

SUSTAINABLE FOOD PRODUCTION PRACTICES 2 in the Caribbean



Edited by
Wayne G. Ganpat and
Wendy-Ann P. Isaac

Sustainable Food Production Practices in the Caribbean

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Sustainable Food Production Practices in the Caribbean

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Edited by
Wayne G. Ganpat and Wendy-Ann P. Isaac



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Foreword

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With each passing day, the need to produce healthy and nutritious food in a sustainable manner increases. While scientists and food producers actively seek out alternative ways to produce food to meet this demand, other challenging events to food production now require a redoubling of efforts. The ever increasing impacts of climate change in the Caribbean which have been predicted to be manifested in more frequent extreme events such as stronger hurricanes, longer droughts, severe floods, and more virulent pests and diseases, now demand that sustainable food production should rise to the top of the region's agenda for immediate action.

The pressing need for food following extreme events is likely to force producers to engage in non-sustainable practices such as: injudicious use of inorganic chemicals, misuse of scarce water resources, practise extreme land tillage practices, abandon rest periods, and clear virgin forests, all in an effort to produce food rapidly in a period of high demand. All of these, and other likely non-sustainable practices which may be adopted because of urgency to meet the demand for food in a dire situation, could roll back the gains the region has made in the last few years towards implementing more sustainable food production practices.

The role of education in the effort to produce safe and nutritious food in a sustainable manner is of paramount importance, and therefore cannot be overstated. Research will have little impact if food producers are not adequately educated and well-equipped to make deliberate and determined efforts to adopt more sustainable approaches to food production over the entire value chain.

To support the region's effort to develop a sustainable food production system, the first volume titled *Sustainable Food Production Practices in the Caribbean* was published in 2012. This second volume is meant to provide a seamless transition from Volume 1. It provides technical information, in an easy reading style on a variety of practices, which if adopted, have the potential to transform present unsustainable approaches to food

production to those which can meet the region's food needs while reducing stresses and strains on the environment. The quality and appropriateness of the information in this volume, as well as the de-emphasis on technical jargon, makes this book essential reading for students in agriculture at all levels and in particular, the CSEC and CAPE levels and for those pursuing the various Diplomas in Agriculture around the region. While it can be also used as a reference book by students at the higher level, some eager farmers could make use of its offerings. Although the two volumes are useful as essential resource materials for the region's extension practitioners, their content is relevant and appropriate to tropical agriculture generally.

The region has taken too long to embark on the road to sustainable food production, and the consequences are ever present, as can be seen in the denuded hillsides in some countries, an over-abundance of weeds, pests and diseases, unusable soils, and the heavy use of chemicals. The region has a long road to recovery. Sustainable production of safe and nutritious food is therefore critical to the welfare of all people in the region. This second volume is aimed at supporting the region's effort to develop sustainable food production systems by promoting the use of appropriate practices, as the region cannot always expect the problems faced internally to be solved externally. Land, water and other non-renewable resources in the region are very limited, and are now being threatened by events over which we have little control. Despite this however, all of us who live in this region can take actions to mitigate any negative impacts. To overcome these imminent challenges, the region must strengthen its efforts to work harder and smarter to achieve more sustainable food production systems, a legacy for future generations of the Caribbean.

Preface

Wayne G. Ganpat and Wendy-Ann P. Isaac

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At present, a grave concern facing the Caribbean is the creation of sustainable food production systems. Over the past four decades, the increasing unsustainable use of agricultural inputs has become very evident in the farming sector, without much warnings being given about the adverse health and environmental impacts associated with them. Over the next few decades, countries in the region can expect increases in food prices due to rises in fossil fuel prices and climate change events. Alternative, sustainable farming and food systems must be encouraged if we are to maintain a supply of healthy food at reasonable prices. Our region cannot afford to remain complacent about food security and must urgently take swift action to boost the agricultural sector and empower our food producers.

The 12 chapters in this book are a blended collection of sustainable best management practices that were not covered in the first volume, *Sustainable Food Production Practices in the Caribbean*. Included chapters present other innovative technologies for adoption to meet food security needs in the Caribbean region. Topics covered in this volume include: the role of small producers, family farms and women farmers in sustainable food production and food security; youth as adding value to agriculture in the region; small animal systems (rabbits and ducks); rain shelters and net-houses for vegetable production; natural and indigenous crop protection methods; sustainable water management practices for food production in the Caribbean; sustaining the environment (farm and beyond the farm); appropriate logistics to reduce losses in the postharvest handling system; appropriate agrosystems in the Caribbean; agricultural diversification and non-traditional systems for sustainable food production; agroforestry systems and practices in the Caribbean; and a note that introduces a method for growing tilapia in Atlantic seawater in St Kitts.

This book should be useful for those involved in food production throughout the region as it seeks to educate them about practices that threaten the Caribbean's conditions of sustainability, which have resulted in a misuse of resources, soil and water pollution, land erosion and loss of biodiversity. The book analyses these problems and offers approaches,

methods, tools and techniques to enable a more sustainable and rational use of our resources which include our human capital – the people, especially the youth. It is anticipated that this book will be a useful reference to preserve and enhance sustainable productivity to ensure food security and sustainable agriculture in the region.

Chapter One begins with an analysis of the role of women and small family farming systems in the domestic food sector and food security in the Caribbean. The chapter reviews the historical role of women in Caribbean agriculture, briefly describing women's work in the fields on the plantations, as well as in the production of food for home consumption. It describes the roles of women and shows how their contributions in the domestic food sector are particularly important for food security in the region and areas in which such contributions can be strengthened.

With the average age of farmers in the region being over 50 years, and the continuing perception that agriculture is unattractive to young persons, **Chapter Two** is positioned from a context of change and empowerment for youth engagement in agriculture across the Caribbean region. The authors contend that in order for young people to be fully integrated in society, they must be given the resources to become fully empowered for productivity. Based on an analysis of rural youth agricultural programmes across the globe and the formal reports of Caribbean youth leaders, a model for engagement is proposed. Because of the diversity in the region, a flexible rather than a fixed model is suggested. Each country could choose from the essential components to make its own model. Using this approach, the authors believe that the face, and more importantly, the productivity of agriculture can be changed. For this to happen however, young people within the Caribbean must be supported by appropriate, sustainable interventions that allow them to fully engage the sector. The chapter suggests several such interventions.

Chapter Three presents a production guide for potential rabbit and duck farmers. The authors point out that over the last decade, there has been a move from small backyard production to medium-sized intensive commercial and semi-commercial rabbit production systems in Trinidad and Tobago. In tandem, there has also been an increase in duck production and a similar trend towards intensive and semi-intensive production systems. The authors clearly outline guidelines for increased productivity in these enterprises. Those persons wishing to enter these areas will also find the information quite useful.

Chapter Four provides a comprehensive overview of best management practices (BMPs) for sustainable production of vegetables in rain-shelters and net-houses. In contrast to the first volume of this book, the focus is placed on the production of leafy vegetables, mainly lettuce, rather than tomato. However, owing to similarities among protective structures, some of the principles and practices, which are described in detail in the first volume, have been summarized and new, valuable information is presented.

Chapter Five seeks to undo the historical emphasis on synthetic pesticides through a review of various natural and indigenous/traditional crop protection strategies used throughout the Caribbean. It details the significance of promoting and supporting these ecologically based strategies for the sustainable production of food by small producers to ensure food security in the region. The results of surveys conducted among aging farmers throughout the Caribbean are used in this chapter which also explores other examples which could be successfully adopted from other countries. The chapter concludes by emphasizing the need for research and development to capture, assess and disseminate natural and indigenous crop protection strategies widely across the Caribbean.

With expected decreases in the amount of rainfall in coming years, water availability for agriculture within the region will be severely affected unless sustainable water management practices are engaged. Therefore, to achieve a sustainable, functioning environment and a food secure Caribbean region, water management practices that are appropriate must be an integral part of the way we use our water resources. Adopting sustainable water management practices will alleviate several economic, social and environmental impacts, and will have far reaching benefits to cope with the myriads of constraints that are inimical to achieving food security in the Caribbean region. **Chapter Six** outlines some of these sustainable water management practices for food production in the Caribbean.

Chapter Seven examines what is involved in sustaining the environment of the farm by focusing on several of the complex interrelationships that exist between food production and food safety within an environmental context. The chapter also provides recommendations to reduce the adverse impacts of agro-environmental hazards and food safety considerations which have a direct impact on societies globally.

The need for logistics management of fruits have come to the fore following the recent global energy crisis followed by the global financial crisis. Logistics management is an important tool in the area of post-harvest management and its main purpose is to enhance competitiveness, while ensuring a focus on serviceability. **Chapter Eight** outlines some of these logistic management strategies available for adoption, using mangoes as an example.

In the Caribbean, multi-species systems whether mixed cropping systems, livestock farming systems or integrated ones, provide several environmental services. Using these systems as examples, **Chapter Nine** examines the major driving forces that condition changes in farming practices – agro-ecological engineering, and proposes methods that might support the design of innovative agricultural systems. The authors provide concrete examples from several Caribbean and other tropical environments.

Chapter Ten treats with agricultural diversification and non-traditional systems for sustainable food production. It deals with the challenge of creating a sustainable supply

of food for local consumption in the Caribbean with some potential for export. While it is important to note the recent trends in large-scale production, including a long decline in plantation systems geared for the export of single crops, and more recent attempts to boost commercial farming for delivery to niche export markets, the chapter looks at recent and emerging efforts to implement non-traditional systems geared to small-scale farming. These systems are aimed at strengthening local food security and adapting traditional farming methods in the face of climate change.

Chapter Eleven traces the historical evolution of the agro-forestry system, and gives a broad overview of agro-forestry from an international perspective. Agro-forestry is presented as an exciting opportunity for farmers but not as a cure-all for all our land-use problems. As with any other land-use option, agro-forestry involves trade-offs, i.e., some short-term gains may have to be given up for the sake of long-term sustainability. Throughout the chapter, references and examples are provided for countries belonging to the Caribbean Community (CARICOM).

The final chapter in the book, **Chapter Twelve**, presents a note that introduces a method for growing Tilapia in Atlantic seawater in the island of St Kitts as a sustainable alternative to the traditional coastal fishery systems.

In conclusion, it is our deep desire that this book will be a fitting complement to Volume 1 and that all who read it will be greatly enriched by the wealth of information presented by the various contributions.

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The Role of Small Producers, Family Farms and Women Farmers in Sustainable Food Production and Food Security

Theresa Ann Rajack-Talley

INTRODUCTION

In the world today, there are over 500 million small producers and family farms. Eighty percent of all farm holdings in developing countries, including the Caribbean, are family owned and operated, and although they practise small scale production, grow 80 percent of the world's food that feeds billions every day. Small producers and family farms are also known to be important preservers of the world's natural resources as they conserve ecosystems and biodiversity. At the same time, they experience many barriers because of the size of their operations, systems of production, what they produce, their modus operandi, and their management practices. Further, the areas where women predominate as farm managers, partners, family labour and/or wage labourers, are continuously neglected because of gender discrimination. As a result, it is difficult for many small producers and family farms to move beyond subsistence levels. Consequently most of the world's poor are the very ones producing half of the world's food – the women and men small farmers and their families.

Most farming families live in humble homes and operate low-resource farms. They are often stereotyped as uneducated, resistant to technology and modern practices, and are criticized for having a non-profit management orientation. Nevertheless, the data show that small producers and family farms are consistently producing food in sustainable ways. The United Nations (UN) reports that small producers and family farms play a major role in hunger reduction and sustainable development and has designated 2014 as the *International Year of Family Farming*. They also suggest that

agricultural production worldwide should be transformed from predominantly large-scale and intensive farming systems to small-scale sustainable models, in order to alleviate poverty and eradicate hunger (UN 2011). In the Caribbean, this means a tangible shift from the favoured male-dominated, ‘cash’ crop export-oriented focus to domestic food production and greater emphasis on the role of women in agriculture. This will require a repositioning of the farm family system from the periphery to the centre of the region’s agricultural sector. A redirection of Caribbean agriculture is extremely important at this time for two main reasons. First the food import bill has been rapidly climbing and was estimated at US\$3–6 billion for the region for the 2012–2013 period. With the exception of Belize and Guyana, most of the Caribbean countries are net importers of food, averaging 60 percent in some cases and as high as 80 percent in others. Such high levels of food importation compete with local food production and gives rise to uncertainties in the domestic agricultural sector and food prices. Further, a heavy dependency on importation to satisfy food demands presents a threat to the region’s food security and the dietary patterns and nutrition of Caribbean people. The importation of foods is usually accompanied by a fast food culture and the use of highly processed foods that elevate levels of salt, fats and sugars, and often results in an increase in obesity, hypertension, and other health related conditions. Secondly, the removal of protective markets for some of the region’s most important agricultural exports such as sugar and bananas has resulted in a decline in the sales and prices of these products on the open market. Consequently, farm families who depended on the sales from export crops experienced serious losses in income. To a large extent, prior farm owners had no other alternative but to become wage earners and seek non-agricultural sources of income, losing the freedom and autonomy that family farms offered. Additionally, hundreds of farm labourers from rural villages across the Caribbean are now unemployed.

These developments in the Caribbean have fronted an urgent call to diversify the agricultural sector and focus on food security and sustainable development. At the core of this plan lies the network of small producers and family farms that are scattered throughout the landscape of the region. Since women play major roles as small producers in local food production and marketing, such a reorientation also necessitates addressing gender issues in agriculture (FAO 2011). In other words, supporting small farming systems and gender equality are both necessary for sustainable agricultural development that meets the food and healthy dietary needs of people, maintains and generates employment, and supports the social, cultural, and economic development of rural communities and society at large.

The following analyses and discussions attempt to explain further the role of small producers and family farms in sustainable agricultural production, food security, and economic growth for the Caribbean. In the process, the negative images of the ‘peasant’

farmer are demystified and the role of women in domestic food production, processing and marketing, inevitably becomes central to the discussions. They begin with a brief account of the history of small producers and family farms and their role in agricultural diversification. The continued importance of the sector and small farm production systems are discussed along with a profile of the small producer and the family farm. Core to the discourse is the relationship between the plantation system and the family farming system, the export market and the domestic food sector. Within the discourse, women's roles are highlighted, their potential explored, and the challenges they face identified. At the end of the chapter, recommendations are made that tie together small producers, family farms, gender equality, and sustainable food production in the Caribbean.

However before we discuss the role of small producers, family farms, and women in food security and sustainable development, it is important to understand what is food security and what do we mean by sustainable development. The World Food Summit of 1996 defined food security as having three main pillars:

- Food availability: sufficient quantities on a consistent basis;
- Food access: having sufficient resources to obtain appropriate foods for nutritious diets; and
- Food use: appropriate use based on knowledge of basic nutrition along with adequate water and sanitation.

On the other hand, according to the Atangana (2012), the President of the Pan-African Farmers' Association, for agricultural development to be sustainable the following basic principles should be adhered to:

- The system should be able to feed the family and ensure an income;
- The system must work in harmony with the environment and therefore be based on agro-ecological production;
- The sector should also be able to sustain employment; and
- Sustainable agricultural development should incorporate agricultural diversification as an alternative to industrial type mono-cropping systems

Achieving sustainable food production, therefore, ensures food security and having food security means that the basic right of people to the food they need is met. Within these two understandings, the small producer and the family farm appear to be good models on which sustainable food production can be built. Moreover, both the small producer and the family farm have proven to be persistent and strong features of the rural landscape of many Caribbean countries. On these farms women are the main growers of local foods,

and in the home they assume responsibility for planning and preparing the meals/diets of families, and society at large. It stands to reason therefore, that regional food security can be increased by changing the focus of agricultural production to support the small producer and the family farm, as well as enhancing the wide ranging role of women. But who are small farmers and how can family farms contribute to sustainable development?

THE SMALL PRODUCER AND THE FAMILY FARM

Farmers who produce on a small scale are often part of a family farm operation and are sometimes referred to as peasants, small farmers or small cultivators. In the Caribbean, the history of their evolution is tied to the post-emancipation period of plantation production under colonialism. However, peasant-type activities were observed long before emancipation when under slavery (pre-1938 period) enslaved women and men grew most of their own food and were allowed to sell the excess in open-air markets. The small producer and family farming systems as we know them today were started after emancipation and located either on the peripheries of the plantations or on abandoned estates. Some were established in the mountainous interiors – wherever ex-slaves could find land. The now freed peasant workers had no choice but to continue to work on the plantations for cash, however, their orientations were to reject the plantation system of mass production, monoculture agriculture, and a dependence on foreign control.

