissues is achieved. 'A vitrification protocol includes the following typical steps: 1) loading with cryoprotective substances to a mixture containing 2 M glycerol + 0.4 M sucrose or varying sugar concentrations 2) dehydration with a plant vitrification solution 2 (PVS2) that contains 30% (w/v) glycerol + 15% (w/v) ethylene glycol + 15% (w/v) DMSO + 0.4 M sucrose; or PVS3 that contains 40% (w/v) glycerol and 40% (w/v) sucrose  and 3) rapid freezing by transferring the cryotubes that contains the tissues and 1 mL of the vitrification solution in liquid nitrogen' (Panis, 2018). Upon storage, rewarming, removal of cryoprotectants and recovery of tissues are being done. Vitrification has now become a widely applicable technique for plant cryopreservation and protocols have been developed for considerable number of species. The problems associated with this technique are "toxicity" or "excessive dehydration effect" of the concentrated vitrification solutions.

## Droplet-vitrification

One of the latest techniques developed for cryopreservation is considered as droplet-vitrification (Sakai and Engelmann, 2007). Application of concentrated vitrification solutions [Plant Vitrification Solution 2 (PVS2) or Plant Vitrification Solution 3 (PVS3)] along with the rapid cooling in LN is used in this technique. Plant tissues are placed on an aluminium foil with small drops of vitrification solution before they are immersed in LN. The aluminium foil is then transferred to a cryotube filled with LN for the storage purpose.  This allows easy identification of samples as well. Rapid thawing is achieved once the aluminium foil is taken out from the cryotube and exposed it to the unloading solution.

After Pennycooke and Towill reported the first droplet vitrification application in 2000, several research groups worked on the technique to develop protocols for papaya (Ashmore *et al*., 2001), *Prunus* (de Boucaud *et al*., 2002), yam (Leunufna and Keller, 2003) and banana (Panis *et al*., 2005). Increasing number of species are being added to the group which it has been successfully applied the droplet- vitrification. The technique is considered user friendly and the success rate is comparatively high.

## Encapsulation–vitrification

It is a combination of encapsulation/dehydration and vitrification procedures. Plant tissues are first encapsulated in alginate beads prior to treatment with the vitrification method. It has been noted that, the time take for dehydration is greatly reduced when applied encapsulation/ vitrification, compared to that of encapsulation/ dehydration. This method is developed enabling the use of vitrification for the problematic species which are too sensitive to PVS2 vitrification solution (Engelmann *et al*., 2008). Conservation of small specimens such as suspension cultures and hairy roots is more convenient for this technique. The technique has been applied to several species such as shoot tips of strawberry (Hirai *et al*., 1998), lily (Matsumoto *et al*., 1995), statice (Matsumoto *et al*., 1998), and shoot primordia of horseradish (Phunchindawan *et al*., 1997).

## Cryo-plate Methods

New cryogenic techniques which use cryo-plates (V cryo-plate and D cryo-plate) for plant cryopreservation have been developed recently. These two methods are different based on the technique used at the dehydration step. Materials are dehydrated in a laminar air flow current in D cryo-plate (Dehydration cryo-plate) method (Niino *et al*., 2013) whereas it is done using a vitrification solution in the V cryo-plate (Vitrification-cryoplate) method (Yamamoto *et al*., 2011). Recovery rates are expected to be high in these two methods due to very high cooling and warming rates when the plant materials are adhered continuously to the aluminium cryo-plates. Most common explant type used in these techniques is the shoot tip. Shoot tips of strawberry (Yamamoto *et al*., 2012 b), mulberry (Yamamoto *et al*., 2012c), mint (Yamamoto *et al*., 2012a), blueberry (Matsumoto *et al*., 2014), potato (Yamamoto *et al*., 2015) and sugarcane (Rafique *et al*., 2015) have been cryopreserved through V cryo-plate method.

Chapter 7

# Long Term Conservation of Plant Genetic Resources Using Cryopreservation

There is a growing number of genebanks, botanical gardens and research stations who apply cryopreservation technique on large scale to preserve different types of plant material for the purpose of conservation. One of the basic methods of storing plant germplasm is achieved through the pollen storage. Routine storage of pollen in cryogenic stages is done by plant breeders to use them in future crop improvement programmes (Towill and Walters, 2000). Pollen storage is carried out by several institutes worldwide. In India, The National Bureau for Plant Genetic Resources (NBPGR) and Indian Institute for Horticultural Research conserve pollen of 65 and 600 accessions respectively belonging to different species (Ganeshan and Rajashekaran, 2000; Mandal, 2000). More than 700 traditional flower accession pollens are conserved using cryopreservation in China (Li *et al*., 2009). Pollen viability of 102 species of ornamental plants assayed after long term storage under cryogenic storage at International Peony Garden in Luoyang, Henan province, China showed the ability to retain viability (Ren *et al.,* 2019).

Seed cryopreservation is done with the intension of preserving orthodox seeds of rare and endangered species which have limited longevity. NBPGR (New Delhi, India) has a collection of seeds of 1,200 accessions collected from 50 different species and the majority of them are threatened medicinal plants (Mandal, 2000). Several hundred accessions of rare and endangered species are stored under cryostorage conditions at Kings Park and Botanic Garden in Perth, Australia (Touchell and Dixon, 1994) and the Center for Conservation and Research of Endangered Wildlife at the Cincinnati Zoo and Botanical Garden in the USA (Pence, 1991) in the form of seeds (regional endangered species) and spores and tissues (Bryophytes and Pterydophytes). Tropical Agricultural Research and Higher Education Center (CATIE); Cañas, Guanacaste in Costa Rica and in Institut de recherche pour le développement (IRD) in Montpellier, France holds a large collection of coffee seeds were cryopreserved (Dussert and Engelmann, 2006).

Dormant buds are also considered for cryopreservation of certain species. The United States Department of Agriculture (USDA) genebank and Julius

Kühn Institute (JKI) in Dresden, Germany are conserving apple dormant buds under cryopreservation (Hofer 2015). Two thousand and 291 apple accessions were cryopreserved at the National Laboratory for Genetic Resources Preservation (NLGRP), Colorado between the years 1988-2014 (Volk *et al*., 2017). Four hundred forty accessions of mulberry which were conserved at the National Institute of Agrobiological Resources, Yamagata, Japan were duplicated under cryopreservation (Niino, 1995). Furthermore, important embryogenic cell lines of conifer (Cyr 2000), coffee, cacao (Florin *et al*., 1999) and oil palm (Dumet, 1994) developed biotechnologically have been cryopreserved for future use.

Most successful application of cryopreservation in genebanks for long-term storage of vegetatively propagated plants is achieved using shoot tips as the explant. 'Currently, it is estimated that over 10,000 accessions of vegetatively propagated crops starting from *in vitro* cultures are safely preserved for the long term through cryopreservation. This constitutes 16% of the total number of accessions hold by all the institutes collectively for these crops. More than 80% of these belong to 5 crops; potato (38%), cassava (22%), bananas and plantains (11%), mulberry (12%) and garlic (5%)' (Panis, 2018). The International Potato Center (CIP) in Lima, Peru conserves nearly 1320 cultivated landraces of potato under cryopreservation while Leibnitz Institute of Plant Genetics and Crop Plant in Gatersleben, Germany conserve more than 1000 old potato varieties (Keller *et al*., 2006) under cryostorage. It is important to note that different conservation strategies have been applied for potato accessions at the CIP. More than 2300 wild potato accessions are conserved as seed collections at - 20°C. As metioned previously under section, short term and medium term storage using slow growth, major portion of cultivated accessions (mostly landraces) out of 4723 total accessions are conserved *in vitro* at 6-8 °C for medium-term storage (Vollmer *et al*., 2016). National Center for Genetic Resources Preservation (NCGRP) in USA, National Institute for Crop Science (NISC) in Korea, Czech Potato Cryobank and National Genebank of China are the other institutes who preserve potato (249, 130, 50 and 24 accessions respectively) under cryogenic storage (Vollmer *et al*., 2016). The Bioversity International *Musa* Germplasm Transit Centre (ITC) in Leuven, Belgium is hosting the world's largest banana germplasm collection. Over 600 banana accessions are conserved in cryogenic stage while over 1500 accessions are kept *in vitro* conditions under slow growth.

Moreover, the cryogenic collection of banana accessions is duplicated at the IRD, Montpellier, France for safety purposes (https://www.bioversityinternational.org/banana-genebank/). Nearly 540 cassava accessions are conserved under cryopreservation at the International Center for Tropical Agriculture (CIAT) in Cali, Colombia (Gonzalez-Arnao *et al*., 2008).