THE HISTORICAL EVOLUTION OF SMALL PRODUCERS AND FAMILY FARMS

Marshall (1983) identified three stages of growth of the small farming system or the peasantry as he called it. The period of *establishment* (1838–1850/60), during which there was a huge desire by emancipated slaves to acquire land and use the skill and knowledge they gained from working on the plantations to become independent cultivators. Land acquisition, however, varied from one Caribbean country to another. In the smaller territories with well-established sugar plantations, such as Barbados, St Kitts and Antigua, there were fewer opportunities to access and purchase land. On the other hand, in Jamaica, Trinidad, British Guiana, and the Windward Islands, there were greater opportunities for land acquisition and the establishment of small peasant farms.

Secondly, there was the stage of *consolidation* which extended to the 1900s. During this period, the monies earned from selling mainly ground provisions were used by the plantation labourers to purchase their own small farm holdings and become independent cultivators. Many small villages were established at this time and the small-scale farmers expanded their operations to include the production of crops for the export markets. As the small

operators shifted into crop production for export, competition for land increased and land availability became somewhat problematic. This was followed by a period of *saturation* – the third phase of the peasantry, which occurred in the post-1900 era. The expansion of small independent farm operators could no longer occur within plantation-dominated societies, and in some places their numbers were drastically reduced. At this time, relations with the plantation systems and structures were strained due to ‘real or perceived’ competition between the two for land, labour, and markets.

Over the years therefore, the experience of colonization spawned two distinct but related agricultural sectors in the Caribbean. On one hand, there is the plantation sector and on the other, a system of small producers and family farms. The plantation sector is centred on commercial production of cash crops, while the subsistence sector of small producers and family farms mainly produced food for home use and for the domestic market, with some linkages to the export markets (Rajack-Talley and Talley 2000). Because of the difference in scale of production, resource availability and use, as well as the monetary importance placed on export marketing, the plantation sector was cast in an industrial model and seen as the stronghold for development in the Caribbean. Conversely, the small farmer or peasant was negatively depicted as a laggard, mainly because he/she lacked the land, finances and access to information and technology to produce at the plantation level.

The historical accounts of the small farm development explain that the emergent peasantry did not consist of ‘slackers’ or ‘laggards’, but innovators who used the little resources they possessed and modified the traditional plantation system of production and economics. So for example, at the end of the 20th century when the traditional export, sugar, was threatened by European beet sugar, it was recommended by the British Royal Commission in 1982 and 1986, that plantation agriculture be diversified and small scale farming encouraged (Marshall 1985). Subsequently, there was some increase in domestic food production and diversification into alternative crops for export such as cotton in Antigua and Barbuda, Barbados, St Kitts, Nevis, and Montserrat; arrowroot in St Vincent; nutmeg in Grenada; cocoa, coconuts and citrus in Jamaica and Trinidad; rice in Guyana; and lime in St Lucia and Dominica (Greenwood and Hamber 1980). These alternative cash crops were first grown on small family farms, alongside the more traditional sugar cane, bananas and domestic food crops. Many of these were later adopted by the larger plantations and considered important contributors to the GDP of different Caribbean territories. In a sense, agriculture diversification (which is once again being advocated) can be traced to the small farm holdings and family farms.

Small farm production systems therefore posed challenges to the hegemonic importance of the plantation systems of production, as far back as these early times. Not only did the

small farms provide the Caribbean with self-sufficiency in food production and food security, but they also supplemented the export trade markets. Both groups worked together for a time but the relationship soon became strained as the network of small producers and family farms grew. The competition between the two sectors for land, labour and other resources fiercely increased. Over time, small farmers were not only a strong economic entity, but also a political force to be reckoned with. For example, the West Indian Royal Commission reported that small farmers were responsible for the establishment of the Agricultural Society in Jamaica and the appointment of ‘travelling agricultural officers’ (the first group of agricultural extension officers). Following on this, farmers’ cooperatives (e.g., Agricultural Societies, People Co-operative Banks, etc.), were established as farmers pooled their resources to buy land, build drains, and share labour costs on the farms. The political sphere of their influence was further enhanced through the establishment of small villages, the expansion of farmers’ markets and the building of schools and churches. In many ways, the activities of the small farming households converted plantation sites into indigenous communities and modernized societies throughout the Caribbean (Marshall 1983; Lewis 1936; Mintz 1984). In comparison, the colonial forces both at home and abroad, not only neglected small farmers as a group, but also gave them little resource support and even occasionally dealt with them with open hostility.

The history of the small farmer in the Caribbean has been one of mixed perceptions and experiences. While the networks of small producers and family farms were making significant economic, social, and political contributions to the sustainable development of Caribbean societies, government policies for a long time favoured the larger commercial agricultural holdings. Small producers and family farms were treated with more of a palliative approach rather than reformative, particularly with matters of land settlement schemes, credit facilities, research, and extension services. Over time, the lack of support and resources eventually took a toll on small producers and family farms and many were limited to production at subsistence levels, unable to compete with the large plantation systems producing ‘cash crops’ for the export markets.

CHARACTERISTICS OF THE SMALL PRODUCER AND THE FAMILY FARM

Today, small producers and family farms persist with much variation in physical, financial, human, and social resources, including size of operations, land ownership and management. However, the following characteristics are commonly noted:

- Small producers and family farms continue to co-exist alongside the plantation system of production;
- They have limited access to land and other resources;

- Farm lands are either owned, or rented/leased, shared with other family members, or illegally occupied (squatters) on government or absentee landlord-owned estates. It is also common to find farmers utilizing a combination of these different tenure arrangements;
- Farm size can vary, but small operations range from 0.2–2.0 ha. There is also a group of landless farmers;
- Many farmers have separate plots of land that are dispersed, of different sizes and tenure arrangements; and not all the land is utilized at the same time;
- Mixed farming is practiced, which incorporates a combination of crop production, livestock husbandry, forestry, artisanal fishery and small scale aquaculture;
- Some farmers practice agricultural diversification, producing food both for the home and the local markets, as well as for the export market;
- Farmers devote a major part of their time to cultivation using mainly their own labour and that of family members, with little paid help from non-family labourers. The primary farmer both manages the farm and is part of the farm labour;

The livelihoods of family members are dependent on the farm, but many rural households cannot depend entirely on agricultural production and combine income from the farm with cash earned from off-farm agricultural and non-agricultural activities.

SOCIO-DEMOGRAPHIC CHARACTERISTICS OF THE SMALL FARMER

Information on the socio-economic description of the small farmer is not readily available but the common depiction is of an aged, predominantly male population. This may be the case in many countries such as Jamaica for example, where the average male farmer is 50–60 years old. However, the census of agriculture data for many Caribbean countries record the small farmer as male, ranging in age from 41 to 54 years, while women farmers are recorded as comprising 30 percent of the farming population. In a few countries young people are becoming involved in farming, however in general, youth under the age of 25 years show little interest and women under 35 are absent from the statistics as farm holders. Approximately, 50 percent of small farmers have some level of primary level education, 20 percent have secondary school certification, and a few have post-secondary or tertiary education (FAO 2012). These demographics are important when working with the small farmer as they help to determine the best form of communication, how to exchange information and technology, and overall, how to work with the farming families.

Most farmers continue to access their information from informal sources, family members, other farmers, and based on their own experiences. They also talk with agricultural shop

owners and extension officers. Radio and to a lesser extent television programmes focused on aspects of farming, are also of interest to them. More recently, farmers turn to their children to access the internet for information and research. Interestingly, while it is common to hear farmers say that they do not want their children to follow in their footsteps and encourage and invest in their children's education, they do engage their children in farming as part of a family business. However, the family farming businesses of these small Caribbean farmers do not conform to your stereotypical business model. As a result, it is often missed by professionals who argue that farmers need to change their approach and become more businesslike – rather than see the family farm model as one of many different business models that can lead to sustainable development.

More often than not, farming offers an opportunity when all other doors are closed either because of lack of qualifications, job opportunities, or resources. As a whole farmers comprise a mixed group of individuals. Some are innovators, while others are less willing to change their traditional methods of farming. Most admit that they enjoy farming, have a profound love and respect of the land, and take pride in having a keen sense of the importance of being able to produce food for family and country.

ARE SMALL FARMERS RISK AVERTERS OR RISK TAKERS?

Whether small farmers and farming families are innovators or traditionalist is best understood by examining the many reasons why they do not readily change their agricultural practices. The most common factors include inadequate information and the lack of the requisite technical and financial resources. However, even when these are provided some farmers are still hesitant to adapt and improvise because they are not yet convinced that the risks associated with these 'unproven' ideas are worth taking chances. Caribbean small farmers do have what has been described as an *aversion to risk* under uncertainty (Beckford 2002). Others also suggest that Caribbean small farmers exhibit the characteristics of *risk appraisers and/or adoption appraisers* (Beckford and Campbell 2013). There is however, one valid explanation for such behaviour that is usually missed by scientists and policy makers, that is, farmers exercise human agency in their decision-making, especially when the survival of their families is at risk.

In most small farming households, families are highly dependent on food and income derived from agricultural practices that have sustained them for years, albeit at meagre or adequate levels. When new ideas are presented, it is imperative that farmers and their families appraise the risk of the situation and assess the possibilities of losing everything, along with the potential hunger and poverty that may result. In other cases, the farmer and his/her family may also assess the ability of the household to avert any negative outcome

and whether or not they can recover without going hungry and poor, if they fully adopt new ideas. It is because of these types of assessments that small producers and family farms have traditionally practised mixed farming and crop diversification. If one product fails due to a disease, catastrophe in the market, or because of flooding and other natural disasters, they can rely on the other farm enterprise to feed and/or earn an income to take care of their families.

Farmers are very sensitive to the outcomes if their farming practices fail. Beckford and Campbell (2013, 50) rightly link the small farmer's 'safety first mantra' to years of experience of not having government and/or other institutional support and safety nets. Small cultivators are members of households and villages and are responsible for making rational decisions in the best interest of all. Their methods of assessment before making decisions are seldom noted and widely misinterpreted as an inherent unwillingness to adapt. Farmers are not necessarily 'diametrically opposed to innovations' but they must first be convinced based on their own assessment that the recommended farming practices are safe, and the methods and technologies are both useful as well as affordable to the household budget (not just the farm), before they adopt (Beckford and Campbell 2013, 51).

As it relates to farming families on small farms, Le Franc (2006) has noted that there are other life threatening priorities other than economics. The hesitancy of farmers to change their practices should not be perceived simply as a cultural phenomenon. They are known to make rationale choices as human beings and if they do not adopt what is perceived as an economically sound idea, it is often because they have not been convinced that it can work, and/or that there is a safety net to protect his/her family if it does not. If we give farmers human agency then the typecast of the unresponsive farmer and laggard will be rejected and the frustrations that researchers, scientists and policymakers experience when working with small producers and farming families, could possibly be resolved. Equally important, we will be able to see clearly, why and how, small operations and family farming systems have been able to withstand the wrath of natural disasters and changing market demands, as well as positively view how many of their farming practices relate to food security and sustainable development.

AGRICULTURE, SMALL PRODUCERS, THE FAMILY FARM, AND SUSTAINABLE DEVELOPMENT

Although the tourism, mining and energy sectors are seen as the mainstays of Caribbean economies, agricultural production has always been linked to the region's economic development, export trade, and foreign exchange earnings. Further, the livelihood of many

families, particularly those who live in the non-urban or rural parts of a country continue to be dependent on farming and its link to industries and other activities. The gross domestic product (GDP) from the sector has been on the decline, but agriculture still maintains a significant share of the overall GDP in some Caribbean countries. The 2012 data from the World Bank show that the GDP from agriculture was as high as 21 percent in Guyana, 15 percent in Dominica and 13 percent in Belize; and as low as seven percent in Jamaica and St Vincent and the Grenadines, six percent in Grenada, four percent in St Lucia, and two percent in Antigua and Barbuda, St Kitts and Nevis, and one percent in Barbados (World Bank 2014).

These figures however, do not give an accurate representation of the worthiness of the sector as they are calculated solely on the production records of primary commodities. The Inter-American Institute for Co-operation on Agriculture (IICA) asserts that if we count the agricultural produce and by-products that are in the commoditized food chain supply, the GDP estimates in most countries are actually three to seven times higher (Trejos, Arias and Segura 2010). Thus, current statistics that use traditional measures grossly underestimate and undervalue the sector's economic contributions. On the other hand, if we assess the GDP from agriculture using the IICA-suggested method, we will get a more accurate reflection of the economic importance of agriculture to the region.

Economic gains from agriculture however, are not only derived from GDP but also from the sector's absorption of a large percentage of the adult workforce in many countries. Agriculture is the single largest employer in the world, providing livelihoods for 40 percent of today's global population. It is also the largest source of income and jobs for rural households. In the Caribbean, the agricultural sector accounts for close to 3.3 million agricultural workers, or 32 percent of the labour force in 15 countries including Haiti (Bourne 2008).¹ Farmers make up about eight percent of the labour force in the least agrarian countries such as Trinidad and Tobago, but account for as much as 20–30 percent in countries like Belize, Guyana, Grenada, Dominica and Jamaica, which are more heavily dependent on agricultural production (Potter *et al.* 2004). In addition, the sector offers employment opportunities in a wide range of different job categories and levels, including professionals who work as scientists in different fields, veterinarians, extension officers, teachers and a range of para-professionals. Many others are employed in jobs attached to the forward and backward linkages in the food sector, especially in agro-processing and marketing businesses.

1. 17 percent of the employed labour force if Haiti (or 1.1 million agricultural workers), is excluded from these statistics. Also, these statistics may have changed with the removal of protected markets for banana and sugar.

Although the agricultural sector as a whole may not be the dominant contributor to the GDP of some countries in the region, it does play a significant social role in providing steady employment, food provisioning, and as a source of income for many. The common position however, is that it is the export sector, consisting of the large plantation estates privately owned or operated by individual governments, that is of greater socio-economic importance and core to the development of Caribbean economies. This position is further supported by the idea that the plantation system of production is needed to compete on the 'open' and 'free' market with plantations in Central America such as those owned by Chiquita and Dole. Conversely, the network of small farming systems were and still are, considered obstacles to a more modernized agricultural sector and the development of Caribbean societies. But can issues of food insecurity, poverty, malnutrition and hunger be resolved through large-scale commercial production of 'cash' crops? Moreover, can the UN's call to support the family farm change the region's long history of domination and dependency on male-dominated plantation systems of production, and the importation of food?

THE IMPORTANCE OF SMALL PRODUCERS AND FAMILY FARMS TO SUSTAINABLE DEVELOPMENT

By 2050, the world population is expected to increase to nine billion people, with an accompanying demand for at least 60 percent more food. The FAO Assistant Director General, Latin America and Caribbean, is convinced that small scale farming can significantly contribute to meet this growing food demand (FAO 2012). This projection is based on data for Latin America and the Caribbean which showed that small producers mainly on family farms accounted for more than 80 percent of agricultural production, 27 percent to 67 percent of total food production; and occupied between 12 percent and 67 percent of the agricultural land area. Equally important, approximately 57 percent to 77 percent of all agricultural employment in the region was linked to small-scale agriculture production on these farms (FAO 2012). These statistics are illustrative of how small scale farming on primarily family farm make economically and socially significant impacts to the region's development.

Economically they produce food items for their families, neighbours, and other villagers; for the small towns and larger cities; and for the local roadside vendors and domestic markets. Some family farms also produce crops for the export markets subsidising the sales from the large commercial estates. They also supply cross-border markets liaising with intermediaries, such as hucksters and higglers, in the food supply chain across the Caribbean seas. These small family-owned and operated farms are consistent suppliers of food because their livelihoods depend on it...it is what they do. Family farming is *a way of*

life and a way to live. They use all the resources available to them to feed their households and earn an income from the farm that can sustain a decent family life. Profits attained are shared between family and household needs. Extra earnings are re-invested in the farm to improve production capacity. In other words, the farm family is the main investor in the farm, even though the farm is not often referred to as a family business.

Since family members are the main source of labour, the farm is also a place of employment. It not only sustains numerous rural household members, but creates jobs and is essentially a consistent source of inter-generational income. Family farms therefore, not only provide the farming families with part (or all) of its food, but also guaranteed employment. Periodically they hire rural labourers on the farm and create link jobs in transportation, packaging, processing and marketing of their produce. Within this context, the well-established network of small producers and family farms generate social safety nets through direct and indirect employment of rural or non-urban populations, and the provisioning of food.

Caribbean economies also benefit greatly from agro-industry businesses (food, beverages, tobacco, spices, etc.) that are important to their GDP earnings. In Trinidad and Tobago for example, the 2004 data show that 3.1 percent of the country's GDP was derived from the agro-industry sector and another 45.2 percent from manufacturing. Ironically, this country is a net importer of food, as well as a net exporter of beverages, tobacco and other food exports. While currently small producers are not the major suppliers for many agro-industries they do have the potential, including the family labour, to transform certain products into by-products that add value to primary agricultural products. The region also has a long history of cottage industries in which women pre-dominate. The concept and practice of agro-processing is therefore very much alive in Caribbean culture and in the homes of farming families. Therefore investment in research, training, small business, credit, and sector linkages with agro-processing, are all worthwhile endeavours that can contribute to food security and sustainable development.

But development cannot be sustainable if the environment is not first protected. The lay person travelling through the undulating terrain of many Caribbean countries sees the smoke on the mountainside and becomes aware of the 'slash and burn' practices of some farmers. This image oftentimes is transferred to all small farmers. However, it is more common to find that traditional farming families are the protectors of the environment and biodiversity. According to FAO (2012), family farming systems are more inclined to use native varieties, conserve and practise soil improvement, and are less dependent on inorganic ameliorates (fertilizers, pesticides, etc.) and other hurtful chemicals. Furthermore, small producers and family farms have always practiced crop diversification, mixed farming and forestry – practices that mitigate environmental degradation.

Nevertheless, little credence is given to small producers and farming families who have been the guardians of the environment, indigenous knowledge, and good agricultural practices. By passing farming knowledge and traditions across generations, small producers and farming families have withstood the physical challenges usually associated with agriculture. Additionally, because their scale of operations is usually small, it is easier for them to respond to environmental impacts or changing market demands. The lack of resources and support means that their systems of farming may not always move production to high profit-making levels, but they do continue to provide food for families, and practice methods that are safe and sustainable. Interestingly, agricultural diversification is now being highly recommended for the region and the same methods of farming that small farmers have historically practiced are being touted as the ‘new’ approach for sustainable development.

Lastly, small producers and family farms contribute to sustainable development because they stabilize the scattering of villages and small towns located throughout the countryside. Farmers either live on their farms or in nearby villages or towns. Either way, the farming environs are not simply a place of production but a home to many farming families. The network of small producers and family farms in any one location stimulates economic activities, create opportunities for small businesses, and sometimes successfully converts villages into small towns. They balance rural and urban livelihoods, halt rural-urban drifts, and slow down outward migration from Caribbean countries. Conversely, when settlements are stable they become valuable conduits for preserving and enhancing indigenous knowledge, traditions, and customs of local communities. It is therefore imperative that small producers and family farms continue to make a livelihood and economically grow so that there is continuity and preservation of the culture of many rural communities and small towns. This contribution by small producers and family farms is often not valued or perceived as important to sustainable development (box 1.1).

In general, while small-scale operations and the family farming system present many advantages for food production, food security and sustainable development, the male-dominated plantation production systems that rule the region are currently unsustainable. The revitalization of the small producer and the family farm, as well as the enhancement of women’s role in agriculture, will ensure the production of local vegetables, fruits and root crops, as well as the rearing of healthy animals. Small family farms will stabilize the production of staples for the region such as rice, yams and bananas, and provide less processed food products. Moreover, a highly productive peasant sector and family farming system will lead to expanded and/or steady employment, gender equity, healthier families, stronger communities and an overall strengthening of Caribbean economies. Core to these activities is the role of women in Caribbean agriculture.

Box 1.1: Contribution of small producers and family farms to sustainable development

Small producers and/or family farms contribute to sustainable development because they:

- Produce food for families, communities, and the local, regional and export markets;
- Are a constant source of employment for families, villagers, and income earners in linked activities;
- Provide a safety net to generations of families including members of their communities;
- Protect the natural environment and biodiversity;
- Are more likely to use organic products and native species in their methods of farming;
- Practice agricultural diversification and mixed-method farming and can better respond to environmental and market changes;
- Are a source of indigenous knowledge and practices that are passed on over generations;
- Preserve traditions and local cultures;
- Own their labour, farming business, and are free to make their own decisions;
- Stabilize rural communities and stimulate economic activities in villages and small towns.

WOMEN IN AGRICULTURE

The overall proportion of the economically active population (EAP) working in agriculture declined during the 1990s, but the percentage of economically active women working in agriculture at the global level remained at nearly 50 percent through to the twenty-first century. While this percentage of women in agriculture is expected to decrease overall, the percentage of economically active women working in the sector in less developed countries (LDCs) is projected to remain above 70 percent (FAO 2006). The relatively high participation of women in agricultural work is due in part, to the greater involvement of rural male populations in off-farm employment, and/or the increase in male migration to urban areas in search of work. As a result, more women assume responsibility for the family farm because they must provide food and income for their families to survive, along with or in absence of, their male partners.

In the Caribbean, women are involved at all levels in the agricultural sector, including small scale production as individual farmers, on family farms, as farm labour on other farms and plantation estates, and in the marketing and processing of fresh foods. The number of women in agriculture varies from one Caribbean country to another as do the populations that are engaged in agriculture. However, in all cases, the contribution of women is highly underestimated in agricultural census data, which are confined to transactions in commercial cash crop production for the formal market sector. Information on the production and marketing of agricultural produce for local use where women are mainly found working, are left out of the agriculture data bases. Women also dominate the regional export food trade buying fruits, vegetables, and root crops directly at farm gate and exporting to neighbouring islands where they are sold in wholesale markets. For example, female hucksters and higglers from Grenada and St Vincent transact business in Trinidad and Tobago and Barbados, similar to other hucksters among the Eastern Caribbean countries. While there is some documentation of the regional trade, the participation of women hucksters is also not accurately represented in the agriculture labour force statistics.

As a result, women in Caribbean agriculture are almost invisible in the statistics though highly visible as small farmers, on family farms, in local and regional markets, in agro-processing plants, and in gender specific jobs on large commercial farms. When official statistics underestimate women's participation in the agriculture sector, their contributions to domestic food supplies, households' diets and incomes, as well as the national wealth of a country through agricultural work, are also undervalued. This creates a serious shortcoming in the proper planning for food production, food security and sustainable development.

HISTORICAL ROLES

Caribbean women's economic and social contributions to the agricultural sectors is not new but can be traced to their historical beginnings. Under colonization and the peak of the slave trade in the seventeenth and eighteenth centuries, the plantation economies of Caribbean territories were well propelled by imported slave labour of both women and men from West Africa. Sugar was one of the most valuable commodities on the market and slave labour was the cheapest resource for sugar production. Enslaved African women played several roles that contributed to the economic life of the sugar plantations. They provided labour in the cane fields and worked as domestics and nannies in the plantation houses. Slave labour then, was unpaid and women's and men's labour were exploited without any moral or ethical restrictions. Women and men performed the same tasks in the cane fields as there was no sexual division of field labour (Rajack 1991).

What is less known about the roles of enslaved women is that outside plantation-related work, they were the primary producers and marketers of food within slave communities (Mathurin 2006; Reddock and Huggins 1988, 1997). It was more profitable for the plantation owners to have the enslaved women and men produce much of their own food. As such, even as they worked on the sugar estates, they also engaged in peasant-like activities cultivating subsistence food crops to feed themselves. Because women were perceived as 'less dangerous' than men, they were permitted to sell any extra food grown, at a common public market on Sunday mornings. The prevalence of women in the local market, and as hucksters/higglers in the municipal markets, is a continuance of the historical dominance of food markets by women throughout the Caribbean.

With the ending of slavery in the mid-twentieth century, many of the enslaved African women retired from agricultural fieldwork with the hope of working in other non-plantation type jobs and/or becoming housewives and homemakers. Very soon after, the downward wage pressure and rising food prices promoted large-scale migration of male ex-slaves in search of work in other countries. To fill the void, women once again moved into agricultural production on the plantations, as well as continued growing food to feed their families (Momsen 1991, 1993; Mintz 1974, 1984). On the plantations, the freed African women were for the first time employed for wages but under a stringent gender division of labour that paid them lower wages than men. By that time, a gender stratification of labour with differential pay for women and men had emerged under the system of indentured labour (Rajack 1991; Reddock and Huggins 1988, 1997). The wages earned by women and men were so low, that they had to supplement their household incomes by growing some of their own foods and selling the extra produce in local markets, as they had done prior to emancipation. The women drew on their business experiences from selling in the open public Sunday markets and established themselves as the primary marketers in the internal food market systems of the region.

In Trinidad and Tobago, Guyana, and to a lesser extent in other Caribbean countries, the abolition of slave labour led to the demand for indentured labour from India that was also under British colonization. Within the indenture labour regime, women often carried out the same tasks as men – planting, weeding, hauling of trash, applying fertilizers, cutting, bundling and loading of the sugar canes. The plantation owners however, paid women wages well below those of the men and justified the wage differential by categorizing women in the same group as 'weakly' men and boys. In the early twentieth century, the average weekly wage was one dollar for men while women were paid wages that were one half to two-thirds that of men. The gender stratification of labour with wage differentials was carried over into the post-colonial period and adopted by the government-owned sugar companies of the Caribbean (Brereton 1983; Rajack 1991; Reddock and Huggins 1988, 1997).

WOMEN IN CONTEMPORARY CARIBBEAN AGRICULTURE

Today, women continue to work as wage earners primarily in labour-intensive jobs on the large estates cultivating sugar cane, banana, cocoa, coffee, coconut, citrus and other plantation crops. They are mainly hired on a seasonal basis for planting, weeding, and harvesting of certain crops and in post-harvest and processing of other produce for sale. Their low wages are normally justified by the job category of their work, similar to the application of labour stratification of the old plantation systems. Nevertheless, the wage earned is an important source of income to many rural, low-income and poor households. Women's participation in the production of 'cash' crops for the export trade contributes to the GDP that is derived from the agriculture sector. However, because of the seasonal and/or part-time nature of their jobs, their participation is not accurately counted in the statistics on the agricultural labour force, which tends to exclude non full-time employees.

Similarly, women dominate in the full production, post-harvest processing, and marketing of food crops for the domestic sector. Here again, because the domestic food sector is part of the informal economy it is not as regulated as the commercial production sector and data on women's roles is absent. Nevertheless, women's most significant contribution to food production and food security lies in the roles they play on family farms. There, women consistently engage in the provisioning of food for many homes, as well as for national and regional markets. On the family farms women participate in all aspects of the productive cycle in both crop and livestock production, but there are some noticeable gender patterns in the division of labour by sex (Rajack-Talley and Talley 2000).

Box 1.2: Sex versus Gender

The concepts of 'sex' and 'gender' are sometimes wrongly used as the same and can be confusing. Sex refers to the innate biological categories of male or female. Gender refers to the social roles and identities associated with what it means to be a man or a woman. Gender roles are shaped by ideological, religious, ethnic, economic and cultural factors and are key determinant of the distribution of responsibilities and resources between men and women (Moser 1989). Being socially determined, however, this distribution can be changed through conscious social action, including public policy. Every society is marked by gender differences, but these vary widely by culture and can change dramatically over time. According to Quisumbing (1996), sex is biology and gender is sociological. Sex is also fixed and gender roles change.

WOMEN ANIMAL FARMERS

Livestock production by women is an important component of their mixed farming practices or as an enterprise by itself. Women are more likely to engage in small animal production (e.g., sheep, goats, poultry, etc.), while men tend to be involved in large livestock production (e.g., beef cattle and pigs). Even when women participate in large livestock production such as raising dairy and beef cattle, they primarily engage in those activities that are associated with their stereotypical roles as nurturers, homemakers and mothers in the home (Rajack-Talley and Talley 2000). For example, women are commonly found in activities that involve feeding, milking and/or taking care of young and sick animals. As a general rule, the more ‘strenuous’ jobs are usually done by men, such as collecting forage, building pens, hoof trimming, and machinery operation.

As livestock keepers in the Caribbean, women farmers are also managers of the poultry, sheep and goat and dairy farms. Ownership of small livestock is particularly attractive to women because it can be practised close to the home and allows for the balancing of domestic chores with farming activities (Rajack and Hosein 1993).² Some of the animal products (e.g., eggs, milk, and meat) are used for home consumption, and part sold locally for cash income. Sales usually occur at those times of the year when demand is high (e.g., Christmas and Easter) and/or when the household needs extra cash (e.g., at the beginning of the school year, for weddings and christenings). According to one farmer, *‘having a certain amount of sheep in my backyard is like having money in the bank for a rainy day’* (Rajack and Hosein 1993).³ The slow but steady outward migration of people from rural/non-urban communities has also resulted in a year round increase in the demand for basic food items including eggs, milk, poultry, and fish to feed burgeoning urban populations. The poultry and small scale dairy projects managed primarily by women are therefore important in meeting some of the food needs of the family, extra income for family social events, as well as the periodic increase in consumer demands and growing urban populations.

To sustain such needs, women and men livestock farmers also need to expand their size of operations. However, it is more challenging for women farmers because of the gender differential in access to resources, including land, labour, technology, credit and extension services. These gender-based inequalities exist although female-headed livestock enterprises have been shown to be as successful as male-headed livestock production farms. Moreover, research has shown that on small family farms, shifts from subsistence to commercialized

2. Research has shown that women’s participation in farming does not reduce their workload in the house.

3. Comment from a participating farmer in CARDI’s sheep and goat project.

levels of animal production can result in conflict over control of the livestock businesses between male and female farmers on the same farm (Rajack 1996). This is primarily because, in Caribbean societies, men are stereotyped as the main income earners and women's income are considered supplementary to household budgets. Consequently, there is no stress if women manage subsistence production, but if levels of growth results in major income earnings for the household, gender roles can become strained and the livestock enterprise a contested terrain.

If the farm operations of women are subsumed by male farmers on the same farm, or by other male-headed livestock enterprises, then women are more likely to become employees rather than managers and owners of their agricultural businesses. Thus, movement towards sustainable production of the livestock industry has gender consequences unless steps are taken to ensure that women farmers are not negatively impacted by commercialized production. Further, because of where women livestock farmers direct their products, keeping women in livestock production also secures local food supplies as well as home consumption, nutrition, and single female-headed household budgets (FAO 2011).

At the same time, caution must be taken not to paint women as helpless victims who are inevitably displaced as the livestock sector grows and develops. Women farmers do have agency and resist attempts to displace them or terminate their source(s) of income (Rajack 1996). Women, particularly in low-resource and/or female-headed households, understand the important role they play in providing basic food and other needs for their families, as they cannot afford to be financially marginalized in their homes. Generally, they also take great pride in feeding their community and society. Unfortunately, in livestock development projects the threat of women being displaced and their resistance to pending marginalization is too often missed by extension officers and animal scientists, as well as policymakers. So too, are the related implications to sustainable production of meat, eggs, milk, and other animal products for local food demands. As a result, a concerted effort should be made to ensure that as the sector grows, women have access to the resources they need, and that gender implications are factored into sustainable development planning and livestock practices. Some women may prefer to rear poultry and other small livestock, and find that these are more appropriate to their farm and family life. Others may want to venture or expand into larger scale operations or bigger animals and should be supported and provided with the technology, information, training and finances required. Moreover, there is a need to move away from the stereotypical beliefs that pigeonhole which livestock enterprise is more suited for women *vis-à-vis* men, and also the concept of the male as the livestock manager and the female as the livestock farmer and labourer.

WOMEN CROP PRODUCERS

A similar parallel is found in crop production where women produce all crop types in the domestic food sector, but there are gender-distinct crop enterprises, orientations and divisions of labour. Women participate mostly in planting, weeding, harvesting and post-harvest crop activities. On the other hand, men tend to engage mostly in land preparation, application of agro-chemicals, and the use of farm equipment and machinery (Kleysen 1996⁴; Rajack-Talley and Talley 2000). As owners of their farms, women tend to have smaller plots of land, use fewer purchased inputs and their output is usually smaller. Yet, they still produce 60 to 80 percent of food in most developing countries, that is, half of the world's food supplies (Momsen 1991; Mehra and Rojas 2008) because they concentrate on local food production for their households, communities, society and the region. The food crops are grown on small family farms on which women are either farm managers, farming partners, farm family labourers, or farm wage labourers. According to Rajack-Talley and Talley (2000), any analysis of the domestic food sector in the Caribbean is essentially an analysis of women's role in food crop production.

Overall, gender patterns in the division of farm labour are linked to women's reproductive and other domestic responsibilities. Studies have shown that size and life stage of a family influence the type of farm practice, level of involvement, and time devoted to agricultural work (Barrow 1986; Rajack-Talley and Talley 2000; Overholt et al. 1985; Sen 1981). For example, women with young children elect to work close to or at home, and arrange all their farming activities so that they can accommodate their family needs. Accordingly, women without children (or adult children) have greater flexibility in terms of time, tasks, location, and the type of agricultural work they engage in. These gender distinct familial characteristics are important factors in farm and home management plans when working with farming families in food production for food security and sustainable development. Families in earlier life stages are more likely to be responsive to practices that are manageable and require women's physical presence near or on the farm. The family farming system is therefore a more appropriate fit for these women and their families. Other women may need support in broadening their scales of operations and would require more land, most likely further away from a housing area, a different type of technology, more credit, different crops, and a management and marketing system that is more commercial in orientation.