Despite being the prime method to conserve plant genetic diversity, no single protocol can be applied to all types of explants and all the species is the major problem associated with cryopreservation which prevents large scale application of this technique Protocol needs to be optimized for each and every plant species as well as for different explants to be cryopreserved which is time consuming. When considering seed cryopreservation, not all orthodox seeds are fitting for cryopreservation (Acker *et al*., 2017). Seeds which contain high oil contents loose viability very easily and cryopreservation of large seeded species is somewhat costly (Engelmann, 2011). Insufficient funding, lack of skilled personnel and lack of equipment/infrastructure facilities also slow down the application of cryobanking capacity (Panis, 2018). According to certain unrevealed physiological barriers prevent successful post thaw regeneration in certain species despite the extensive research carried out (Engelmann, 2011).

Cryopreservation is so far considered the best method for plant genetic resource conservation due to several advantages. Since samples are stored at ultra-low temperatures during cryopreservation, metabolic weakening of samples during storage is halted, extending their prolonged existence under long-term storage. The conserved materials are not prone to contamination risks; maintenance is easy with little attention and limited space is required for storing large number of accessions. Cryo storage relies on liquid nitrogen and no refrigeration is needed. The process is more convenient since no regular sub culturing or regeneration is needed. Cryopreservation is said to be more cost effective compared to conventional germplasm storage methods. Cost benefit analysis done by several research groups proved the financial advantages of the cryopreservation application. Annual cost for conserving one tree accession under field conditions at the NCGRP is US $77 while it is US $23 under slow growth conditions *in vitro* and US $1 under cryogenic conditions (Hummer and Reed, 2000). This clearly indicates how economical the cryopreservation conservation is. A comparison made at the CATIE in Costa Rica where the world's largest coffee field collection exists revealed that expenses to maintain the germpalsm in field collections aremore compared to the expenses bared by the institute to maintain the cryo collection. Moreover, the study indicated that the method is even more economical when higher numbers of accessions are in conserved under cryopreservation (Dulloo *et al*., 2009)

## Conclusion

Biotechnology has a tremendous potential to contribute towards the conservation of plant genetic resources mainly under ex situ conditions. The progress recorded for *in vitro* culture technology facilitates the collection, exchange, multiplication and conservation of problem species either under slow growth conditions or cryopreservation. Conservation strategies should be designed to cover wide range of accessions and whenever possible gene banks should be duplicated. Cryopreservation gives an opportunity to do both.

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## CHAPTER 08

# *Lasia spinosa* (L.) Thw., A High Potential Underutilized Aroid in Asia: A Step Towards Utilizing Neglected Crop Genetic Resources for Food and Nutritional Security

**R.H.G. Ranil[1*], D.K.N.G. Pushpakumara[1], P.C.G. Bandaranayake[2], W.M.T.P. Ariyaratne[1], D.S.A. Wijesundara[3], R.M.S.R. Chamara[1]and J.P. Eeswara[1]**

[1]*Department of Crop Science, Faculty of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka*
[2]*Agricultural Biotechnology Centre, Faculty of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka*
[3]*National Institute of Fundamental Science, Kandy, Sri Lanka*

## Abstract

*Lasias pinosa* (L.) Thw. is considered as a high potential underutilized aroid in Asia. Even though *L. spinosa* consists of substantial level of medicinal as well as food properties, it is not widely cultivated and not popular among the famers compared to other vegetables. In spite of its wide range of morphological and genetic variation, *L. spinosa* has not yet been properly documented and studied adequately. This paper compiles and discusses available evidences of *L. spinosa* in Asia on its taxonomy, phytogeography, ecology, habitat requirements, morphological and genetic variation, cytology, medicinal and food properties, phytochemical values and cultivation aspects, while emphasizing future perspectives. Some of our findings are also included to fill the gaps in the available literature.

**Keywords:** Genetic resources, *Lasia spinosa*, medicinal and food properties, morphological variation.

*rhgranil@gmail.com

## Introduction

Indigenous vegetables are important sources of food in many parts of the developing world since they play a significant role in food and nutritional security for the underprivileged people in both urban and rural areas (Weinberger and John, 2004). Many communities use them a sa primary food or as secondary condiments in dishes prepared from domestic varieties. Therefore, indigenous vegetables were considered as valuable source of energy and micronutrients contributing to the diets of the rural people in the past and still they continue to be an important component of dietary requirements. In this scenario, understanding of nutritional value and cultivation potential of these indigenous vegetables are important.

*Lasia spinosa* is one of the indigenous vegetable which is considered as a highly nutritious, but underutilized in various regions in Asia such as Bangladesh, China, India, Nepal and Sri Lanka (Fig. 1). The tender leaves and rhizome of *L. spinosa* are commonly used in curries. Apart from imparting its food value, *L. spinosa* plays a substantial role in traditional medicine system in various indigenous communities in South and South East Asia. Its leaves and rhizomes are reported to be used for treating tuberculosis, swollen lymph nodes, stomach aches, snake and insect bites, injuries, and rheumatism (Jayaweera, 1981; Goshwami *et al.*, 2013a; Rahmatullah, 2010; Yusuf *et al.*, 2009; Goshwami *et al.*, 2013b; Mritunjay Kumar *et al.*, 2013; Yusuf *et al.*, 1994; Uede *et al.*,2002; Nguyen *et al.*, 2004). Even though, pharmacognostical and phytochemical properties such as antioxidant capacity, antimicrobial property and cytotoxic activities, etc. of *Lasia* was well studied (Goshwami *et al.*, 2012a, 2013a; Das *et al.*, 2014; Dubey *et al.*, 2014), application of such findings in pharmaceutical industries is far from adequate.

*Lasia spinosa* is found on swamps, riverbanks, ditches, moist places in tropical and subtropical forests, sometimes cultivated along fish ponds and rice fields in Asia (Bangladesh, Bhutan, Cambodia, China, NE and SE India, Indonesia, Laos, Malaysia, Myanmar, Nepal, New Guinea, Sri Lanka Thailand, Taiwan and Vietnam) (www.eflora.cn/foc/pdf/Araceae.pdf). *Lasia spinosa* shows a wide range of morphological variations in Asia (Ara, 2001; Hossan and Sharif, 1984;

Sultana *et al.,* 2006; Alam *et al.,* 2012; Hore and Tanti, 2014; Nicolson, 1987). The genetic diversity of the species has not been properly studied, but existing information suggest that considerable diversity exists within the species. Taxonomic status of *L. spinosa* is not fully resolved yet. It is more complicated due to high level of polymorphism. Therefore, screening and study of morphological and genetic diversity is a prime need to resolve taxonomic ambiguities and such information will provide important platform for conservation and utilization of this high potential aroid in Asia.

In this review, we compile and discuss available literature on *L. spinosa* including taxonomy, phytogeography, ecology, cytological and phytochemical significance, food value and medicinal properties, while highlighting future research priorities. Furthermore, this account is enriched by the findings of ongoing project on "Potentials of spineless Kohila (*Lasia spinosa* (L.) Thw.) to be used as a promising crop in Sri Lankan agriculture". We believe that such information will be useful for taxonomists, plant breeders and conservation biologists who work on edible aroids and their conservation.

## Origin and Geographical Distribution

The native range of *L. spinosa* is extending from Indian subcontinent to Malesia across East Asia. It is naturally distributed in Eastern Asia (China, Taiwan), Indian subcontinent (Bangladesh, Bhutan, India, Nepal, Sri Lanka), Indo-China (Cambodia, Laos, Myanmar, Thailand, Vietnam) and Malesia (Indonesia, Malaysia, Papua New Guinea) (Alam *et al*., 2012; Sultana *et al.*, 2006; www.eflora.org; www.iucnredlist.org). Figure 1 shows the native range of *L. spinosa*. Although, the available phytogeograhical information is not adequate to conclude its origin, Indo-Malaysian region can be considered as the putative center of origin for *L. spinosa*.

**Figure 1:** Geographical distribution of *Lasia spinosa*.

(Source: Alam *et al.*, 2012; Sultana *et al.*, 2006; www.eflora.org; www.iucnredlist.org)

## Ecology and Habitat Requirements

Although *L. spinosa* is generally found in semi-aquatic habitats, occasionally it behaves as an aquatic plant that completely immersed in water (Plate 1). Because of its amphibian nature, *L. spinosa* is getting comparative advantage to survive under limited water availability, showing a wide range of environmental adaptability. Based on our observations, we feel that it is a semi-aquatic plant and does not prefer to grow in habitats exposed to direct sunlight. Further, it naturally prefers to thrive in standing water.