4. See for example tables 1.10 – 1.11.

WOMEN FARM MANAGERS

Interestingly, not only are there gender patterns in the division of farm labour in both livestock and crop production, but there are also gender distinct farm management practices on small farm holdings. A common trend observed is that on family farms women and men both engage in joint agricultural production and/or work and manage separate plots and enterprises. Rajack (1996) observed these various arrangements and have identified four gender distinct models of farm management. These are:

Separately managed enterprises: Women and men are responsible for separate crops or livestock production. It is common for women's agricultural projects to be located near to, or at home. Decisions on each enterprise are made separately, although the couple usually discusses farming issues and help each other with the work.

Same enterprise but separate tasks: In this management model, women and men are involved in the same crop and/or livestock production but participate in distinct tasks – stereotypically female and male jobs. Under this arrangement, men are the major decision-makers and farm managers, while women are considered farm family labour. Discussions on farming issues are at a minimum level.

Shared tasks but not shared enterprise: This farm management model is based on the understanding that both women and men can do the same tasks – not set gender distinct work. The responsibility for all the farm enterprises is also shared. However, the male is considered the head-of-the-household and as such, is treated as the major decision-maker and farm manager. The woman farmer is not documented as being economically active in agriculture. In these situations, women may seek other forms of independent income generating enterprises such as in cottage industry.

Women or men managed enterprise and tasks: In this model, the division of labour, decision making and farm management is simple. It is all done by one or the other where one partner in the couple has very little to do with farming. The person identified as the farmer (male or female) makes the agricultural decisions, performs the lion's share of work and manages the farm.

Although there are no recent studies on women farm managers in the Caribbean, what is known is that all four models exist within the region. Past studies showed that although there are wide variations from one country to another, women as major farm decision-makers can be as high as 47 percent and as joint managers with men up to 42 percent. Overall, where women perform most of the tasks in the farm enterprise they also tend to

be the major decision-makers. Gender specificity was also observed in the types of farming decisions made by women. For example, women participate more in decisions about what type of crop to grow or livestock to rear, how farm labour is to be organized, and where produce is to be sold (Kleysen 1996; Rajack-Talley and Talley 2000).

Current research on gender distinctions in farm management practices and decision-making are urgently needed. If the trend identified in earlier studies by Kleysen (1996) and Rajack (1996) hold steady, then the high numbers of women who make farm decisions (independently or jointly) and the types of decisions that they make have significant impact on:

- How information and resources (technology, labour, and finance) are allocated and managed on family farms;
- What is produced and what methods of farm practices are adopted.

This data can be useful in assisting the farm family to better plan for improved food production systems and farm management, both of which are important in promoting sustainable development.

WOMEN MARKETERS AND TRADERS (HUCKSTERS)

In addition to pre- and post-harvest activities, marketing has always been an income earning activity historically performed largely by Caribbean women (Lagro and Plotkin 1990; Mintz 1974). The custom of enslaved women selling the extra food that they were allowed to produce for themselves on the plantation in Sunday markets, rapidly expanded immediately after emancipation (Besson 2003). As independent small producers and family farms were established, the common market outlets also expanded to now include sales at the farm-gate to hucksters or higglers, agents and middle men, and also directly to customers at the local domestic or retail markets. Hence, contemporary patterns of marketing at local sites, huckstering or inter-island trading within and between the islands, sidewalk tray or 'fruit stand' selling, are not new practices for Caribbean women. Currently, women are responsible for producing and selling between 12 to 50 percent of local foods, mainly fresh fruit and vegetables, root crops, some export crops such as bananas and rice, as well as a range of other non-traditional (cut flowers, ornamentals, etc.) export crops (Mantz 2007).

In the Caribbean, Mantz (2007) identified three distinct forms of market vendors in which women predominate, namely marketers, higglers and hucksters.⁵ The women involved are self-employed individuals engaged in economic activities, encompassing bargaining,

5. Men also participate in all three forms, but historically women dominate in each category of the marketing operations.

bartering, and selling of produce. The traditional market vendors sell their goods at centralized market locations, or at regular fruit stalls on the side of the road, or in an arcade of stalls. Higglering occurs at street corners, busy intersections, or any high traffic where for example, there is road construction and a slowing down of traffic. Both these forms of operations involve simple transaction of goods and are local/domestic marketing systems.

The third category of women marketers are the hucksters. In this group, women function more like entrepreneurs and are involved with inter-island trading that requires more than just buying and selling of goods but also the shipping of produce, travelling, and foreign exchange activities. The economic roles of these women have never been captured, although they serve as important forms of providing food and generating economic activities. Mantz (2007) for example found that 'huckstering' by the predominantly Dominican women accounts for the second largest foreign exchange earnings for that country.

These trading patterns continue to be under the aegis of women and are sustained with little or no capital from governments or the private sector, but from women traders, small producers, and family farms. The trade requires the establishment of some level of relationship with clients and sellers, and must maintain a reputation for providing farm fresh and safe produce cultivated locally/regionally. Market selling is also a tenuous activity that requires high levels of financial competence, as well as negotiation and business skills. Pricing information is attained mainly via the radio, daily newspapers, telephone calls to current or potential customers, other marketers and agents. The level of trade and capital exchange is often not recorded and thus undervalued, alongside the entrepreneurial abilities of women.

Little research has been done on women traders but what is known suggests that it is a long-standing matrilineal vocation, in which marketing skills are passed from mother to daughter and other female members in the same family. It is not unusual to find, aunts, nieces, sisters and others plying the same trade. Mantz (2007) describes this occurrence as 'women for women' and a most vibrant and self-sustaining economic activity. Although several hundred women remain committed to the trade, their numbers are shrinking for a myriad of reasons. Labour shortages and the education of young female family members are possible push factors away from a risky and difficult female business. However, there is still an active movement among the islands of Dominica, Guadeloupe, Antigua, St Kitts, St Martin, and The Virgin Islands, St Vincent, St Lucia, Grenada, Guyana, and Trinidad and Tobago, among others.

The socio-economic importance of the three categories of marketing activities at the local and regional levels has been seriously undervalued and unrecognized as a key link in the food security chain of the region. Consequently market vendors, higgler and hucksters

have not been given much support although they have managed to survive. The lack of attention is due, in part to the fact that the activities occur in the domestic food systems of the informal economy, and also because they are ‘women’s’ activities. Given the more recent downward trends, if these important food marketing systems are to be sustained, support is required to make the trade a viable one in which male (and female) marketers do more than just survive but make a decent income that can comfortably support a family. Equally important, any kind of support provided should have a gender focus that involves women themselves in areas such as training, mentorship, and skills building, as well as methods of accessing credit and the conduct of business and financial transactions. Only through this involvement and further research on the women will we be able to understand what are these gender specific ways that have worked for years. It will also provide recommendations for growth and development for women by women. In other words, efforts must not only be focused on food marketing sustainability, but also on how women can remain the leaders of the trade.

GENDER BARRIERS

There is no doubt that women play crucial roles in food security for their homes, their communities, the domestic market, in the wider society in which they live, and across the blue ocean to others where fresh fruit, vegetables, root crops and other food items are scarce. In the process they manage the natural resources and biodiversity of farmlands (FAO 2006). Despite years of proven capabilities and contributions, many women small farmers are still unable to move from subsistence to more commercial forms of agriculture so that they can grow additional food to feed the region, and at the same time earn enough to comfortably support their families. They are prevented from doing so because they experience discrimination at two levels.

Firstly, as small producers focused on food crops, domestic livestock, and agriculture by-products, women are not perceived as important as the larger cultivators who are producing for the export markets. Consequently, women as small farmers are not given the type of resources and support as the bigger farmers and the plantation systems of monocultures. More recent, the food import crisis in the region has stirred governments, along with regional and international organizations to advocate for greater support for the farm family and its role in providing food for the region. But this is a recent initiative and will take a long time for resources to reach women and men small producers and farming families before their agricultural endeavours can become more desirable and economically viable.

Secondly, because of their gender, women farmers are exposed to the same gender discrimination present in mainstream society. Gender discrimination in the Caribbean

is partly based on stereotypes founded on the Eurocentric notion of the role of women as housewives. The process of ‘housewifisation’ has led to gender specific tasks and responsibilities on the farm and a particular perception about women’s capabilities. Women are rarely thought of as farm managers and producers of export cash crops and livestock products. Instead, they are viewed and treated primarily as farm labour and helpers to male farmers on peasant and family farms, and low-wage employees in packaging and processing of export products.

This double subjugation of women farmers has restricted their access to agricultural resources and services such as land, credit, training, technical assistance technology and institutional support. Conversely, more resources are allocated to the export-oriented agriculture sector in which men typically own and/or are more actively employed. In particular, *land distribution* patterns are very uneven with respect to farm size, and this further limits women’s access to credit and other farming resources.

As a result, compared to men, women farmers are more likely to:

- Operate smaller farms, on average one half to two-thirds the size of men farmers;
- Farm on small and fragmented pieces of land either family-owned, rented or occupied without permission;
- Keep fewer livestock, typically of smaller breeds, and earn less from the livestock they do own;
- Have a greater overall workload that includes a heavy burden of domestic activities
- Have less education and less access to agricultural information and extension services;
- Use less credit and other financial services as most credit schemes favour middle to large farms in which men produce cash crops. Consequently, they tend to draw on indigenous loan schemes such as ‘sub’ in Dominica, the ‘box’ in Guyana, and ‘sou sou’ in Trinidad;
- Purchase less inputs such as fertilizers, improved seeds and mechanical equipment;
- Employed in part-time, seasonal, and low-paying jobs in which they receive low wages;
- Receive less agricultural training, technology, extension services and technical assistance (less than 10 percent of women farmers are reported to receive these services).

According to FAO (2010, 3):

If women had the same access to productive resources as men, they could increase yields on their farms by 20–30 percent. This could raise total agricultural output in developing countries by 2.5 to four percent, which could in turn reduce the number of hungry people in the world by 12–17 percent

CONCLUSIONS AND RECOMMENDATIONS

As the region's agricultural sector is integrated deeper into the global market it faces high trading competition for all its traditional 'cash' crops, as well as a burgeoning food import bill. This can (and already has) stifled the Caribbean's agricultural sector, both in the export markets and the local production of food in the domestic markets. As a result, there is a steady decline in GDP earnings, farm household incomes, and wage employment in the sector overall. Equally important is the social impact of this trend on the region's food security due to the increase in reliance on external supplies for food and other agriculture related by-products. If this pattern is not halted soon, then the argument made by Caribbean scholar George Beckford in the 1970s that the region will be in a state of 'persistent poverty' if it does not move away from the domination of the region's agriculture by external forces, is still relevant today (Beckford 1972).

Recently a similar proposal was made by FAO that 2014 be designated as the year of the farm family, and that the Caribbean should focus more on supporting small family farms rather than the larger systems of food production. Several meetings were held in the Caribbean during 2011 to discuss the region's agricultural policies and food prices (FAO 2012),⁶ at which participants more or less agreed with Beckford's theory that the agricultural policies of the past favoured the larger private agricultural enterprises and neglected the small producer and the family farm. As a result, once the vulnerable and insecure plantation crop industries were placed on the 'free and open market' many farmers, particularly the banana farmers in Dominica, St Lucia, St Vincent and others were forced out of the market and placed several families in severe economic crisis. Consequently, large numbers of people migrated from the rural areas of the islands, and for a period of time, communities were being emptied of their populations. Images of 'padlocked' homes of banana farmers who fled in search of other ways to make a living, were observed in small villages. The sugar cane

6. Meetings were held in Santiago, Chile (June 7–8, 2011) Port-of-Spain, Trinidad and Tobago (June 13–14, 2011), San Salvador, El Salvador (June 15–16 2011), and Mexico City, Mexico (October 17–18, 2011).

farmers and wage employees in the region's sugar industry also faced a similar situation whereby farmers and employees in the sugar industry in St Kitts, Trinidad and Tobago, and other countries had to search for other sources of income to support their families. The impact of the collapse of the guaranteed export markets that traditionally supported many Caribbean households was also felt by the many villages and small towns that depended on the economic activities generated from these households. Businesses began to suffer and the economic and social life of these communities has since paused.

Poverty studies conducted by the Caribbean Development Bank (CDB) in the last decade report on the impact of these shifts on poverty, particularly on the health, nutrition and education of farming families and rural/non-urban populations.⁷ Farmers are no longer able to support their family needs and as such there is a greater dependency on government assistance. For women, many of whom historically played central roles in their families' household budgets as farmers, small producers, and/or wage earners in commercial agriculture enterprises, not only are the survival of their families threatened, but also their economic independence. On a larger scale, these macroeconomic constraints experienced by small producers and family farms have directly impacted the region's food production, food security and the sustainable development of every single Caribbean country.

Earlier discussions showed how small producers and family farms contribute directly to: (i) the sustenance of their families, neighbours and communities; (ii) employment generation for many; (iii) the production of food for local and regional markets; and (iv) the sustainable development of the region. Small producers and family farms make it possible for millions of people across the region to have access to fresh vegetables, fruits, root crops, fish, meat and other animal products. In addition, they play an important part in the cultural customs and indigenous knowledge-base for generations of people. Collectively they have a multiplier effect in the creation of economic and social wealth in rural villages and small towns. And yet, their *modus operandi* has been criticized because it is not primarily focused on profit making, but in providing a valued product and/or service based on family values rather than corporate values. It is for this same reason that since colonization there has been a tendency for governments to support the male-dominated plantation systems centred on the production of 'cash' from crops and livestock, rather than on small producers and family farming systems.

Conventional agricultural education has also paid little attention to small scale farming including that of family farming systems. Moreover, the information generated focuses

7. See Caribank.org

more on what does not work on these farms and less on their potential. What is taught to agricultural students about best practices is not positively linked to what is actually taking place on the farm. Similarly, agriculture census collect data on size of farm and what is on the farm; gender-disaggregated data is absent and a proper understanding of the systems that farmers use that are safe, sustainable and can be enhanced, is also missing. As a result, small producers and family farms are associated with subsistence production, and as such patronized as recipients of government assistance. Thus, parents themselves encourage their sons and daughters to become educated and leave farming and at the same time, hope that the family farm will remain as a family owned enterprise that has existed for generations – providing food, incomes, and self-employment. They know that circumstances beyond their control make this hope difficult and some changes are needed. Women are particularly strong-minded about keeping the family farm because it allows them to provide some of their family dietary needs, and have an independent source of income without having to leave the farm and the home.

There is no doubt that the region's food production systems, food security and the sustainable development of villages, towns and societies are heavily dependent on the small producers and the family farms of the Caribbean. However, because of years of neglect, negative stereotyping, and lack of support from government policies as well as agricultural research, education, technical and extension services, many have fallen below, or are at subsistence levels of production, others have simply migrated entirely out of agriculture..

STRENGTHENING SMALL PRODUCERS AND FAMILY FARMING

To strengthen the small producer and the family farming system we need to fully understand the nature of the farmer, the family, the systems of production, gender issues and the rationale behind the farming practices adopted by the small producer and the farm family unit. Participatory research and development (PRD) approaches have been found to be the most suited to collect and analyse this information along with the farming family. The process can be a dialectical one in which the scientists/extensionists collect data and at the same time disseminate information that can help the small-scale food producer to enhance her/his adaptive capacity and resilience. Through the PRD process the farming members can become architects of their own farming practices and farm management.

Data collected from PRD can be used to inform policies and national investment decisions that can revitalise family farming and enhance the role of women farmers. Further, the following recommendations are made that may be interrelated and therefore not exclusive or exhaustive.

- Increase access to and control over productive resources, including land (tenure), water, credit, technology and extension services;

- Additional agricultural biodiversity support for plant and livestock materials that can strengthen the resilience of local food systems and ensure food safety;
- Closer linkages between what farmers are producing and the nutritional value recommended by the Caribbean Food and Nutrition Institute (CFNI);
- Improve local and regional food markets and place them under the control of small producers and family farms. Designs of systems should collectively evolve from farmers, scientists, marketers and consumers so as to provide high quality food from farmers that are accessible to all;
- Engage in more collective use of resources and lobbying (because of economies of scale) through establishing or strengthening farmers' organisations and co-operatives;
- Strengthen the organizational skills, financial accountability and economic viability of individual farm enterprises as well as farmers' groups so that in the long term the management of certain support services can be transferred from governments to farmers and their organizations;
- Work with farmers to develop a system of direct financing tailored towards farm families, small producers, and women farmers. Thus, specific credit lines will be established to support self-managed funds of individual farming enterprises as well as for farmers' organisations and co-operatives;
- Continue enhanced vocational training for farmers, women and rural youth in all areas of food production, food security and sustainable development is required. Training should include entrepreneurship skills and innovative technologies, but should be in harmony with what is already being practiced on the farm and within the families. This includes how to include young women and men in modern farm technologies and social media that can enhance small producers and family farms without adding high risks, real or perceived. Farmer to farmer training methods has proven to be most appropriate and should be readily adopted;
- Provide socio-economic safety net packages to small producers and family farms that protect them from the repercussions of natural disasters, failed new methods of farming, as well as change in market demands. This should include remittances to reinvest in farming activities as well as for meeting the needs of households and families.