## Taxonomy

The genus *Lasia*, represented by two species, *Lasia spinosa* (L.) Thwaites and *Lasia consinna* Alderw belongs to the family Araceae has an Indo-Malaysian origin and considered to be native to tropical and sub-tropical Asia and New Guinea (Ara, 2001; www.eflora.cn/foc/pdf/Araceae.pdf). *Lasia consinna* shows a restricted distribution and confined to Indonesia (Hambali and Sizemore, 1997; Hay, 1988). *Lasia spinosa* has been described under different names by various authors after its first collection by Paul Hermann from Sri Lanka in 1698. Nicolson, (1987) has listed 18 synonyms for *L. spinosa* in his enumeration of Araceae in Sri Lanka whereas others listed 15 synonyms (www.theplantlist.org). There are several arguments on species delimitation, due to polymorphism in the species. As far back as in 1864 Thwaites reported it as "very variable species" and 123 years later, Nicolson (1987) confirmed this using the specimens collected from Sri Lanka. Apart from Sri Lanka, it is represented by two and four morphological forms based on leaf morphology in India and Bangladesh, respectively (Ara, 2001; Hore and Tanti, 2014). Furthermore, in Bangladesh two morphological forms based on flower colour was identified (Alam *et al.*, 2012). However, some taxonomists (www.the plantlist.org) believe that all these are variable forms of *L. spinosa*. Therefore, the correct taxonomic status is still needs to be verified.

## Morphological and Genetic Variation

*Lasia spinosa* shows a wide range of morphological variations in Asia (Alam *et al.*, 2012; Ara, 2001; Hore and Tanti, 2014; Hossan and Sharif, 1984; Nicolson, 1987; Sultana *et al.*, 2006). Hossain and Sharif, (1984) have first distinguished different forms and postulated them as an ecophenic variation. Later, Ara (2001) has reported four different morphological forms based on leaf morphology in Bangladesh, sagitate form; lamina dissected form; entire lamina margin form; and a mixed form of sagittate and lamina dissected. A karyotype analysis in three morphological forms (sagittate, lamina dissected and mixed from) in Bangladesh revealed that 27 bivalent number of chromosome from sagittate from and 26 from both lamina dissected and mixed forms. Furthermore, they postulate that the mixed form might be a natural hybrid between the sagittate and the lamina dissected form (Sultana *et al.*, 2006). Recently, Hore and Tanti (2014) also reported two leaf morphological forms, namely (i) lamina dissected leaves and (ii) a mix form with both sagittate and lamina dissected leaves from Assam, India. However, akaryo-morphological analysis of these two forms revealed 24 and 26 bivalent numbers of chromosomes in somatic cells from lamina dissected leaf form and mixed form, respectively. Further, they have not recorded any satellite micromosome in any morphological forms, whereas Sultana *et al.* (2006)

reported five and two satellite micromosome from mixed and lamina dissected form, respectively. Hore and Tanti (2014) postulated the difference of chromosome number and micromosome may be due to ecological adaptation. Table 1 summarizes the results of karyotype analysis of different morphological forms.

Apart from the leaf morphological forms, Alam *et al*. (2012) reported two forms based on spathe colour; namely common red flower form and rare green form. Cytological investigation of these two forms revealed 2n=26 and 2n=28 in the common red flower form and rare green flower form, respectively. Furthermore, molecular investigation using RAPD markers revealed that these two forms are distinguishable with RAPD markers. Based on these investigations, Alam *et al.* (2012) concluded that the green flower form and the red flower forms are entirely different morphological forms.

The information available on taxonomy and morphological variation of Sri Lankan population of *L. spinosa* is vague. The wide range of morphological variation of *L. spinosa* has been recorded by several botanists even within the same geographical area. Trimen (1900) was of the view that there was only one species with variable leaf forms. Bauren, (1917) claimed that there were two distinct varieties of *L. spinosa* in Sri Lanka. One has entire hastate or sagittate leaves (*ath-kohila* or *Sinhala-kohila*) while the other has a dissected lamina (*relou-kohila* or *angili-kohila*). Ibrahim *et al.* (1983) noted that there are two *Lasia* varieties in Sri Lanka, the one has only hastate leaves (*Sinhala-kohila*) and the other has heterophyllus leaves, hastate and dissected leaves, arising on the same rhizome, although they have not given adequate evidence to justify their varietal concept. Thus, identification of correct taxonomic status and variation of existing Sri Lankan population is fundamental to select superior germplasm for the crop improvement and to develop cultivation guidelines.

We did a germplasm collection recently covering major cultivation regions and the accessions were characterized using standard metrological traits (Kumari *et al*., 2017). Based on the result of this ongoing study, authors are in the view that the Sri Lankan population also consists of three distinct leaf morphological forms, namely (i) sagittae, (ii) lamina dissect; and (iii) mixed form (Fig. 2). During this study minor variation of each form was observed and discovered a novel spineless type (Plate 2C). People use dark colour morphological form in indigenous medicine and locally named as *Kalu kohila* (Black Lasia) (Plate 3). It is an introduced species (*Cyrtosperma johnstonii* N.E.Br.) to Sri Lanka but originated in Solomon Islands. Moreover, this species is mostly misidentified as a local variety by the indigenous community (Kumari *et al*., 2017). However, morphological data and other existing information are not adequate to determine place these variable forms in an acceptable taxonomic positions. Further, this variation might be purely due to macro and micro environmental effect. To eliminate such effects, all collected materials are now grown in the same location with replicated trails. Planed studies on molecular characterization of collected materials with DNA barcoding and SSR analysis will resolve the phylogeny of *Lasia* in Sri Lanka.

The long period of isolation from mainland India combined with climatic and geographic characteristics may be the main reason to have such pronounced morphological and genetic variation in Sri Lankan population of *Lasia*. The ongoing study on morphological and genetic variation will provide valuable information source to determine the correct taxonomic status of different morphotypes or ecotypes of *L. spinosa*. Other than Bangladesh, India and Sri Lanka, the information on morphological and genetic variation within natural or cultivated populations are not available. However, it is a prime need to screen the populations in other Asian countries to understand the genetic composition and structure of this species for the selection of superior germplasm for future crop improvement programs.

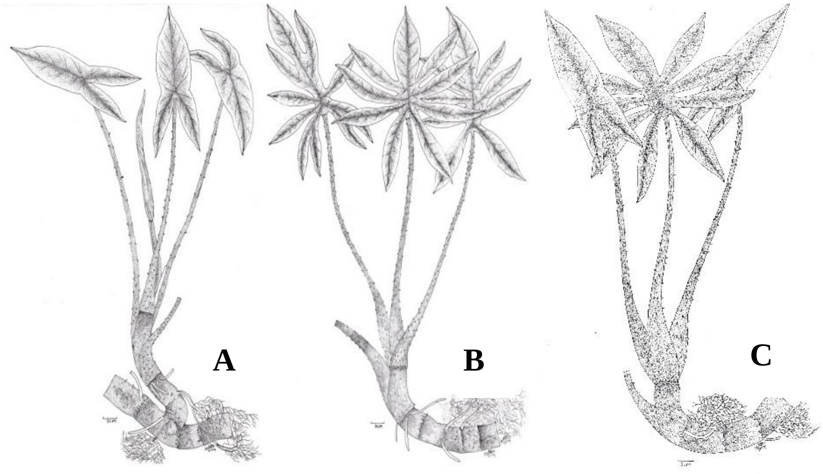

**Fig 2**: Three morphological forms of *Lasia spinosa* reported in Sri Lanka. A: Sagittate form; B: Lamina dissected form and C: Mixed form. (Kumari *et al*., 2017).

Genetic background of the plant is the major determinant of the chemical composition of a particular plant. Interestingly, only two reported studies on cytological work to identify different morphotypes (Hore and Tanti, 2014; Alam *et al*., 2012) and one study on genetic characterization of those types using Random Amplified Polymorphic DNA (RAPD) (Alam *et al*., 2012). Identification of superior genotypes is the essential first step in any breeding and agronomic programs. Therefore, it is encouraged to conduct such studies with local germplasm of any country or region considering agronomic and medicinal properties.

**Table 1:** Summary of karyotype analysis of different morphological forms of *Lasia spinosa*.

| Morphological form | 2n | | Centromeric formula | | Total length of 2n chromosome (µm) | |
|---|---|---|---|---|---|---|
| | A | B | A | B | A | B |
| Sagittate | 27 | *na* | 19m +7sm+ 1st | *na* | 102 | *na* |
| Lamina dissected | 26 | 24 | 9m+15sm+2st | 4m+14m+3sm+1st+ 2t | 57.78 | 1.09-4.42 |
| Mixed form | 26 | 26 | 14m+11sm+1t | 7m+14m+5sm | 74.46 | 2.31-4.08 |

Note: A and B denoted by the findings of Sultana *et al.*, (2006) and Hore and Tanti (2014), respectively. *na*: not assessed.

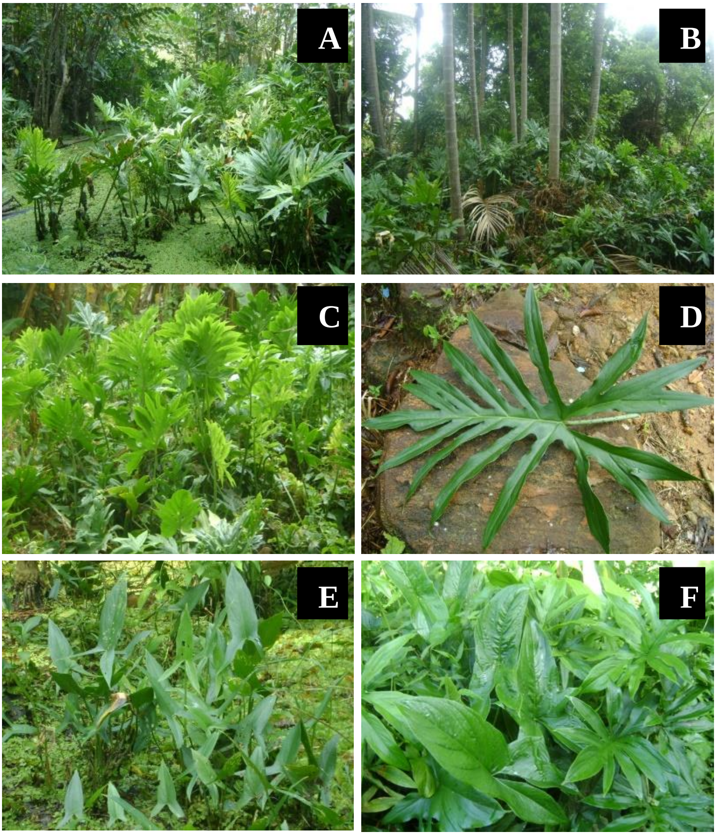

**Plate 1:** Different morphological types of *L. spinosa* and their habitats. A: plants thrive well in aquatic habitat. B: in shaded homegarden. C: lamina dissected type population. D: deeply lobed lamina dissected type leaf. E: sagitate type population. F: mixed form

**Plate 2:** Morphological characters of *L. spinosa*. A: rhizome with highly dense spines. B: rhizome with moderately dense spines. C: rhizome without spines. D: inflorescence covered by the spathe. E: a microscopic view of inflorescence. F: a mature fruit.

**Plate 3:** Black *Lasia*: A: Dark green colored mature leaves; B: Immature leaves with pink colored prominent veins; C: Collection of hairy leaf stalk.

## Pharmacognostical and Phytochemical Properties

Herbal products have been used in traditional systems in various civilizations since ancient times and the attention has even increased over last few decades. *L. spinosa* is one of such widely used plant species in many Asian countries for wide range of tonics and ailments. Other than the primary metabolites and trace elements, it consists of various secondary metabolites such as alkaloids, flavonoids, tannins, terpenoids, saponin and steroids (Bramha, 2014). Because of increased attention and demand, a considerable amount of scientific investigations are done on its pharmacological phytochemical and nutritional properties.

*L. spinosa* consists of 17.6 kcal/100g protein, 83 kcal/100g moisture, 1.16 kcal/100g fats, 34 kcal/100g ash, 17 kcal/100g total solids, 35.7 kcal/100g carbohydrate. Micronutrients such as Zinc, Magnesium, Molybdnum, Copper, Iron and Manganese are also present in 7.44 ppm, 6.22 ppm, 1.18 ppm, 0.31 ppm, 17.06 ppm, 1.33 ppm respectively (Brahma *et al*., 2014). According to stems compared to deep frying in respect of in-vitro bioaccessibility, the mature stem is a good source of pro-vitamin A and carotenoids. Preparation of a curry with coconut milk is a better method of cooking the stems compared to deep frying in respect of in-vitro bioaccessibility (Priyadarshani and Jansz, 2006). Rhizome is also a rich source of dietary fiber with 40%-75% of total dietary fiber on dry weight basis (Shefana and Ekanayake, 2009).

Antioxidants have received significant attention over last few decades due to their potential applications in human health. *L. spinosa* rhizome consists of total antioxidant activity of 145-957 µmol/g TEAC on a wet weight basis, making it a good source of antioxidants (Shefana and Ekanayake, 2009). Similar studies have conducted by other research groups and confirmed its potent antioxidant activity (Goshwami *et al*., 2012a; Maisuthisakul *et al*., 2008). Dubey and colleagues particularly studied the bioactive ethyl acetate fraction, from the methanol-water (80:20) extract of *L. spinosa* rhizome for gastroprotective and antioxidant activity and showed its anti-ulcerogenic and antioxidant activities (Dubey *et al*., 2014).

Goshwami and his group investigated the antinociceptive activities of partitionates of methanolic extract of leaves of *L. spinosa* and revealed that most of partitionates consist of significant antinociceptive effects (Goshwami *et al*., 2012b). The young tender leaves of *L. spinosa* are used to treat intestinal worms' infections in folk medicine of Naga tribes of India (Temjenmongla *et al.*, 2005). To study the science behind that, experiments were conducted to evaluate anthelmintic activity of methanolic extract of leaves of *L. spinosa* against helminthes (Goshwami *et al.*, 2013b). The results of present study indicated that methanolic extract significantly exhibited paralysis and also caused death of worms especially at highest concentration of 100 mg/ml, and concluded that the leaves of *L. spinosa* possess potent anthelmintic activity. Tubers of *L. spinosa* are a significant component of kohiladi decoction recommended by Sri Lankan traditional and Ayurvedic physicians to stop bleeding and clotting of blood. Weerasekara *et al*. (2005) did research on kohiladi decoction and found out that it has anticlotting action in vitro and proclotting activity *in vivo*.

Hasan (2014) determined the anti- hyperglycemic effects of methanolic and ethanolic extracts of leaf of *L. spinosa* plant in oral glucose tolerance tests compared with standard (glibenclamide) in Swiss albino mice (Hasan *et al*., 2014). In their experimental system, different extracts (methanolic and ethanolic) and dosses (200 and 400mg/kg body weight) for each extracts were orally administered and the serum blood glucose level was measured by glucometer after 2 h. Significant hypoglycemic activity was observed regarding both of the extracts and dosses compared to control. Both extracts revealed a significant hypoglycemic activity and the methanolic extract showed the higher inhibitory activity than ethanolic extract. Their results indicate that both stem and leaf extract of *L. spinosa* shows potent anti-diabetic activity in mice model and its potential applications.

Mahmood and colleagues studied the antihyperlipidemic activity of methanolic leaves extract of *L. spinosa* and for its role in the prevention of hyperlipidemia induced pancreatitis in rats (Mahmood *et al*., 2015). Experiments done with mice model systems revealed that the hydroalcoholic extract of *L. spinosa* roots possesses significant anti-nociceptive, anti-inflammatory, and anti-diarrheal potential (Deb *et al.*, 2010). Goshwami colleges investigated the scientific basis for the traditional uses of the crude methanolic extract of the leaves of the plant while evaluating its antinociceptive activity in mice, anti-inflammatory and antipyretic activities in wistar rats. Their results showed that the crude methanolic extracts of *L. spinosa* showed analgesic, anti-inflammatory and antipyretic effects Goshwami *et al*.,2013a). Further, leaf extract of *L. spinosa* is effective against all the three life cycle stages of encysted muscle larvae of parasite, *Trichinella spiralis* (Yadav, 2012).

Although, several studies are conducted on potential therapeutic applications of *L. spinosa*, work on biochemical analysis is limited. Majority of work is on qualitative analysis and no major compound present is identified so far. It is well understood that the secondary metabolism of the plants depends on environmental factors and therefore biochemical and medicinal properties vary depending on where they were grown. However, no such studies are conducted to date. Such studies will be useful for selecting better sites for large-scale cultivation of *L. spinosa*. Further, chemical composition and medicinal properties changes with the age of the plant tissues and identification of correct harvesting stage to achieve maximum medicinal benefits is important. Comprehensive studies on above topics will lead to identification of markers to be applied in the field level.

## Food Value and Uses in Traditional Medicine

In Sri Lanka, the tender leaves, petiole and rhizomes of *L. spinosa* are used as a supplementary disc with staple food rice. The tender leaves and petiole are cooked and served as a vegetable. The peeled rhizomes are also cooked and used for the same purpose. The peeled rhizomes in raw forms are used to prepare*sambal*. Porridge is also prepared using the rhizomes (Jayaweera, 1981; Shefana and Ekanayake, 2009). Its food value as a vegetable in Bangladesh and China, has also reported by Alam *et al*.,2012 and www.eflora.org, respectively. In Thailand, it is given orally to male animals for increasing the libido (Suthikrai *et al*., 2007). A comprehensive ethnobotanical survey will help for future crop improvement program and pharmaceutical industries.