GENDER SPECIFIC RECOMMENDATIONS

While all the recommendations discussed above should be gender sensitive, gender specific considerations and recommendations are also suggested. Currently, most national, regional and international food production policies and plans included addressing gender issues and women's role in agriculture. However, invariably these are included as add-ons and/or treated as separate concerns and solutions. By themselves, they fail to address the differences in the resources available to men and women, their roles, the constraints they face – and how these differences might be relevant to proposed interventions for women farmers. It is also assumed that interventions in areas such as technology, extension services, credit, infrastructure, and market access will have the same impacts on women as they do for men, when in fact they do not. As a result, the following gender specific recommendations are suggested that can enhance women's full participation in food production and food security strategies:

- Increase efforts to collect and analyse gender disaggregated data in order to understand role differences in food and cash crop production as well as men's and women's differential managerial and financial control over production, storage and marketing of agricultural products;
- Ensure that women have equal opportunities as men to own land, have access to agricultural services, including technology, farming incentives, training and extension. Equally important too, is that these services and resources should be tailored to meet women's specific farming needs;
- Focus on appropriate inputs and technology that can 'free up' women's time on the farm and in the home so that they can balance their domestic responsibilities with farming activities;
- Link what is grown, sold, processed or prepared for the home to the nutritional status of families especially children, as well as the general population;
- Review government policies and re-orient them to ensure that all constraints to women's roles in food production and in food security are addressed. This includes access to resources and services for women managed farms, as well as better employment and income earning opportunities for women with equal pay and social benefits linked to family care taking;
- Support and encourage women's organizations and networks. Include representation from these groups at all levels of planning, training, decision-making and policy formulation that relate to small producers, family farms, and women farmers.

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Youth: Adding Value to Agriculture in the Caribbean

Nicole Webster and Wayne G. Ganpat

INTRODUCTION

The average age of farmers in the region is estimated to be over 50 years with some countries averaging over 60 years. The drudgery, hard work and little financial rewards associated with agriculture seem to be the major deterrents to young persons entering the sector. This perception of the sector as not being profitable has been actively promoted by many successful farmers, who for reasons of tax evasion and concessionary treatment, proclaim a litany of woes and do all in their power to discourage new entrants. While several initiatives have been tried in the region to reverse this situation, the problem still persists and has now become more urgent.

We live in a changing world that has the ability to provide the youth of today a life incomparable to their ancestors. They have access to educational systems that prepare them to be forward thinkers, access to resources that can provide them a sense of financial security, and technology that puts the world at their fingertips. Despite this plethora of resources and access, many youth across the globe will never have a taste or a glimpse of this life. Their lives will be shaped by a more dismal side of life that plagues over three quarters of youth living in developing countries (Bennell 2007; World Bank 2006). These youth experience successes and failures due to the political frameworks and bureaucratic arrangements in society. There is however, the opportunity to challenge these conditions through policies and actions that deepen the context of living for youth, especially those who live in the rural bellies of society.

To a large extent, the successes and failures in rural communities across the globe are shaped by agriculture. Typically, one thinks of agriculture as the bread of life for rural communities because of its ability to provide

and sustain individuals. Agriculture has multiple objectives such as creating employment opportunities, providing raw materials for agro-based industries, ensuring self-sufficiency in food production and food security, servicing of balance of payments, and contributing to the gross domestic product (GDP) (FAO 2002; Young et al. 2001). In some cases, it is the backbone of society and determines the standard of living for large segments of the population. Increasingly agriculture is being viewed through the climate change prism wherein there is significant support for its role in mitigation. For youth, especially those in rural areas, agriculture is a way of life. As such, development experts have suggested that training and programmes should be targeted towards them early in life so that these future farmers may develop critical skills related to new practices, and as adults, will generally be more receptive to the changing face of agriculture. Early exposure will provide youth valuable skills and help them acquire experiences in group processes that will enable them to easily step into adult leadership roles in their communities as part of peoples' participation in activities that contribute to sustainable agricultural and rural development.

This chapter is positioned from a context of change and empowerment for youth engagement in agriculture across the Caribbean region. We contend that in order for young people to be fully integrated in society, they must be given the resources to become fully empowered for productivity. Based on an analysis of rural youth agricultural programmes across the globe and the formal reports of Caribbean youth leaders, a model for engagement is proposed. Because of the diversity in the region, a flexible rather than a fixed model is suggested, with each country being able to choose from the essential components to make its own model. Using this approach, we believe that the face and more importantly, the productivity of agriculture can be changed. For this to happen however, young people within the Caribbean must be supported by appropriate, sustainable interventions that allow them to fully engage the sector.

AGRICULTURE IN THE NEW MILLENNIUM

The changing face of the twenty-first century must incorporate the new faces of the millennium. Policies and practices must speak to the immediate and long-term needs of youth. They are the future and must be given a template that challenges the status quo and converts theory into practice with a new-world twist. This systematic approach to programming will assist in developing the farming community and agriculture for the next generation. Of the nearly one billion youths between the ages of 15 and 24, approximately 85 percent are from low income countries (Bennell 2007; FAO 2005; ILO 2005), where numerous problems such as inadequate housing, sub-standard health care, pollution, food

deficits and deficiencies, rural to urban migration, and high unemployment rates plague the society (Deshingkar 2004). This current situation leads us to believe that it will be difficult to attain sustainable development under such conditions; however, a change is possible if policies and programmes are structured to systematically address these problems. For example, in Africa, nearly 200 million young people are waiting to be educated and prepared for employment. In the Caribbean, Asia, and the Pacific we find a similar situation, whereby youth, especially the rural population on the fringes of society, are last to receive the assistance and support from society. Among all these regions of the world, it has been estimated that the number of rural youth will continue to rise at exponential rates (ECLAC 2008). Unless addressed, today's problems will continue to plague the rural segments of society at ever increasing rates.

YOUTH AND AGRICULTURE

Youth, in one sense, can be seen as a collective group of people who have the potential to change the world. Despite their age, gender, and geographic location, they have a unique way of approaching life; from a fresh perspective and with zeal. However, due to financial and social barriers for example, many are not given the opportunity to create change or see change happen. For youth in the rural context, especially those in the agricultural sector of society, they are often left out of the equation for development and change. Young people find themselves sitting at the fringe of society looking on as others define their potential. Their lack of access to educational opportunities and limited voice in society are roadblocks to success.

RURAL AGRICULTURE AND YOUTH

The United Nations Economic Commission for Latin America and the Caribbean (ECLAC) estimates that roughly 30 percent of Latin America's populations are located in rural areas (ECLAC 2008). This astonishingly low figure, translates into an awareness of the needs of this vulnerable population, and rural squatter camps and slums found within the region support a life of hardship for its inhabitants. Rural people, especially the rural poor in developing countries, depend heavily on agriculture as a means of subsistence. Research has shown that between 75 and 85 percent of the rural population in Asian and African countries is engaged in agricultural production (Godfrey 2005). Although these numbers are slightly higher than one would find throughout the Caribbean and Latin America (nearly 50 percent throughout the region), the agricultural sector makes an important contribution to the GDP in many countries in this region. Even more important, is the impact of agriculture on the quality of life of individuals who live in these communities, including rural youth.

The ability to keep rural youth interested in living and working to sustain a quality of life is non-negotiable in today's world, and involves the creation of a blueprint of policies to improve impoverished conditions. Funding must be provided, and the level of resources available must be improved to deliver a higher quality of life. Policies regarding rural youth must be specific with clear strategies and guidelines to keep them from remaining on the fringes. In addition, in situations of limited resources, as is the case with most Caribbean countries, the funding made available to meet their needs and solve their problems must be used in an efficient manner. While these issues are significant, what is even more important to the development of rural youth, is addressing the changing face of agriculture and farming that confronts this present generation.

RURAL YOUTH IN THE CARIBBEAN CONTEXT

In the Caribbean as in many other developing countries, while the population of farmers is becoming smaller, the average age of farmers is increasing, and the rate of replacement of older farmers by younger ones is not the same as in the past. Moreover, many countries have dwindling extension services to support farmers, both young and old, while simultaneously budgets are being redirected to support other programmes deemed more important. Youth in agriculture programmes are therefore not given the attention that is required. Under the circumstances with these challenges a decrease has been observed in the size of local and national economies, something which impacts the quality of inputs, agricultural production, staff and particularly extension and training for farming communities. Rural youth agricultural programmes that focus on building leadership skills and agriculture knowledge, and reinforcing critical thinking and moral development suffer curriculum and staff cutbacks. There has also been a discontinuation of financial incentives to stimulate and support youth involvement.

Moreover, the non-formal educational component which has been a staple component in rural agricultural learning is often not given the adequate attention it deserves in order to meet the needs of rural youth. The lack of staff, resources, training, and funding hinders the total growth and development for rural youth, and while these issues may be seen as formidable challenges for governments to overcome, they can be improved in the short to medium term. In this discussion, the essential components of a model for the constructive engagement of young people are being suggested. It is hoped that this will assist the youth to become more engaged in the agricultural sector as productive constituents empowered by facilitating policies and organizations, thus enabling them to utilise modern technology in a business-like manner to achieve economic independence. At the same time, they will also become vested citizens in society helping to address societal issues such as criminal activity, poverty and economic destabilization.

TRANSFORMING YOUTH

Transformational learning as defined by Hart (2006) is regarded as the intersection between service learning and critical pedagogy. Students learn to analyse their civic attitudes, assumptions, and actions through political, economic, and social conditions and inequalities that exist in everyday life. Daigre (2000) contended that young people engaging in transformational learning must begin by problematizing the power structures they experience in their community, and to a larger extent in society and should be encouraged to ask critical questions about the implications of these structures. One practical way students can analyse power structures is by re-examining the formal classroom versus the informal classroom structure. Instead of viewing schools as the keeper and disseminator of knowledge, students work to solve problems and become engaged as agents of change in their communities. In this way they become both leaders and teachers helping to change the society in which they live. Young people are in positions to transform ‘facets of school life that may have served to alienate and oppress students’ (Hart 2006).

As young adults and youth become aware of concepts of leadership and change, they should then also begin examining how to create meaningful change. Only through an examination of these structures will students begin moving toward a true appreciation for agriculture (Hart 2006). For example, students who live in communities with rampant poverty could learn to openly create spaces with politicians, community leaders, social policy, and media messages to find solutions for the problem. For this to happen however, youth relationships with agriculture must be actively supported by opportunities within the current infrastructures and powers that exist.

To facilitate the inquiry of change, youth and communities must re-frame the inquiry from the individual to the systemic (Bickford and Reynolds 2002). For example, when investigating issues of participation in agriculture, youth should re-frame, ‘what can this do for me?’ to a state of ‘what can I offer to this?’ Similarly, Daigre (2000) advocated for the analysis of the root cause of social problems by questioning the current political system and the social injustices embedded within them. Youth must be encouraged to look for the links between the entrenched institutional systems and how these impact their present position. Just as imperative as questioning the political systems, students must also learn to critically analyse their personal role in the system (Freire 1998). Hart (2006) suggested that youth must constantly reflect on stereotypes and assumptions they may have about the population they are serving, how their individual actions affect power dynamics, and how their work connects to the larger political and social structures. This is essential for youth to make a difference in any sphere, more so in the area of food production.

YOUTH ENGAGEMENT APPROACH: YOUTH MAKING A DIFFERENCE (YMD)

In order to effect a true change in the lives of rural youth, especially those engaged in agriculture, the central thesis of the discussion posits that there must be a rethinking, a paradigm shift in how we view youth in these areas. Youth must now be seen as viable individuals who have the ability to meaningfully contribute to the fabric of society. They have the ability to think, develop and act in a way that can cause serious change. They must not be treated as outcasts of the society, but rather as individuals who, when given the opportunity along with the correct tools and resources, and with sincere, meaningful support and guidance, can make a difference. They can, if their potential is properly directed, add tremendous value to agriculture. The YMD approach also makes some basic assumptions about government and its position on youth and agriculture. These include:

1. Promoting youth in agriculture high on the agenda of national governments.
2. Full commitment by governments to providing the funding and resources needed for youth development and agriculture.
3. Incorporating youth and agriculture as key aspects of their plans of work.
4. Setting realistic goals and benchmarks to measure development.
5. Including youth voices in the vision for agricultural development.
6. Viewing youth as part of the solution and not the problem.

These points, juxtaposed against our vision of youth engagement can lead to a paradigm shift in the way we approach programming for rural youth involved in agriculture.

AN ANALYSIS OF SELECTED AGRICULTURAL YOUTH PROGRAMMES

A review of several programmes across the Caribbean, Latin American, and the West African region reveals that most youth agricultural programmes within rural regions focus on building skills and moral development. Many programmes are grounded in developing positive character development and morals through Christian-based activities, such as the Young Boys and Girls Programme of Kenya. These programmes primarily focus on young people between the ages of eight and 18 who are still living with their parents. Young people attend day camps or after-school activities, which are monitored and/or facilitated by an adult. The take away message for youth involved in these programmes appears to be that in order to make it in life, one needs to be a good citizen. No emphasis is placed on building agricultural or leadership skills, as is the case in other youth programmes in the more tropical regions of the world.

The 4-H Model and Grassroots Efforts

Among many Latin American and Caribbean (LAC) countries, the thrust of youth development programmes is built on the US model of 4-H. While the basis of this model was created to train rural youth throughout the United States in the early 1800s in agricultural production and canning, the format has morphed into a program for engaging youth in positive activities in the twenty-first century. This programme provides youth with opportunities to build important skills such as leadership, communication, and character building. The overwhelming majority of these experiences are embedded within a non-formal educational framework to allow for flexibility and making the youth voice heard. Within the LAC context, the 4-H model entails a number of key characteristics of the US model, while embracing local culture and context. For example, the curriculum is translated into local languages and is often tailored to meet the specific needs of the targeted youth. While these activities focus on the overall development of the youth, many do not incorporate the agricultural knowledge needed to thrive in today's agricultural industry, perhaps as a result of the institutionalization of 4-H in society. In some cases, countries incorporate 4-H as fully funded and supported programme within a Ministry (i.e. Ministry of Education or Ministry of Agriculture), while others treat it as a stand-alone programme that requires a cast of dedicated volunteers and funding for support. Because many young people view the 4H programme as a school activity, very few make the transition to becoming full-fledged members of the farming community.

An offshoot of the 4-H model have been the grassroots efforts observed in countries such as Jamaica and Barbados, where concerned individuals who see the need to educate the young while preserving culture and agriculture, have started local programmes for youth, which involve bringing youth onto their farms to teach them about agriculture and its benefit to themselves and their country. These programmes, which also have a mentorship aspect, teach young people about farming practices that are sometimes seen as traditional, but yet are being promoted by scientists in classrooms in other parts of the world as sustainable methods. Fundamental to this type of programme is recognition of the benefits to be derived from engaging youth in a waning industry, while also teaching them about a culture that has fed and sustained society. As such, the creation of a core cohort of youth who are able to become citizens who have an appreciation for farming while also being able to sustain their own lives in a holistic manner, is considered a major outcome of this drive. In spite of their good intentions however, these programmes do not form an integral part of the institutional fabric of developing nations.

Embedded in the Government

Programmes such as the Youth Apprenticeship Programme in Agriculture (YAPA) and the Youth Enterprise Initiative in Trinidad and Grenada respectively, are examples of programmes embedded into the core of the central government. Ministries of agriculture and education take a vested interest in the development of young people and help to create programmes that assist in enhancing their agricultural knowledge and skills. In the case of the YAPA programme for example, youth are able to gain agricultural knowledge through hands-on activities, which are facilitated by local farmers who share their knowledge via on-farm demonstrations and other types of experiential activities. These government-led programmes provide a realistic view of agriculture and give their participants a template from which to begin their agricultural careers, with the youth involved being given the opportunity to put their knowledge to practice through the management of their own plots and small enterprises, something that is considered a necessary and beneficial component of the skill building process. Nevertheless, despite serving as a mechanism to provide youth with a chance to venture into commercial agriculture, the efficacy of the programme has been questioned as a result of the lack of government follow through in areas such as training, pre- and post-funding and land for farming. The depth and breadth of the programmes have also been queried due to a lack of vision and questionable management practices.