The rhizomes of *L. spinose* are used medicinally for treating tuberculosis of lymph nodes, swollen lymph nodes, stomach aches, cough, snake and insect bites, injuries, and rheumatism (Wu *et al*., 2010). It is also used against stomach ache, colics, rheumatism, and to treat sore throat (Duke, 1998). It has played a role in traditional medicine system in various indigenous communities in South and South East Asia (Goshwami *et al*., 2013; Jayaweera, 1981; Kumar *et al*., 2013; Nguyen *et al.,*2004; Rahmatullah, 2010; Uede *et al*.,2002; Yusuf, 2009; Yusuf *et al*., 1994).The summarized information of medicinal uses of *L. spinose* in some countries is given in Table 2.

Currently, the indigenous vegetables have become important and the attention of the scientists is being diverted to conserve and use them. A major reason for this is the danger of extinction, via narrowing the genetic base. Further, the food and nutrient security of the rural population could also be addressed by paying greater attention to the indigenous vegetables which they are familiar with. Considering the problems of over and unbalanced nutrition and related issues such as obesity, hypertension diabetes and cancer prevalent in the urban populations, these crops will play a major role in the future food supply chain. Presence of *L. spinosa* and some other valuable indigenous vegetable and fruits in luxury supermarkets agree with above notion. *L. spinosa* is such a high potential indigenous vegetable which is having high food and medicinal properties.

**Table 2:** The summarized information of medicinal uses of *L. spinosa* in selected Asian countries.

| **Country** | **Medicinal uses** | **Reference** |
|---|---|---|
| Bangladesh | The plant is recommended for colic, rheumatism intestinal diseases. Corm is used as a remedy for throat affections. Leaves and corms are given as a cure for piles. The tuber of plant is used for treatment of rheumatoid arthritis, constipation and to purify blood. | Rahmatullah, 2010; Yusuf *et al.*, 2009; Goshwami *et al.*, 2013b; Kumar *et al.*, 2013; Yusuf *et al.*,1994 |
| India | The young tender leaves and stalk are used to treat intestinal worms' infections and demonstrate profound anticeptodal efficacy. Furthermore, leaves are used for stomach ache and other pains. The rhizome is used for treatment of lung inflammation, bleeding cough and the whole plant in uterine. | Temjenmongala 2005; Anonymous, 1948; Jayaweera, 1981 |
| Sri Lanka | The juice of the rootstock is given as a remedy for piles, haemorrhoids. Black Lasia is used as a treatment for chemical poisoning, Haemorrhoids and pistula. | (Jayaweera, 1981; Anonymous, 1948; Shefana and Ekanayake, 2009). |
| Vietnam | The plant is used as an anti-rheumatic and anti-inflammatory remedy. | (Uede*et al.*, 2002; Nguyen *et al.*, 2004) |
| China | The rhizomes are used medicinally for treating tuberculosis of lymph node, swollen lymph node, stomach, snake and insect bites, injuries, and rheumatism. | www.eflora. org |

as it has long been used in a variety of culinary preparations across many different Asian ethno-linguistic groups. Our understanding also that demand for *L. spinosa* among the urban community has increased suddenly. It is probably due to the general belief that the use of agrochemicals is minimum in the cultivation as it has inherent ability to resistance for pest and diseases. Further, application of inorganic fertilizer is also negligible in the cultivation of *L. spinosa*.

## Future Perspectives

The indigenous varieties are threatened through extinction of their genetic resources. The erosion of genetic resources of indigenous vegetables is accelerated further due to the introduction of high yielding hybrid varieties in the recent past. The hybrids are replacing not only the indigenous varieties but even the improved selections which were grown by the farmers in many countries. Unless actions are taken, the genetic base of vegetables will be narrowed, which may lead to serious catastrophes in the future. In that sense, study on food and medicinal value of *L. spinosa* is a prime need. Furthermore, understanding of existing genetic diversity is also important for the conservation and utilization of such neglected, but high potential crops.

Without accurate taxonomic identification, research carried out in academic and applied branches of life science are worthless (Kholia and Fraser-Jenkins, 2011). A correct and updated species description is one of the most beneficial tools and key requirement for plant identification. Furthermore, the type description of a particular species may differ from the individuals of the same species due to changing environment (climatic and soil parameters), geographical or reproductive isolation, etc. The little taxonomic work revealed that morphological and genetic variability of Asian population of *L. spinosa* as well as problems associated with its species delimitation. Therefore, a comprehensive taxonomic study with morphological, cytological, phytochemical and molecular evidence is needed to resolve taxonomic complication. A continuous monitoring and documentation of species characters and updated descriptions are also vital in future studies.

*Lasias pinosa* have been subjected to various phytochemical analyses. However, detailed studies are needed considering environmental variation as well. Such studies will lead to identification of specific bioactive compounds and their therapeutic values. As we understood, available research findings are not adequate to attract the entrepreneurs. Therefore, developing a continuous dialog between researches and pharmaceutical and other companies is important to develop value added products. For an example, Pupulawaththa *et al*. (2014) has developed fiber rich soft dough biscuits fortified with *L. spinosa* flour with a significant amount (7g/100 g, on dry basis) of dietary fiber. Tharangani *et al*., (2012) has also developed a chicken burger by incorporating *L. spinosa* and oyster mushroom. Apart from its traditional food preparations, introduction of value added products bring more attention in commercial venture.

The information on cultivation status of *L. spinosa* is not readily available in any Asian country. There are no large-scale cultivations in Sri Lanka. The crop is restricted to small pockets in marshy lands, paddy fields and home gardens. The cultivation package developed by the Department of Agriculture is not popular among these small scale growers. Though its nutritional properties are well understood, it is very popular as a vegetable. The less palatability due to high fiber content can be postulated as one of the possible reasons for that. Furthermore, there is a belief among the public that it absorbs high amount of heavy metals from contaminated soil and water. Kananke *et al*. (2014) have found that level of Ni, Cd and Pb in *L. spinosa* exceed the permissible limits set by FAO/WHO for human consumption in their market survey.

The Collection and conservation of wild populations and cultivated forms are important for both *ex-situ* and *in-situ* conservation. The ongoing study aims to collect and evaluate its potent genetic and morphological variability in 46 of Agro-ecological regions in Sri

Lanka. Such germplasm will provide superior material for cultivation purposes and future crop improvement program. During our literature survey we realized that the knowledge on morphological and genetic diversity, taxonomy and reproductive biology of *L. spinosa* is incomplete. Therefore, we hope that information gathered and discussed here will set baseline, while showing new direction for plant breeders, taxonomists and conservation biologists who work on *L. spinosa* and its relatives.

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# CHAPTER 09

# The Role of Stomata in Enhancing Productivity of Crop Plants

**H.I.U. Caldera***

*Department of Plant Sciences, Faculty of Science, University of Colombo, Sri Lanka*

## Abstract

Stomata provide a gas exchange pathway through which two important physiological processes of the plant, namely, photosynthesis and transpiration occur. Thus, they play a key role in the productivity of a crop as well as in its water use efficiency. This has led to studies on stomatal characteristics with a focus on their manipulation in order to create crops that show a higher productivity, especially in the context of future climate change scenarios. These manipulations have included changing stomatal size, stomatal numbers and stomatal responsiveness in model plants such as *Arabidopsis thaliana* and selected crop species. Some recent literature on the subject is reviewed with an emphasis on research work related to tropical crops. The existing research gaps and future directions are also discussed.

**Keywords:** Climate change, crops, productivity, stomata, water use efficiency

*iroja@pts.cmb.ac.lk

## Introduction

Stomata are small pores which are present on the aerial organs of plants, predominantly on the lower surface of leaves. The sessile nature of plants require them to continually adapt to the changing environment around them, and stomata play a key role in the said processes. The manner in which stomata respond to the multifaceted effects of the environment and thereby control photosynthesis and transpiration is an important determinant of growth and water status of a plant/crop. The interplay between stomata and the environment through these two key physiological processes is an important element of crop yield determination in an agricultural setting.

## Stomatal Conductance and Crop Yield

The cumulative rate of photosynthesis over a crop growing season is a primary determinant of crop yield and studies have therefore focused on strategies to enhance photosynthetic carbon dioxide fixation (Lawson *et al.*, 2012). One of the limiting factors for photosynthesis is resistance to gas diffusion through the stomata.

Stomatal aperture and development are controlled by a network of intrinsic factors such as plant hormones and ionic fluxes as well as extrinsic environmental signals such as light intensity, water availability, temperature and atmospheric carbon dioxide concentration (Willmer and Fricker, 1996; Hetherington and Woodward, 2003; Casson and Gray, 2008). It is the plastic responses of stomata to intrinsic and extrinsic factors that makes it an attractive target for studies on plant adaptations for enhancing productivity.

In the long term, the interactions of stomata with the outside environment involve changes leading to variation in either stomatal density (stomatal numbers per unit area) or stomatal index (number of stomata to the number of total epidermal cells). When considering the short term adaptations, these interactions involve changes of the stomatal aperture and associated stomatal conductance.

Several studies have shown correlations between stomatal conductance and yield. For instance, Fischer *et al*. (1998) found a correlation between mean grain yield and stomatal conductance (r=0.94, P<0.05) of several varieties of wheat (*Triticum aestivum*), and suggested that stomatal conductance as a potential indirect selection criterian for yield. Similarly, Lu *et al*. (1998) suggested stomatal conductance as a selection criterian for irrigated cotton and wheat when grown under high temperatures.

However, the dual role played by stomata in key physiological processes can be conflicting. While open stomata lead to assimilation of carbon in the plant, it can also increase the loss of water *via* transpiration. Stomatal function is therefore highly relevant for crop productivity and plant water use efficiency (Lawson and Vialet-Chabrand, 2019). Thus, manipulating this the said dual role opens up novel areas through which crop productivity can be further improved.

## Stomata and their Role in Enhancing Water Use Efficiency

Water use efficiency (WUE) in a physiological sense is defined as the ratio between the simultaneous rates of net photosynthesis and transpiration. Therefore, changes in WUE can occur due to the variation in photosynthesis, variation in transpiration or a combination of both (Nilson and Assmann, 2010). Stomatal characteristics such as stomatal density, patterning and responsiveness are important determinants of water balance and thereby the WUE (Dillen *et al*., 2008). For example, certain *Arabidopsis* genes such as ERECTA (Masle *et al*., 2005), HDG 11 (Yu *et al*., 2008), GPA1 (Nilson and Assmann, 2010) have been shown to regulate WUE by controlling stomatal numbers. In fact, some of these genes such as ERECTA also affect the photosynthetic capacity and thereby have further impact upon WUE (Masle *et al*., 2005). Further, it is interesting to note that several key regulators of stomatal development such as peptide ligands and transcription factors originally identified from *Arabidopsis thaliana*, are conserved in grass species which include crops such as rice and barley (Endo and Torii, 2019; Zoulias *et al*., 2018; Hughes *et al*., 2017).

Altering of stomatal characters to improve WUE can lead to lowered stomatal conductance and subsequent negative effects with regard to photosynthesis and evaporative cooling (Bertolino *et al*., 2019). Hence, there is a delicate balance between reducing stomatal numbers for WUE while maintaining plant/ crop productivity. Global water usage is predicted to double by 2030 and stomata can play a central role in efforts to increase photosynthesis and crop yield, particularly under drought conditions (Lawson and Vialet-Chabrand, 2019). Developing crop varieties that are able to either sustain or improve yield with less water has now become a priority in agricultural research (Bertolino *et al*., 2019) and stomatal manipulations is one important aspect therein.

With regard to stomatal manipulations in the context of enhancing plant productivity, three key areas can be identified. These are; manipulating stomatal size, manipulating stomatal numbers and manipulating stomatal responsiveness.

## Manipulating Stomatal Size

Stomatal size is usually determined by measuring the length of the guard cells. It is an important variable that determines the maximum diffusive conductance of stomata to carbon dioxide as well as the overall structure and broader ecophysiological functions of the leaf surface (Franks and Beerling, 2009). Studies have found that high yielding cultivars have a larger stomatal size in crops such as rice (Ohsumi *et al*., 2007).

In general, stomatal size is reported to be less plastic than the stomatal number with respect to many factors, though variability in the magnitude and direction of response does exist in different plant species (Holland and Richardson, 2009). Stomatal size is negatively correlated with stomatal density (Hetherington and Woodward, 2003; Franks and Beerling, 2009) leading to leaves having smaller stomata in higher numbers or vice versa. Smaller stomata may be beneficial to a plant as they have a faster response time due to their greater membrane surface area and this coupled with a larger number of stomata may help a plant respond faster to environmental perturbations (Drake *et al*., 2013).

## Manipulating Stomatal Number

Manipulating the number of stomata in a plant requires a sound knowledge of stomatal development, which though is well known in *Arabidopsis*is relatively less studied in many agricultural crops (Caine *et al*., 2019; Bertolino *et al*., 2019). Recent studies on cereals such as rice have shown that lack of *OsEPFL9* expression leads to reduced stomatal density (Yin *et al*., 2017) while overexpression of *HvEPF1* leads to a similar result in barley (Hughes *et al*., 2017). In the latter, the barley plants had a greater water use efficiency and drought tolerance coupled with no change in yield. Caine *et al.* (2019) manipulated a high yielding rice cultivar (‘IR64’) to produce fewer stomata by overexpressing rice epidermal factor *OsEPF1*. These plants had a lower stomatal conductance and used only 60% of the normal amount of water used at 4-5 weeks from germination. They further found that in comparison to controls, the plants were able to survive for longer under drought and high temperature when subjected to elevated carbon dioxide conditions. Therefore, such cereal plants with lower stomatal numbers may be useful under future climate change scenarios as well.

Stomatal numbers are also important in respect to microbial infections of plant diseases. For instance, De Costa *et al.* (2006) reported that total microbial density of rice plants was positively correlated with their stomatal density. Thus, modulating stomatal numbers can also impact crop health and thereby its productivity due to this relationship.

## Manipulating Stomatal Responsiveness

Changes in the guard cell volume in response to external and internal stimuli adjust the stomatal aperture and thereby affect the flux of gases between the leaf internal environment and the atmosphere (Lawson and Blatt, 2014). Thus, stomatal behaviour plays an important role in controlling the volume of carbon dioxide entering the leaf for photosynthesis and in minimizing the amount of water loss. Considering the latter, reducing the number of stomata is one approach to minimize excess loss of water. However, this can negatively impact the carbon gain of plants. Furthermore, a drastic measure such as lowering of stomatal numbers would be useful only in instances where plants would be subjected to prolonged drought. In an agricultural setting what is often encountered is a much more dynamic situation with regard to the plant growing environment. Therefore, the solution required would be enhancing the ability of the plant to rapidly react to the changing environment while maintaining or increasing its productivity.

In one such attempt a synthetic, light-gated K+ channel BLINK1 (Blue Light-Induced K+ channel 1) was used to enhance the speed of stomatal opening under light and its closing after irradiation (Papanatsiou *et al*., 2019). The engineering of this extra ion channel led to a 2.2 fold increase in total biomass in the model plant *Arabidopsis thaliana* under fluctuating light conditions. This rapidity in stomatal movements would be particularly useful under natural environments where passing clouds or self-shading effects could lead to stomata opening and closing for longer periods than necessary.

However, according to Bertolino *et al*. (2019), although rapid stomatal movements might help to maximize WUE under fluctuating light environments, it is unlikely to have much impact on water loss over long periods of water stress under field conditions.

## Conclusion

One question that arises concerning manipulation of stomata is whether plants with a lower number of smaller stomata be able to increase stomatal conductance, maintain water flow and photosynthesis at high temperatures as predicted in the future. Such plants with lower stomatal numbers may, in fact, show a lower WUE under high temperature as they would be unable to maintain cooling (Bertolino *et al*., 2019). Thus, it is important to carry out stomatal modifications and test these under field conditions that mimic extreme scenarios. Also, while stomatal function can be manipulated it is important to be aware of the interactions between stomatal size and numbers and the impact they can have on rapidity of stomatal movement (Lawson and Blatt, 2014).

Furthermore, studies have shown a diversity of responses even amongst ecotypes within *Arabidopsis thaliana* when it comes to environmental responses of stomatal traits (Caldera *et al*., 2017). Therefore, it is important to conduct the studies on specific crop varieties when modifications are carried out as responses may vary.

In the wake of future climate change scenarios, there is an expectation of crops increasing photosynthetic capacity and productivity in a future carbon dioxide rich atmosphere. However, water availability will play a crucial role in this projection as will the predicted increase in temperature. In this background, stomatal manipulations can play a major role in preparing climate-ready crops which warrants further research in the area of stomata and environmental interactions.