The Agricultural Professionals Development Programme (APDP) in Trinidad and Tobago was initiated by the Ministry of Food Production as a means of increasing the number of farmers in the country. It was designed to boost the capacity of agriculture graduates to meet the challenges impacting the domestic agricultural sector, and is in line with the Ministry's National Food Production Action Plan for the period 2012–2015. The APDP operates as a platform for engagement of graduates with a vision, 'to assist Trinidad and Tobago to become a more food-secure nation through the creation of a globally competitive workforce of agricultural graduates through professional and technical skills enhancement within a motivational and structured environment' (IICA 2012). Graduates with a degree in Agriculture or Agribusiness have an opportunity to embark upon a one year customized internship in one of five areas namely Crop Production, Livestock Production, Aquaculture, Agribusiness or Agro-processing (IICA 2012).

The Helping out our Primary and Secondary Schools (HOOPSS) programme in St Lucia is described as playing an important role in the socioeconomic fabric of St Lucian households, especially in rural areas (IICA 2012), due to dwindling youth participation in agriculture. HOOPSS is built on a philosophy that only the actual engagement of young persons in theoretical and practical farming best-practice can provide that critical knowledge

necessary for sustainable employment and ultimately, household food security (IICA 2012). The project also seeks to sensitize and expose students to the viability of agriculture as a business, and to promote the creation of agricultural leaders through school gardens and farm activities. Ultimately, it is hoped that this will drive the development of agriculture in St Lucia and as well, address food security and nutritional concerns of the school feeding programme. Success is based on continuous collaboration amongst its many stakeholders, mainly, the Ministry of Agriculture (technical support), IICA (implementation support), and a number of formal linkages with actual markets such as the primary school feeding programmes, local restaurants, hotels, and most notably, Consolidated Foods Limited (CFL) a major supermarket on the island.

The Gilbert Agricultural and Rural Development Centre (GARDC) in Antigua started as a pilot project before being formalized with external funding (Maximay 2005). Its mission is to develop and maintain a demonstration centre to serve the Organisation of Eastern Caribbean States (OECS), by providing a place for practical, hands-on training in sustainable good agricultural practices that protect natural resources to assist the nation with food security and poverty alleviation. The centre, which has offered agricultural and enterprise training mainly to youth between the ages of 16 and 30 years since 1993, focuses on life and entrepreneurial skills development, with a specific emphasis on the use of natural resources in agriculture and other forms of rural enterprise.

COMPONENTS FOR SUCCESS BASED ON REVIEWED EXPERIENCES

The above review suggested that agricultural development directed at youth in rural areas of the world has been supported by a variety of models ranging from government supported, top-down approaches, to a more grassroots-type orientation funded by local citizens, and others supported by regional agricultural organisations. Notwithstanding, the economic hardships, agricultural downsizing, and inadequate funding for youth programmes and agricultural services, for any intervention to have meaningful impact, it must incorporate basic youth development elements along with core agricultural components. The review of a number of youth agricultural programmes across the Caribbean, Latin America, and Africa, has brought to the fore essential issues that can promote youth involvement in the sector, and allow them to add value to the sector.

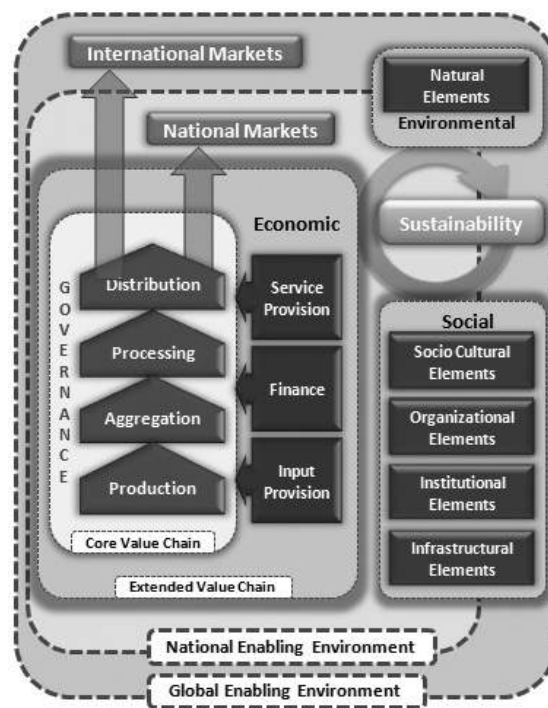
Taking all this into consideration, the essential components of a model will now be offered to help address some of the inherent issues countries face when trying to assist rural youth. Any, or all of these components, can be used by countries to construct their own template

for implementation that is in line with financial and other resources. It also allows for social, cultural and other types of contextual information to be appropriately inserted into the model. Components, several of which have been referred to in previous regional reports, rather than a fixed model, provide the ability to be flexible while also providing a framework for success (King 2006; Maximay 2005; Gordon and Glean, 2004), as well as international country reports on development of youth in agriculture programmes.

FRAMEWORK FOR THE ANALYSIS

The framework presented in figure 2.1 serves to explain the central thesis of the discussion, that youth should be seen as key actors in the chain who can add value to agriculture. As presented by the FAO (2013), the framework is built around the core value chain in which value chain actors, i.e., those who take ownership of the product, and who produce or procure from the upstream level, add value to the product, and then sell it on to the next level. Value chain actors are mostly private sector enterprises, but can include public sector organizations such as institutional buyers (e.g., food reserve agencies, emergency food buyers such as the World Food Programme [WFP]), and even youth.

Figure 2.1: The Sustainable Value Chain Framework



Source: FAO (2013)

Value chain actors are sustained by business development support providers who do not take ownership of the product, but who play an essential role in facilitating the value creation process. Along with the value chain actors, these support providers represent the extended value chain. Three main types of support providers can be distinguished. Firstly, there are those who supply physical inputs, such as seeds at the production level or packaging materials at the processing level. Secondly, there are the service providers in areas such as field spraying, storage, transport, laboratory testing, management training and market research. Thirdly, are the providers of financial services, which are separated from other services given the fundamental role played by working and investment capital in getting the value chain on a path of sustained growth. The facilitation of access to inputs and services then becomes essential for youth if their roles as actors in a value chain are to be fully actualised. A critical element of the core value chain is its **governance structure**. Governance refers to the nature of the linkages between actors at different links in the chain, and within the overall chain. As related to youth, some higher levels of governance and management of youth development in the sector would be another critical element for youth as agriculture promoters.

Value chain actors and support providers operate in a particular **enabling environment** in which social and natural environmental elements can be distinguished. Social elements refer to the man-made creations that make up a society, and which can be grouped into four types: socio-cultural elements (consumer preferences, religious requirements), organizational elements (national inter-professional associations, research and educational facilities), institutional elements (regulations, laws), and infrastructural elements (roads, ports, communication networks, energy grids). Thus communities, schools, neighbourhoods, regional and international organisations, concerned leaders of farmer groups, and civic minded citizens, all have roles to play in creating the enabling environment for increased youth participation in the food sector. The **sustainability** of the value chain plays out simultaneously along three dimensions – the economic level, the social level and at the level of the environment, all of which must be given adequate attention by all youth supporters.

APPLICABILITY TO YOUTH IN THE CARIBBEAN: VALUE ADDITION

As a constituency, youth add value to the chain of food production as key actors and their views must be factored into any decisions to be taken concerning their sustained involvement in the agriculture sector. A key statement by a youth leader in the region advised that ‘youth need to be properly prepared for the positions made available to them. There shouldn’t be a strong sense of entitlement that the government should provide any and all opportunities’ (CARICOM 2012). Nevertheless, there are issues that constrain youth

participation in the food production sector, which were extensively discussed at the regional level meeting of Caribbean youth leaders in Antigua, in 2012. Some key issues raised are listed below (CARICOM 2012);

Strengths of youth in the region:

- Technical competence achieved through training programmes
- Youthful exuberance
- Persistence
- Strong ICT skills

Constraints:

- Access to initial support for start-up of businesses
- Lack of capital, land, technical support and farm equipment
- Lack of mentorship
- Inadequate resources to sustain youth development and leadership
- Urban bias
- Youth not prepared for leadership
- Older generation not giving youth the opportunity to lead

Opportunities:

Many opportunities and action areas were suggested by participants at the forum which they genuinely believed would assist them to make a successful entry into, and have a sustainable livelihood in the sector. These included:

- Focusing on specialty production modes such as nutraceuticals, culinary herb trays, branded produce (e.g. Fairtrade)
- Exploring linkages with tourism
- Informing youth of the opportunities that exist in the agribusiness sector
- Initiating an internship programme to allow students to hone their skills
- Exposing youth to all forms of protected agriculture and other climate-smart production systems

- Providing services in marketing, landscaping etc.
- Rebranding ‘farming’ to ‘food production’ in an effort to delink with the negative connotations of traditional farming
- Teaching agriculture at all the primary and secondary schools
- Developing a mechanism for information sharing among youth and more experienced farmers in the technical aspects of food production to enable them to become entrepreneurs, as against being labourers
- Encouraging greater use of modern technology and the social media
- Teaching agriculture in an interactive manner rather than classroom/textbook mainly
- Considering opportunities in culinary tourism
- Exploring post-harvest areas such as packaging and marketing of products
- Considering nutrition security as an issue to be of equal or greater importance than food security
- Revitalising the 4H movement as an organisation which can help promote agriculture among youth
- Highlighting the successes in agriculture so that young persons may be encouraged to consider getting involved in the sector
- Developing a regional initiative to promote youth in agriculture
- Hiring national consultants to work with policy makers
- Undertaking advocacy work
- Having persons at senior levels in the sector serve as mentors for young persons, especially agriculture graduates
- Looking beyond primary production and considering the value added operations and manufacturing aspects of an agribusiness enterprise
- Instituting job attachments as an initiative that could build youth capacity
- Identification of training and scholarship opportunities for self-development
- Youth engagement in volunteerism to prepare themselves for the future, and as a practical way of gaining work experience

Recommendations

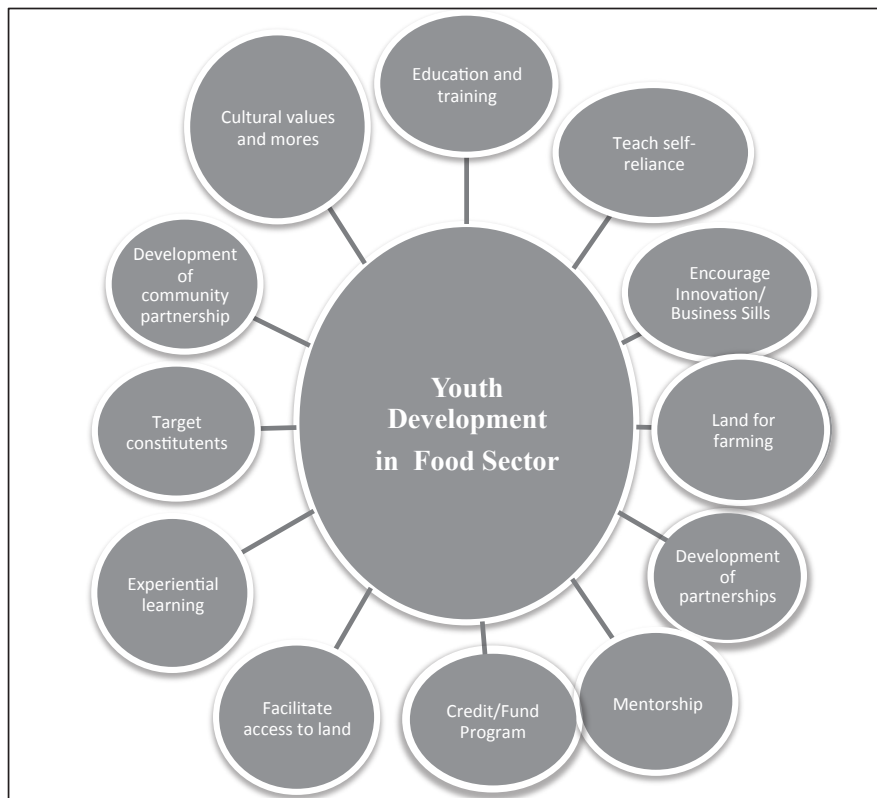
The two major recommendations coming out of the exercise included:

- Inviting policymakers to future youth fora so that they can be more enlightened on the issues; and
- Advocating and lobbying for greater collaboration between the Ministries of Agriculture and Education since both have a tremendous impact on the decision made by youth to enter the agriculture sector.

MODEL FOR YOUTH DEVELOPMENT IN AGRICULTURE

Taking all of the above into consideration, Figure 2.2 is a diagrammatic representation of several issues that we believe impact youth development on the food production sector. Each of these issues is now discussed under three broad headings: Youth centred interventions; Human capital interventions; and, Governmental interventions (enabling policies).

Figure 2.2: Components of the Proposed Youth Making a Difference Model



YOUTH CENTRED INTERVENTION

Identify the constituents: the focus should be primarily on graduates, whether from the universities in the region or technical colleges. New agriculture requires persons prepared to innovate, use modern technology and who are business oriented, something for example, that is in line with the Sudanese model project titled ‘Graduate Employment Fund Program for 2005–2008’¹. Agriculture must be seen as a worthy profession and not as something only pursued by those who fail in the formal education system. While there will always have to be training for young persons who are not academically inclined, a development model must of necessity focus on those constituents who are most likely to succeed in the achievement of national food security goals.

HUMAN CAPITAL INTERVENTIONS

Promote education and training: opportunities for youth to be trained to understand the sector and work efficiently in the sector are important. These educational experiences must prepare youth to tackle the changing tides of agriculture. Cutting edge resources, technology, and other innovative tools must be introduced in order to truly prepare youth for the agricultural industry.

Emphasise experiential learning: while classroom work is important, more emphasis is required on practices. Although the YAPA model in Trinidad and Tobago was assessed and found to have a good mix of classroom and experiential learning activities, the latter were called into question particularly as there was inadequate preparation for the ‘new agriculture’, with still too much emphasis placed on traditional methods of field-based farming in the sun for long hours using minimum technology (Ganpat and Webster 2007). This is certainly not going to attract young persons into agriculture, so it is important that an engaging and interactive curriculum, together with use of latest technology and techniques, be developed to fully engage youth in the field.

Encourage mentorship: the use of business and technical mentors will always be a critical aspect of the proposed transformation of youth involvement in the food sector, especially in the Caribbean, where there are few role models in the form of successful farmers who are prepared to state publicly that the sector is a lucrative one. What one however generally finds is an environment in which the elders convey extremely negative messages to youth about the sector so that it becomes more difficult to encourage youths, especially where they have access to other options, to take an interest and be involved in agricultural production.

1. http://siteresources.worldbank.org/INTAFRMDTF/Resources/Document_5.doc

Mentors with positive dispositions can therefore help direct youth to successful engagement in the sector.

Promote the sector: the food sector has never been proactively sought out by the brightest and the best to lead the transformation, and is not promoted as one of first choice, despite its importance, profitability and current high profile as a mitigation avenue against climate change. National, and even regional communication/promotional programmes or campaigns on a sustained basis can bring the message to an otherwise distracted youth population.

Highlight linkages: the importance of agriculture can be reinforced by demonstrating its linkages to other sectors such as health (from a nutritional standpoint), tourism, infrastructure (e.g. soft engineering solutions for slope protection) and sport (field/pitch/course management). Youth can also assist in bringing to the fore other areas which can be directly or indirectly linked to agriculture.

Teach values: this includes respecting and valuing the environment (flora and fauna, water, and the earth). It is insufficient to teach future farmers skills without providing a sense of value for the environment and encouraging sustainability.

Teach self-reliance: an emphasis must be placed on broadening the scope of agriculture for it to be viewed as a sustainable and acceptable career. Caribbean youth need to be encouraged and empowered to become problem solvers. The time has passed for the promotion of the traditional approach, which upholds the government as some sort of generous benefactor that provides all that is needed. Actions that build self-confidence and self-reliance will not only contribute to transforming Caribbean agriculture, but societies in general.

Encourage innovation: young persons must be taught to experiment and innovate. New agriculture will require constant innovation for farmers to maintain a competitive edge over foreign products. This skill has to be learnt and should form part of the learning experiences. Youth should be encouraged to be innovative and both adopt and adapt strategies that can be used to explore new and emerging opportunities in intellectual property, including branding and utility models, agriculture, and in science and technology.

Teach business skills: traditional training is generally insufficient as it is geared towards improving production skills in situations where there is generally poor farm record keeping across the region. This is insufficient. Post-production and marketing skills are equally important for young people to successfully engage the market economy, and source external markets. Computers and other communication devices must be seen as primary tools for young people in this regard.

Teach sustainability: the resources in the region are quite limited and must be used in a productive manner in the present, while maintaining productivity for future farmers. This will require a reorientation of training at all levels, starting at the university level, where issues of sustainability do not take precedence in most curricula.

GOVERNMENTAL INTERVENTIONS (ENABLING POLICIES)

Provide land for farming: farmers in the region cannot practise extensive forms of agriculture due to limited land areas. Modern agriculture, which is land intensive, requires smaller parcels of land and is regarded as the preferred option today. There are several forms of agriculture that do not require very fertile lands, e.g., protected agriculture using soil-less media, vermiculture, and biotechnology. Agro-based industries also do not require large land spaces to be successful.