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## CHAPTER 10

# Role of Drought Frequency Analysis and Soil Moisture on Management of Agricultural Droughts

**Devanmini Halwatura***

*Department of Zoology and Environment Sciences, Faculty of Science*
*University of Colombo, Sri Lanka.*

## Abstract

Agricultural droughts can be defined as shortage of soil moisture (stress/failure) that affects the containment of vegetation. In the context of agriculture, the assessment of soil moisture (associated with plant available water) is critical because in well-establish plants, deep roots can enhance the water uptake and increase the survival, but shallow roots of seedlings do not have access to the deep saturated soil. Unlike in the past, feasible and reliable methods to measure and model soil moisture and vegetation health are now commonly found, and this makes researchers more interested in using soil-moisture data to estimate agricultural droughts, rather than depending on meteorological drought indices. Thus, in the recent past, crop models and remote sensing methods have been widely applied to estimate droughts. Crop models incorporate information on climate, crop and soil, which may strengthen the understanding of vegetation responses to droughts. But crop models have been criticised because of the uncertainties in input parameters and model assumptions, long running calibrations and data intensiveness. Drought estimation using remote sensing is also becoming common practice, but it has issues such as cost-effectiveness and uncertainties in data acquisition and processing. All these uncertainties and complex and costly approaches promote the usability of calibrated drought indices over measured or modelled soil moisture data to determine agricultural droughts.

***Keywords:** Agricultural drought, droughts, drought indices, soil moisture

devan.halwatura@zoology.cmb.ac.lk

## Droughts

It is expected that by 2025 two-thirds of the world’s population could be under water stress, and 1.8 billion people will be living in regions with absolute water scarcity due to droughts. Droughts are known to cause more ecological and short- or long-term socioeconomic losses accompanying significant secondary and tertiary impacts (especially in food, water and energy sectors) than any other natural disasters. Thus, droughts are recognised as the most far-reaching and costliest natural hazard. Their impacts are also more indirect and diffuse than those of other natural hazards, which makes the identification and cost assessment of drought damage more complex. Between 1993 and 2016, drought cost USD150 billion in Europe, USD100 billion in USA, USD3 billion in Australia (Bureau of Meteorology, 2013; Logar and van den Bergh, 2013), while the total Australian wheat yield in 2006 dropped by 46% and nearly 60% of Indian total cropped areas were affected by droughts (Pandey et al., 2007; Dai, 2012).

## Defining Droughts

Instead of a universal definition of drought, droughts are categorised into different classes based on the affected system(s), for example, meteorological drought, hydrological drought, groundwater drought, river-flow drought, surface-water drought, agricultural drought, soil moisture drought, ecosystem drought, socioeconomic drought, operational drought, etc. (Duarte et al., 2016; Mishra and Singh, 2010; Van Loon, 2016). The environmental and social impacts originate from simple meteorological droughts, then cascade and escalate through hydrological systems and natural ecosystems and end up as a more complex socioeconomic hazard (Dracup et al., 1980; Van Loon, 2016). However, most of these categories do not have a broadly accepted definition (Sayers et al., 2015).

All of the above drought classes are the direct or indirect result of meteorological and hydrological conditions; therefore, some studies proposed to categorise droughts into two or three major groups that reflect different aspects of the hazard, for example, drought (Kiem et al., 2016). The American Meteorological Society (1997) compiled drought types into four major classes, namely, 1) Meteorological or climatological droughts (lack of precipitation and possibly combined with increased evaporation), 2) Hydrological droughts (drying of surface/subsurface water resources), 3) Agricultural droughts (lack of root zone soil moisture), 4) Socioeconomic droughts (lack of water supply for socioeconomic purposes).

## Agricultural Droughts

Agricultural droughts adversely affect the long-term resilience of novel and native ecosystems and these impacts have been intensified in the recent past (Carrick and Krüger, 2007; Doley et al., 2012; Halwatura et al., 2015b). Different ecosystem attributes such as native species distribution, forest structure and function, ecosystem resilience and biodiversity, respiration and primary productivity are profoundly affected by drought events. As an example, floral distribution across various climatic regions is affected by droughts and is accompanied by limitations in plant available water (Matías et al., 2012). Shortage of water directly affects the development of juvenile foliage such as seeds, seedling and saplings. Also, prolonged water deficits may have a critical impact on ecosystems by altering the species composition of plant communities (Corlett, 2016). Due to all of these negative effects on ecosystems and agricultural lands, increasing intensity and frequency of droughts are commonly considered as a great threat to the agricultural practices (Bridge, 2004; Carrick and Krüger, 2007; Mason et al., 2013).

## Drought Indices

Drought does not have a universal definition; therefore, there is no uniform method to quantify its variables: severity and duration. Drought severity is the degree of the rainfall deficit and drought duration is the time period of rainfall deficit and can vary between a week up to a few years (Zargar et al., 2011). In general, the practice of drought estimation is carried out by applying drought indices (Mishra and Singh, 2010). A drought index is a numerical value that reflects the cumulative effects of a prolonged abnormal rainfall deficiency (Mishra and Singh, 2010) and has been applied in various fields, such as early drought warning systems, crop growth and yield predictions, assessment of forest fire threats, heatwaves and dust storms, global climate change and drought mitigation, and threats to sensitive ecosystems and species.

The simplest type of index is a meteorological drought index which depends solely on rainfall, for example Standardised Precipitation Index (McKee et al., 1993), but the role of other meteorological variables, such as evaporation, in drought assessment is highlighted in many studies. Due to the complex nature of droughts and the diverse groups of users, a single index cannot satisfactorily capture all drought variables of interest (e.g. severity, duration, frequency) (Heim Jr, 2002), which inspired the development of various drought indices that represent different drought classes, for example, hydrological drought indices or agricultural/soil

## The Potential Role of Meteorological Drought Indices in Agricultural Drought Analysis

Agricultural droughts can be defined as shortage of soil moisture (stress/failure) that affects the containment of vegetation**.** In the context of ecosystem re-establishment, the assessment of soil moisture (associated with plant available water) is critical (Cammalleri et al., 2016; Wang et al., 2016) because in well-established plants, deep roots can enhance the water uptake and increase the survival, but shallow roots of seedlings do not have access to the deep saturated soil (Padilla and Pugnaire, 2007).

Due to the simplicity of input parameters, meteorological drought indices based only on rainfall (e.g. the SPI) are commonly used to estimate agricultural droughts (Mishra and Singh, 2010); however, agricultural activities depend not only on rainfall or evaporation but also on various biophysical properties of soil (e.g. hydraulic properties, physical properties) and plants (e.g. genotype, growth stage). Therefore, meteorological drought indices may not reliably detect agricultural droughts. To deal with this issue, different modified meteorological drought indices which incorporate evaporation data have been introduced (e.g. Reconnaissance Drought Index (RDI), Standardised Precipitation

Evaporation Index (SPEI)), but they are still normative; that is, droughts tend to be characterised as deviations from long-term averages without incorporating ecologically meaningful thresholds for soil water pressure, such as plant wilting points (Zargar et al., 2011). Some drought indices may be applicable to detect soil moisture deficiencies if the thresholds are calibrated to locally relevant conditions, where they represent the physically relevant thresholds for the specific location. But in most cases, instead of recalibrating on locally relevant data, the indices have been applied based on the original calibrations (e.g. the Aggregate Drought Index was initially calibrated for the US Midwestern states but has been applied in different regions without recalibration) (Zargar et al., 2011).

Unlike in the past, feasible and reliable methods to measure and model soil moisture and vegetation health are now commonly found (Kim et al., 2016) and this makes researchers more interested in using soil-moisture data to estimate agricultural droughts, rather than depending on meteorological drought indices. Thus, in the recent past, crop models and remote sensing methods have been widely applied to estimate agricultural droughts (Chapman, 2008; Osborne et al., 2013). Crop models incorporate information on climate, crop and soil, which may strengthen the understanding of vegetation responses to droughts. But crop models have been criticised because of the uncertainties in input parameters and model assumptions, long running calibrations and data intensiveness (Huang et al., 2013a; Wang et al., 2016). Remote sensing drought estimation methods are also becoming common practice (Carrão et al., 2016; Lessel et al., 2016; Sánchez et al., 2016), but they have issues such as cost-effectiveness and uncertainties in data acquisition and processing (Pal and Mather, 2005; Van Leeuwen et al., 2006). All of these uncertainties and complex and costly approaches promote the usability of calibrated drought indices over measured or modelled soil moisture data.

Calibrating drought indices so that they reliably represent crop stress under locally relevant conditions ideally requires long records of both meteorological and water potential data (Keyantash and Dracup, 2002). Such long series of observations are difficult to obtain for water potential, except at long-term experimental sites that are found only in a very limited range of soil types, climates and plants. Therefore, there is a considerable interest in estimating agricultural drought conditions using simulated soil moisture data. However, very few comparative studies have been published to guide the decision on the most appropriate method for characterising soil moisture droughts.