Create a credit/Fund programme: this can be set up to assist graduates who wish to engage in small- and medium-sized projects. This is in line with the aforementioned Sudan model, and the ‘Youth Window’, a former project of the Agricultural Development Bank (ADB) in Trinidad and Tobago, which had some success. There is also a need for venture capital and humane financing provisions to encourage youth to engage credit arrangements.

Development of partnerships: linkages with organizations and institutions should be actively promoted, and because the sector is diverse, assistance may have to come from a range of sources. Young farmers must be placed in direct contact with these agencies to access information and other support in a timely manner. Linkages with other sectors are also crucial. The tourism and food and beverage sectors can promote wider markets for products.

Continuous monitoring and evaluation: any model geared at effective change would need to be constantly monitored, evaluated and modified where necessary. In a dynamic sector like agriculture, to allow mechanisms to run on for years without evaluation is tantamount to abandoning a seedling or new born livestock.

CONCLUSION

To outsiders, the Caribbean may appear as one people, and indeed, it is in some respects. However, a closer look will reveal tremendous diversity, and while this is cherished among Caribbean people, it makes development planning somewhat difficult. In the foregoing analysis, this diversity in social and cultural areas, economic resources, human resource capacities, land availability and topographies is acknowledged. It is for this reason therefore

that neither the pattern of other development initiatives is followed, nor is a fixed model offered for promoting youth involvement in the agriculture sector. Instead, based on a review of international experiences with youth in agriculture programmes, a range of components is proposed that could be included in any intervention. A particular country or grouping of countries may choose to incorporate components into a culturally and socially acceptable model that is in line with resources and development goals. Because the construction of a definitive model will take a multitude of Caribbean experiences gathered overtime, for now, only the essential components have been identified as we edge towards a model.

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Small Animal Production Systems: Rabbits and Ducks

Cicero H. O. Lallo, Adrian Paul and Sebrena Smalling

INTRODUCTION

The Caribbean, like many other regions in the tropical ecological zone, has serious food and protein security issues given the escalation in grain prices. This is primarily because 80 percent of the region's meat supply comes from poultry. To address this issue, rabbit production was identified by governments within the Caribbean Region as a viable alternative to enhance protein security and food sovereignty. The production of rabbits and ducks in the Caribbean is generally based on small-scale, backyard and low input systems. The fast growth rate of rabbits (compared to chicken), their short generation interval and ability to convert forages into high quality protein (Leng 2008) are attributes that make them ideal for a role in enhancing protein security in the Caribbean Region. Over the last decade, while levels of rabbit production have increased in Trinidad and Tobago, demand still outstrips supply. This has resulted in a move from small backyard production to medium-sized intensive commercial and semi-commercial production systems.

In tandem with this, there has also been an increase in duck production regionally and globally, with a similar trend observed towards intensive and semi-intensive type production systems. For centuries, ducks have provided an important source of animal protein for the people of Asia, where domestic duck farming originated. For these populations, duck meat and eggs have, and continue to be, important sources of high quality dietary protein, energy, vitamins and minerals. In 1996, over 2.5 million metric tons (MT) of duck meat were produced globally, an increase of 11 percent over the previous year. This was the highest increase in the poultry sector for the corresponding period, with chicken increasing only by 4.3 percent

and turkey by 3.2 percent. Similarly in Trinidad and Tobago, Guyana and Suriname, such trends can also be observed. Many farmers are either increasing their stock or new farmers are establishing duck enterprises. Several factors have helped to sustain this trend, including the duck's ability to adapt to a range of environments and the fact that ducks are considered to be hardy animals and show greater resistance to many common diseases and parasites than other domestic poultry. Ducks therefore require a less rigid vaccination programme than broiler chickens. They are however, very susceptible to mycotoxins, and as a result, management of this factor is very important in their production. Another factor also driving increased duck production is the mushrooming of Chinese restaurants, particularly in Trinidad and Tobago, Suriname and Guyana.

Before starting a farm, or when evaluating an existing enterprise, farmers should make every effort to gather as much information on all relevant aspects of production and marketing. The information acquired should be used to guide both the establishment and day-to-day management of the farm. The following are some key areas that should be taken into consideration when beginning an enterprise, and which can serve as a guide for success:

- *What to sell:* Identify and define exactly the products that are to be produced - breeding stock, fryers, fertile eggs, day-old ducklings, rabbits and ducks for the live or processed market.
- *What the market requires:* Find out exactly what are the market requirements and standards in terms of breeds, market weight, and carcass quality.
- *How much the market requires:* This influences the scale of the operation necessary to produce a set level of output.
- *When the product is required:* Determine trends in market demand and market prices. Is it a seasonal or year-round market?
- *Who are the consumers:* Identify the target market(s).
- *The best way to get the product to consumers:* What is the best method of marketing or selling the product?
- *Breeds and adaptability:* Consider the breeds available, their uses and performance under the prevailing environmental conditions in which they will be reared.
- *Performance standards of the breeds:* The ability of available breeds to produce the desired output in the environment in which they will be producing.
- *How best to house and manage the stock:* Identify the most appropriate production system and technology that should be used, considering the level of available resources and the planned output of the farm.

- *Source and availability of duck and rabbit feed:* The availability of a continuous source of high quality life cycle feeds.
- *How to keep the stock healthy:* Seek guidance on the best health maintenance programme.
- *Plans for expansion:* Current demand and market trends are good indicators of future demand, and ultimately influence the scale of the operation and plans for expansion.

RABBIT PRODUCTION

BREEDS OF RABBITS UTILISED IN CARICOM

- Rabbits are reared mainly for their meat in the Caribbean, with a number of breeds and their crosses being found in the region. The most popular ones include:
- Flemish Giant: weighing more than 5.5 kg at maturity
- Californian: a medium-sized breed, which can reach 4.0 kg at maturity
- New Zealand White: animals can attain a weight of more than 4.5 kg at maturity
- Chinchilla: there are different strains of this breed, e.g. the giant strain, which can generally weigh more than 6.5 kg at maturity
- Crossbreeds: including New Zealand White x Californian, Flemish Giant x New Zealand White, Flemish Giant x Californian, Chinchilla x New Zealand White, Californian x Chinchilla x New Zealand White

The most popular cross however is the New Zealand White and Californian, largely because these breeds and their crossbreeds have shown good adaptability to the tropics, as it relates to their 'thermo-tolerance' and performance. The Flemish Giant and Chinchilla are used mainly as terminal sires. The crosses of these breeds show excellent meat: bone ratio.

Terminal sires: Sires used in a crossbreeding system in which all their progeny are marketed.

NUTRITION AND FEEDING

The rabbit is a monogastric herbivore and a hind gut-fermenter, with the caecum making up 40 percent of the gastrointestinal tract (GIT). Thus, the digestive system and the feeding strategy (caecotrophy, the practice of ingesting soft faeces of caecal origin) give the rabbit an advantage over poultry and pigs for use in sustainable farming systems. The caecum with its microbial activity, caecotrophy and high feed intake (between five and 8 g/100g body weight [BW]) is important for digestion, nutrient utilisation and meeting the nutrient requirements of the rabbit. Recycling of nutrients via the consumption of soft faeces (caecotropes) produced from the materials that pass through the caecal cycle, compensate for low or poor quality protein in the diet.¹ The nutrients rabbit require in their feed are grouped into the following categories: protein, carbohydrates, fat, minerals, and vitamins:

- *Protein* – is important for muscle building, and is a major component of the cell membrane, hormones and enzymes. The nutritive value of proteins is dependent on its amino acid composition, the amount of protein consumed by the animal, the portion that is digested in the gut and the portion absorbed as free amino acids or peptides. Because rabbits are non-ruminants they require essential amino acids. In all the amino acids, lysine and methionine are found to be the most deficient because the ingredients used in feed formulations tend to be low in these amino acids. Other amino acids include: isoleucine, tryptophan, leucine, phenylalanine, threonine and valine.

Plant proteins used in feeding rabbits fall into two major categories: seed and leaf proteins. Generally, protein meal from legumes and oilseeds are higher in albumin and globulins (soluble protein) thus, the proteins of legumes are normally higher in essential amino acids than cereal grains (high in storage/insoluble protein) (Villamide, Nicodemus, Fraga and Carabaño 2010). Nevertheless, a major constraint associated with their use in the unprocessed form relates to the presence of anti-nutritional factors (e.g. tannins, trypsin inhibitors, and lectin – a carbohydrate-binding protein), which limits their use. The major protein source used in rabbit concentrate feed is soybean meal.

- *Carbohydrates* – in rabbit feed these comprise sugars and starches, located largely within the plant cell (which are hydrolysed by the endogenous intestinal enzymes of the animal), and cellulose found principally in the cell wall (which is hydrolysed by microbial enzymes, and provides fibre). Compared to starch, sugars (e.g. glucose

1. For further reading go <http://www.mekhan.org/prorab/leng.htm>

and fructose) are readily digested by the animal and absorbed in the small intestine to provide a source of energy (Blas and Gidenne 2010). Starch on the other hand, is nearly completely digested in the GIT of the rabbit but the amount is dependent on the source of the starch and the age of the rabbit. Because rabbits are hindgut fermenters, they are able to digest cellulose and utilise it as an energy source. The fermentative process by caecal microbes produce volatile fatty acids (VFAs) such as acetate, butyrate and propionate, which are absorbed in the hindgut and provide a source of energy for rabbits (Gidenne, Carabaño, Garcia de Blas 2010). Digestive disorders in weaned rabbit may be due to stress brought about by management changes and stress due to physiological changes in the animal. It was normally accepted that digestive disorders in weaned rabbits were due largely to an overload of rapidly fermentable carbohydrate; however the thinking is that the incidence of digestive disorder may be more related to dietary fibre level and a reduction in the starch to fibre ratio in the diet (Gidenne et al. 2010), which can be corrected by increasing the fibre requirements, and lowering the starch content of the diet.

- *Fat* – functions as a primary source of energy, to increase the palatability of the feed and as lubrication in the pelleting process. It also enables the absorption of fat-soluble vitamins in the gut. Adult rabbits appear to have little capacity to digest fat in the small intestine because lipase activity is restricted to the caecum. A high amount of fat in the diet may limit cellulose fermentation in the caecum, resulting in its excretion as a component of the hard faeces.
- *Minerals and vitamins* – these can be satisfied by the use of calcium and phosphorus supplements and a trace mineral salt and vitamin premix in the commercial concentrate, or from the forage portion of the diet.

FEEDING RABBITS

In the Caribbean, rabbits are primarily fed on a forage-based diet supplemented with commercial rabbit feed in a 2:1 ratio to enable a feed conversion ratio (FCR) of 3.0-3.5 g DMI/g BW in grower rabbits. Small-scale backyard farmers generally use higher levels of forages for feeding, as against medium-sized intensive commercial systems, and a commercial rabbit concentrate is fed *ad libitum*, along with some wilted forage. Rabbits given concentrate (high energy density) will consume 5 g/100g BW. When fed forages alone, they need to consume over 8 g/100g BW. Growing rabbits fed concentrate + wilted forage consume 6.0 to 6.6 g/100g BW on a dry matter (DM) basis and average daily gain (ADG) is between 30–32 g/d in Trinidad (Table 3.1). The following are suggested rates for feeding commercial rabbit concentrate and with forages fed *ad libitum*:

- Buck - 80 g/d
- Pregnant/gestating doe - 120 g/d
- Non- pregnant doe - 96 g/d
- Growing stage - 60 g+10 g/week until 100g/d
- Lactating does - 100g/d + 10 g/kit being nursed

Local forages used to feed rabbits include grasses (e.g. elephant grass - *Pennisetum purpureum*, para grass - *Brachiaria mutica* and tanner grass - *Brachiara arrecta*), legumes (e.g. leucaena - *Leucaena leucocephala*, tropical kudzu - *Pueraria phaseoloides* and gliricidia - *Gliricidia sepium*) and protein tree forages (e.g. *Trichanthera* - *Trichanthera gigantean* and rabbit meat - *Alteranathera tenella*), in which protein is concentrated in the leaves. Forages are normally supplemented with a commercial rabbit concentrate feed in intensive commercial production systems in the Caribbean. There are also some producers who feed a concentrate that has been specially formulated by the feed millers to meet all the nutrient requirements of the rabbit, including the fibre requirements. Agro by-products such as spent brewers grains, vegetable scraps, cassava leaves and meal, and sweet potato slips are also used for feeding rabbits.

The greatest challenge to developing sustainable production systems for the Caribbean lies in feeding, as feed costs make up more than 60 percent of total production costs. The escalation in grain prices means that the use of concentrate will have to be minimised, and a greater amount of forages and by-products must be fed. Research has been initiated in the Department of Food Production, Faculty of Food and Agriculture, the University of the West Indies (UWI), St Augustine, Trinidad, in this regard. One study, which examined the use of a combination of forages with reduced concentrate levels for growing rabbits, showed promising results as Table 3.2 and Figure 3.1 illustrate.

Table 3.1: Performance of rabbits (mean values) fed three different forages with a commercial rabbit concentrate

TREATMENTS					
	T ₁	T ₂	T ₃		
Parameters	Tropical Kudzu	Rabbit Meat	Tanner Grass	±SEM	P-Levels
Initial LW (g)	784.70	730.70	917.70	61.90	=0.102
Final LW (g)	2367	2228	2424	7.3	=0.199
Avg. daily gain (g)	31.64	29.94	30.12	1.0.	=0.419
Forage DM intake g/hd/d	32.28	33.58	36.74	0.79	=0.001
g/100g LW	2.09	2.33	2.28	0.12	=0.319
Concentrate DM intake g/hd/d	61.55	61.75	64.91	1.15	=0.018
g/100g LW	3.96	4.31	3.99	0.19	=0.365
Total DM intake g/hd/d	93.93	95.33	101.65	1.03	=0.00
g/100g LW	6.04	6.63	6.27	0.29	=0.363
FCR	2.98	3.26	3.42	0.11	=0.031
Nutrient Intake: g/hd/d					
Crude protein	19.33	15.73	15.18	0.22	<0.01
Crude fibre	27.14	25.12	23.07	1.23	<0.01
Crude fat	2.03	2.47	2.24	0.02	<0.01
Ash	8.63	7.91	13.82	0.12	<0.01

LW – liveweight; DM – dry matter; g/hd/d – grams/head/day; FCR – feed conversion ratio

Source: Paul and Lallo (2014)

Table 3.2: Carcass yield of growing crossbred (Californian x Chinchilla x New Zealand White) rabbits fed different forages with reduced concentrate levels

Parameters	Treatments						±SEM	P-value
	T1	T2	T3	T4	T5	T6		
Slaughter BW, g	2643	2508	2602	2493	2353	2625	90.15	=0.270
Hot carcass weight (HCW), g	1407	1235	1348	1252	1223	1375	55.94	=0.149
Carcass yield g/100g BW	53.15a	49.24bd	51.83ac	50.16bc	51.98ac	52.37ac	0.75	=0.027
Carcass Composition (g/100g HCW)								
Shoulders Weight	15.15	17.01	16.44	15.08	16.06	15.08	0.60	=0.174
Ribs weight	24.55	20.50	22.40	20.37	19.71	23.26	1.20	=0.088
Saddle weight	24.86	25.80	24.93	26.67	26.75	25.03	1.41	=0.853
Hind legs	37.63	38.47	37.72	37.58	37.62	36.74	0.79	=0.779
Head weight	16.04	16.86	16.45	15.41	18.84	15.80	1.07	=0.321
Liver weight	4.56	5.40	6.40	4.98	4.77	5.30	0.63	=0.425
Kidney weight	1.07	1.48	1.11	1.22	1.23	1.21	0.13	=0.382
Separable fat	2.26	2.70	1.23	2.86	3.13	2.19	0.61	=0.364

T1- *Ad libitum* concentrate feed, T2- 50 g concentrate feed + *ad libitum* Tanner grass, T3- 50 g concentrate feed + *ad libitum* Trichanthera, T4- 50 g concentrate feed + *ad libitum* Sweet Potato Vines, T5- 50 g concentrate feed + *ad libitum* Gliricidia, T6- 50 g concentrate feed + *ad libitum*, and a mix of Tanner grass + Trichanthera + Sweet Potato Vines + Gliricidia

Source: Ram and Lallo (2014)

Box 3.1 outlines the best practices that should be employed for feeding rabbits in hot, humid climates.