## Drought Frequency Analysis as a Risk Assessment/Management Tool for Agricultural Droughts

Drought frequency analysis is commonly used to analyse droughts (Byun and Wilhite, 1999; Hamdi et al., 2016), in particular to estimate the severity of a drought of a given annual exceedance probability or the exceedance probability of a drought event (Kwon and Lall, 2016). Frequency analysis may be based on developing a bivariate probability distribution function for severity and duration.

Risk can be determined by the consequences and probability or likelihood of an adverse effect. Risk assessments associated with natural resources and extreme climatic conditions (floods etc.) have become a growing concern (Blauhut et al., 2015; Kiem, 2013; Sayers et al., 2015). Intensity-duration-frequency (IDF) curves of rainfall have been widely used as a planning and risk assessment tool in the development of water resource infrastructure. However, such techniques (e.g. Severity Duration Frequency (SDF) curves) were not used for drought assessments until the early 2000s. SDF curves were originally applied in Greece to determine the relationships between droughts and wet periods (Dalezios et al., 2000) and eventually became a useful tool for drought estimation (Shiau and Modarres, 2009). The SDF curves not only provide site-specific data on the probability of drought occurrence but also give a set of severities and durations for a specific drought exceedance probability. Probabilistic properties of SDF curves, for example, provide information for planning and managing water resources, which can help to develop comprehensive drought management plans based on water availability and can be used to adopt suitable drought mitigation strategies in drought-affected agricultural areas (Khedun et al., 2011; Reddy and Ganguli, 2012).

Chapter 9

# Implementation of Drought Severity Duration Frequency (SDF) Curves as a Risk Assessment Tool in Agricultural Drought Management

Degradation of natural habitats (e.g. deforestation for agriculture or mining) is a huge threat to the natural environment. Ecosystem rehabilitation aims to recover these lands and provides some faith for the future of the environment (Dobson et al., 1997). Climatic conditions, physical and chemical properties of soil, and ecological stresses are key biotic factors to be considered for better rehabilitation (Carrick and Krüger, 2007; Corlett, 2016; Vogt et al., 2016). On top of that, extreme climatic events such as acute temperatures, below average rainfall, and frequent storms are considered as barriers for the success of agricultural practices. Of the above extreme climatic factors, droughts have been considered as a serious and growing issue worldwide.

Soil moisture deficits play a key role in agricultural activities worldwide. Current climate classifications have added great value for management of agricultural/forests lands in many continents. Similarly, frequency analysis of rainfall (to estimate design rainfall) is also commonly used as a planning or risk-assessment tool to determine failure rates of droughts. But using climatic classifications as a planning tool for initial planning of agricultural lands/rehabilitation is not ideal, because young foliage is highly vulnerable to droughts (Audet et al., 2013). Therefore, a comprehensive assessment of droughts is necessary for better planning and risk assessment (Arnold et al., 2014a; Cuneo et al., 2016). What constrains the assessment of failure risk by land managers is a lack of site-specific data on the probability of drought occurrence. Drought SDF curves are rarely considered to assess the risk of failure of ecosystem rehabilitation/failures in agricultural practices in anywhere around the world (Audet et al., 2013; Halwatura et al., 2015b). The lack of drought risk assessment in ecosystem rehabilitation or decision making in agricultural practices underpins the urgency of new approaches to preparing for future droughts.

## Using Simple Meteorological Drought Indices to Determine Agricultural Droughts

In general, SDF curves can be estimated using a range of datasets, such as climate data (rainfall, evaporation), soil water potential (monitored or simulated) and surface runoff data. Each data type may have specific advantages for assessing droughts related to their field of study. For example, soil water potential is biophysically more meaningful than rainfall in estimating agricultural droughts and may be more applicable for agricultural/rehabilitation. Similarly, river flows/surface runoffs can be used to develop SDF curves to determine hydrological (blue water) droughts, which are more applicable for drought assessments in urbanized areas. However, the simplest approaches are preferred instead of physically based soil water models to assess agricultural droughts due to model uncertainties and complexity (Halwatura et al., 2016).

The capability of simple meteorological drought indices in detecting agricultural droughts has been discussed in recent literature. Considering the usability of drought indices versus soil moisture data (monitored and simulated), meteorological drought indices have several advantages over those based on soil water pressure, as they are straightforward, effortless to generate and input data for deriving drought indices are readily available. For example, in Australia there are around 18,000 rain gauging stations, some dating back to the mid-1800s, distributed in 116 rainfall districts (Bureau of Meteorology, 2013) but, publicly available soil moisture data are restricted to coastal areas of south-east and south-west Australia. In developing countries like Sri Lanka, the situation is much worse. Thus, drought indices are recommended based on the complexity and the sensitivities of the input parameters of the physically based model, as well as the failure rate of the drought indices, which are not reasonably low. Therefore, depending only on drought indices without validation might not be a reasonable alternative.

On the other hand, soil water pressure is the most suitable variable for assessing and monitoring plant available water (Cammalleri et al., 2016), unlike drought indices which only provide a normative value (unit-less and cannot be compared with other sites). For example, A study shows that the most severe drought observed in location in Bourke Australia was detected as -3.0 by SPI. This SPI value does not provide any information on how the drought will affect the plant communities, while for the same drought the average soil water potential for 5 cm depth was modelled as -37,811 hPa (Halwatura et al., 2017). The soil water potential value is more than twice the permanent wilting point (-15,000 hPa), which means that plants would definitely die. Therefore, if observed or reliably modelled data are available, soil water pressure values can provide robust measurements of the severity of droughts based on ecologically relevant measures such as plant available water that are comparable with other locations.

## Propriety of Drought Indices to Estimate SDF Curves Relative to Soil Moisture

In many parts of the world, agricultural activities as well as ecosystem restoration projects are struggling with droughts as well as financially. Therefore, a pre-requisite is to follow a risk assessment in order to use allocated funds properly. However, as discussed in above sections performing a comprehensive assessment with SDF curves based on soil moisture is expensive. Depending on the allocated funds and requirements of the rehabilitation plans/agricultural activities such as scale (large, small), stage (planning, initial, and ongoing), and other specifications (use of specific plants or soil), either drought indices or soil water pressure should be selected to estimate SDF curves. Understanding the applicability of meteorological drought indices and soil water pressure in estimating drought risk assessment is critical in choosing the method to be used in a risk assessment.

Meteorological drought indices may be beneficial for planning and management of large-scale rehabilitation projects or large-scale agricultural activities for a number of reasons. Firstly, soil types may vary throughout the landscape making it more expensive to measure soil moisture in different soil types. Also, where rehabilitation is made up of mostly mature plants (ongoing rehabilitation), use of meteorological drought indices maybe more cost-effective, because at that stage, the plants are not highly sensitive to soil moisture. Moreover, for sites where the soil is altered due to various factors (i.e. anthroposols) simulation of soil moisture based on the local soil type may not be appropriate. For example, in the cases where post-mined sites are filled with waste rocks or sand (Hamrin et al., 2001), lands affected by landslides might have a mixture of soil and in areas affected by bushfire the chemical and physical properties of soil might be changed (Neris et al., 2016).

For other situations soil water pressure representing plant available water would be a more appropriate option. If rehabilitation incorporates specific plant types such as habitat restoration of sensitive species that depend on a particular plant – for example, migratory shore bird habitats, mangroves (WetlandCare Australia, 2016) – soil water pressure measurements are more useful than outputs from drought indices. Similarly, at the initial stage of rehabilitation measuring soil water pressure is recommended as seedlings are more sensitive to droughts than grown trees due to their under developed root system. For ecosystem rehabilitation, if the locations have long historical observations of soil moisture data and measured plant-specific soil water pressure values, it is always appropriate to use soil moisture values instead of using drought indices. Then the SDF curves can be developed using soil water potentials and the annual exceedance probabilities (AEP) of soil moisture droughts could be effectively calculated. Further, if the plant-specific soil water potentials are available (e.g. if the permanent wilting point of particular location is available), then the AEP can be directly related to the interested plant species. A similar approach can be used in agricultural practices involving commercial crops. Similar approach can be used in agricultural practice e.g. commercial crops.

## Conclusion

We live in an era where extreme weather events have become even more potentially disruptive than recent past. Especially droughts become more frequent and intense. The capacity of land to provide ecosystem services while assuring its function is also reducing. It is a responsibility of scientists to identify potential threats, find solutions and effectively communicate the possible adaptive measures to overcome the impacts of droughts. This chapter demonstrates the significant utility of drought risk assessment for the initial planning and management of agricultural activities. The facts discussed in this chapter may enhance the capacity of responsible authorities to implement effective strategies and adaptive measures for better planning in agriculture, especially in drought-prone areas around the world.

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