Box 3.1: Best Practices For Feeding Rabbits In Hot, Humid Climates

When feeding rabbits you should:

- Preferably feed them in the evening, at the same time each day
- Provide a good fibre source to prevent enteritis
- Not feed large amounts of highly soluble carbohydrate
- Wilt green forages overnight when these are to be fed
- Ensure a supply of fresh potable water is available at all times (1 nipple /2-3 animals is sufficient)

REPRODUCTIVE MANAGEMENT

Productivity in the breeding unit is defined as the number of young per doe per unit of time (normally measured over a year). Productivity depends on: the interval between successive kindlings, litter size at birth, and the survival of the young (mortality rate). Rabbits, like all other animals will respond to gentle treatment, thereby allowing the breeder to easily handle and manage them. An animal's temperament is therefore something that should be taken into consideration when selecting rabbits for breeding. For example, if one has an aggressive doe, culling may be advisable since she may produce aggressive off-spring. Formerly, the recommendation of one buck for every ten does was used, however at present this has been adjusted to one buck for 25 to 30 does. Nonetheless, under different climatic conditions and management systems, the breeder will have to make a judgment call to determine the buck: doe ratio best suited for his/her system.

Age at first mating

Reducing the unproductive period before the first litter can increase rabbit productivity; however, both body development and age must be taken into consideration in order to determine the proper time to breed animals. For example, smaller breeds mature much earlier than the heavier breeds, and does may become receptive to males at 3.5 months of age and so capable of conception at 4–4.5 months. However, the time animals are bred is not only dependent on age but also based on physical observation of body condition. At the University of the West Indies field station (UFS) in Trinidad, mating is done at 6.5 months, which is usually the time when the animal is sexually mature, and has the body condition to sustain the reproductive function. Medium-sized breeds like New Zealand White and

Californian can be first bred at five to six months of age, while this is done at six to seven months of age with a larger breed such as the Flemish Giant. It should be noted too, that nutrition has a strong influence on the age at first mating, and does should not be served until they reach 80–85 percent of the mature body weight recommended for the breed, even if they may have attained the appropriate age.

Mating process

In most domestic mammals, ovulation takes place at regular intervals when female is in oestrus (heat). The female rabbit does not have an oestrous cycle with a regular period of heat, and so does are considered to be in oestrus ‘permanently’, with ovulation occurring only after mating. The rabbit is therefore referred to as a reflex ovulator. Ova released without fertilisation may accompany a pseudo-pregnancy which may last 15–17 days. Signs of heat in rabbits include: chinning, attempts to join other rabbits in nearby cage, and the vulva appearing pink and moist. Does are always taken to the male for mating where she will readily accept the buck (Figure 3.2). The doe may fight with the buck if he is placed in her pen and may cause injury to the buck. Sometimes, a doe may need to be restrained in order for mating to occur. In other cases, she may refuse one male, but when placed with another male, will readily accept him and mate.

Parturition

The gestation period in the rabbit generally averages 31–32 days and is influenced by the size of the litter being carried. Prior to parturition, the does will show maternal behaviour such as nest building, so that part of the management process must be the provision of a nest box measuring 40 cm x 30 cm x 30 cm. During this period the doe will pull hair from around the nipple area on the belly and dewlap, which will be used to build the nest in the box provided (Figure 3.3). The nest building behaviour observed appears to be linked to an increase in the oestrogen: progesterone ratio, as well as the secretion of prolactin. Note however, that the doe does not always make a nest and may sometimes kindle (give birth) outside the nest box. As with other animals, the secretion of corticosteroids by the adrenal glands of the young appear to play a role in signalling the onset of parturition, which usually occurs early in the morning, and lasts approximately 30 minutes, with kits being born at intervals of one to five minutes.

Box 3.2 provides a summary of the best practices that can be used for breeding rabbits.

Box 3.2: Best Practices for Breeding Rabbits

In breeding rabbits it is important to remember that:

- The female should always be taken to the male for mating
- After copulation the female should be immediately removed from the male and returned to her pen for maternal preparation
- The doe should not be mated if she is not at the required weight, even if she has attained the age of puberty
- Females that have a high service to conception ratio should be culled
- Females with more than eight parturitions should be culled
- A nest box should be provided at least two days before parturition

HANDLING RABBITS

Rabbits should never be lifted by their ears or legs, as this can lead to permanent damage. Small rabbits or fryers should be lifted and carried by gently grasping the animal firmly with the heel of the hands in the areas on its back close to the tail to avoid damaging the pelt or carcass (Figure 3.4). Heavier rabbits should be carried by grasping a fold of skin over the shoulder with one hand, and placing the other hand under the rump to support the weight of the animal (Figure 3.5).

ENVIRONMENT AND HOUSING

El Kholy (2011) indicated that the thermoneutral zone (TNZ) for rabbits ranged from 21°C–25°C. Alnaimy, Fayez, Habeeb and Marai (1994) however cited a temperature of 21°C. For temperatures outside this zone, the rabbit will experience heat stress and has to expend energy to maintain its core temperature. Thus, when the ambient temperature is above 25–30°C, the animal changes its posture and stretches itself out in order to lose heat by radiation and convection. During this period the ear (which acts like a radiator) temperature increases, and the efficiency of cooling will be influenced by the air speed around the animal (Habeeb, Marai, El-Maghawry and Gad 1997). French researchers have recommended a relative humidity of 60–65 percent as optimum for rabbits. Within the tropics temperature and humidity are two key elements that influence thermoregulation, with temperature being the most dominant factor. Because these two factors influence the heat stress experienced by rabbits in a tropical environment, they have consequences for housing design.

Environmental stress has a negative impact on the production and performance of rabbits, which tend to achieve homeostasis by regulating their internal body temperature through changes in skin temperature, ear temperature, and respiratory rate under unfavourable environmental conditions. As temperature increased from 20°C to 33°C, Lebas, Coudert, De Rochambeau and Thébault (1986) reported an increase in rectal temperature by 3.6 percent for New Zealand White and 3.1 percent for Californian White. Skin temperature increased by 0.27°C, and respiratory rate increased by seven percent for every 1°C change in ambient temperature. A 50 percent increase in water consumption was reported as temperature rose from 20°C to 30°C (Marai and Ali 2004).

Thermoneutral zone: The range of environmental temperatures over which the heat produced by a warm-blooded animal remains fairly constant.

Homeostasis: The ability or tendency of an organism or cell to maintain internal equilibrium by adjusting its physiological processes.

Housing systems recommended for commercial rabbit production in the Caribbean are hutches made entirely of wire mesh, situated in covered areas, either suspended from the roof or placed on stands which are further enclosed in an open-sided-house (Figure 3.6). Utilising the open-sided house design facilitates a favourable environment. The design and dimensions of housing systems are important since these can have a direct impact on the housing micro-climate (i.e. environment), the animals' metabolic rate, health, welfare and production (depending on the stocking density).

Rastogi (1991) recommended a hutch size of 0.76 m x 0.76 m x 0.46 m for rabbit production in Trinidad. The NRC (1996) has recommended a space allowance of 1,350cm² for rabbits less than 2 kg, and 1,200cm² for growing rabbits less than 10 weeks old, to allow for the appropriate cage space required to facilitate the increased activity and rapid locomotion of the growing rabbit (Figure 3.7).

STOCKING DENSITY

Stocking densities above the optimum have been found to negatively affect animal health, performance and carcass quality (Yakubu, Adua and Adamude, 2008; Szendro and Zotte 2011), but improve the economics of rabbit production (Verspecht et al. 2011; Yakubi and Adua 2010). Studies done on stocking densities for rabbits housed in cages located in naturally ventilated open-sided house at the University of the West Indies Field Station (UFS) rabbitry indicated that 11 to 13 rabbits/m² was optimum for animal performance and profitability. The study also indicated that the final market weight of the animal was

influenced by the stocking density (Figure 3.8), due to the impact on feed and water intake (Paul and Lallo 2014).

As group size increased, aggressive behaviour was also reported to rise, resulting in animals sustaining lesions to their ears, bodies, tails and genitals (Szendro et al. 2009; Ibrahim, Marai and Ali 2004). Increasing stocking densities have also been found to result in abnormalities in body and fur condition, but Iyeghe and Olorunju (2005) reported that there is no significant interaction between increasing density and abrasions caused by bites.

COMMON HEALTH PROBLEMS

A sound proper biosecurity programme, along with preventive hygiene, cleaning and disinfection, and adequate ventilation must be put in place to maintain the right environment for healthy rabbits. Rabbits are very susceptible to digestive disturbances and fryers and post-wean kits losses may be greater than 40 percent due to diarrhoea. This can have a severe economic impact on commercial rabbit production in the tropics, and is one of the most common health problems associated with rabbits. There are two principal types of enteric diseases:

- Muroid enteritis (caecal impaction)
- Enterotoxaemia caused by *Clostridium perfringes* and *C. spiroforme* proliferation in the caecum, both of which produce very potent toxins

Several factors lead to enteritis such as: the age, genetics and immune status of the animal, presence of pathogenic microbes in the environment, and environmental factors (e.g. micro-climate and heat stress, biosecurity and nutritional factors). Diets high in fermentable starch (such as carbohydrates) predispose post-weaned rabbits to increased incidences of enteritis, and can be prevented by feeding diets low in starch and high in fibre. Enterotoxaemia is caused by carbohydrate overload of the hind gut, thus providing a substrate for the proliferation of pathogens (e.g. *C. spiroforme* requires the presence of glucose).

Fibre promotes normal motility of the hindgut so that where low fibre diets are fed, these promote hypo-motility resulting in prolonged retention time of digesta in the caecum and changes in caecal pH causing a proliferation of caecal microbes. In a review of several studies, Gidenne et al. (2010) reported that dietary fibre has a favourable effect on rabbit digestive health. In Trinidad, many rabbit farmers place a dry, un-husked coconut in the cages to ensure that animals obtain an adequate supply of dietary fibre in their diet. Excessive protein in the diet of the rabbit has also been linked to digestive disturbances, and Gidenne et al. (2010) also reported that a protein level of 1.8–1.9 g CP/ MJ DE seems adequate to prevent this.

COMMON DISEASES OF RABBITS UNDER HUMID TROPICAL CONDITIONS

Snuffles

Symptoms: these include sneezing, watery eyes, white nasal discharge, difficulty breathing, and animals may be observed rubbing their noses. This condition may also develop into pneumonia.

Causative agent: bacterial infection of the nasal sinus, caused by dust inhalation of mashed feeds given dry.

Control/treatment: consult a veterinarian for the prescribed antibiotic treatment (be aware if oral antibiotics are being administered, as these may interfere with the normal digestion of the gut).

Coccidiosis

Symptoms: include diarrhoea with mucous, bloated stomach, loss of appetite, slow growth rate/ weight gain.

Causative agents: parasitic infestation of the intestinal track caused by coccidia (*Eimeria perforans*, *E. magna*, *E. media*, *E. irrisidua*), and which is spread through faecal contamination.

Control/treatment: this involves the prevention of faecal contamination of feed and water, sanitation of housing, direct treatment of drinking water through the addition of 42.5 g of sulfaquinoxaline per 3.8 l water for 14 days, and repeated after seven days. Animals should be treated whether they show symptoms or not.

Enteritis

Symptoms: these are loss of appetite, reduced activity, dull eyes, rough fur coat, animals may appear bloated, diarrhoea and mucous in droppings.

Causative agent: fermented or spoiled feeds and forages.

Control/treatment: this can be achieved using Terramycin tablets with Vitamin A, D and niacinamide (also called nicotinamide, a form of vitamin B3). Administering sulfasuxidine as recommended by a veterinarian can be used to treat the enteric infection.

Ear canker (ear mange)

Symptoms: the disease is characterised by animals shaking their heads, scratching their ears, and the appearance of a brown scaly crust at base on inner ear.

Causative agents: ear mites (*Psoroptes cuniculi* and *Notoedres cati* var. *cuniculi*).

Control/ treatment: includes the removal of the scales and crust from inner ear and swabbing the area with a mixture of 1tsp. olive or mineral oil, and three drops of iodine/ paraffin once/day for three days, and repeated at ten days intervals. Ivermectin can be used for tough cases or any other acaricide drops.

Skin mange

Symptoms: these are scaly skin, scarf (dandruff) itching and scratching and fur loss.

Causative agents: parasitic infection of the skin caused by mites (*Cheyletiella parasitivorax* and *Sarcoptes scabiei*).

Control/treatment: the use of a medicated shampoo and submerging the animal in a 1.75 percent lime sulphur bath comprising lime sulphur (30 percent concentration) and laundry detergent and applied at a rate of one tsp./3.8 l water.

Myxomatosis

Symptoms: these include inflammation and swelling of the eye, ears, nose and genitals, high fever, loss of appetite. Ears may also droop from weight of swelling.

Causative agent: a viral infection caused by the myxoma virus, which is easily transmitted by mosquitoes and fleas. Mature animals are the most affected, and the disease is usually fatal.

Control/treatment: diseased animals should be culled.

Buck teeth (malocclusion)

Symptoms: in affected rabbits the incisors grow long and prevent the animal from closing its mouth thereby leading to reduced feed intake.

Causative agent: this is an inherited trait and not easily cured.

Control/treatment: rabbits displaying this trait should not be used as breeding stock. To reduce the incidence of malocclusion, the teeth of fryers should be trimmed.

Conjunctivitis (pink eye)

Symptoms: characteristic of this disease is the inflammation of the eyelids, from which a watery or thick and purulent discharge may be emitted. The fur around the eyes may be wet and matted.

Causative agent: this is a bacterial infection of eyelids or irritation of the eye from smoke dust sprays or fumes.

Control/treatment: consult a qualified veterinarian for recommendations on an appropriate antibiotic treatment. Use warm water to clean the mucous from around eye.

Sore hocks

Symptoms: affected rabbits display infected or abscessed areas on hocks, and animals tend to shift their weight onto the non-affected foot.

Causative agents: wet floors, irritation from wire rust or rough areas on floors, frequent thumping of feet.

Control/prevention: thus involves cleaning the area around the lesion and removing any blood or inflammation, applying the recommended antibiotic ointment, checking for uneven or damaged floors, and in severe cases, culling affected animals.

DUCK PRODUCTION

COMMON BREEDS OF DUCKS USED IN THE REGION

Domestic ducks fall into two genetic classes: the common duck (*Anas platyrhynchos*) and the Muscovy duck (*Cairina moschata*). The Muscovy is a breed unrelated to the common duck and has its origins in Brazil, South America (neo-tropics), while the common duck has its origins in Asia. The Pekin duck falls into the classification of common ducks, and along with the Muscovy, are the two most important commercial meat ducks worldwide. The cross between the common duck (Pekin) and the Muscovy is sterile, and is referred to as a 'Mule' duck, which is a fast growing meat-type bird. Depending on the country, this cross is also called the Mulard, Mullard or Moulard duck. Although the origins of the Mule duck are uncertain, it is said to have been developed more than 250 years ago by farmers in Taiwan, who crossed Muscovy males with indigenous females in order to combine the high meat yield of the former, with the high laying rate of the latter. Today, although Mule ducks are grown in large numbers in France and Eastern Europe, the principal production of Mule ducks for meat occurs in the Far East and South East Asia.

MEAT BREEDS USED IN THE CARIBBEAN

Pekin

This breed (Figure 3.9 – page 99) is probably the most popular duck breed reared for meat production. It is well adapted to confinement, making it ideal for commercial production. The Pekin duck is well known for its rapid growth rate and, can reach 3.2 kg in about eight weeks. The mature weight of this breed is about 3.6 and 4.1 kg for ducks and drakes, respectively. The drakes are very fertile, and females are very good layers, producing 150 to 200 eggs per year, with very good shell texture. Pekin eggs usually have good hatchability and are easily incubated artificially. The incubation period lasts for a duration of 21 days like chickens, as against 35–38 days for Muscovy ducks. Nevertheless, a major disadvantage of

this breed is that the Pekin is not a very good setter, and very seldom broods its own eggs or raises its young. This represents a major limitation to small farmers who are forced to use a broody layer hen, (Muscovy ducks or a small artificial incubator). The Pekin duck can also be noisy and is very nervous.

Muscovy

The Muscovy duck (Figure 3.10A and 3.10B) is the best multi-purpose (i.e. meat and eggs) breed of ducks. It is normally the breed of choice by small and backyard producers in the region but is also reared by commercial duck farmers. While there are several strains with varied colours, the white is preferred by commercial producers as they produce a high quality carcass. The carcass is larger than that of the Pekin duck, has less fat and larger pectoral muscles. The drakes are approximately 40 percent heavier than the ducks at maturity, weighing up to 5.5 kg, and have a high breast meat yield. The duck weighs approximately 3.2 kg.

The Muscovy is classified as a fairly good layer, producing 120 eggs per year, which are medium to fine in texture, have good shell characteristics and excellent hatchability. The ducks lay 20 to 25 eggs per clutch and will proceed to hatch and rear their young. If the number is restricted to about 20, it is not unusual for the duck to hatch and rear all. This makes them good setters with good mothering ability. They are therefore highly favoured by small farmers who use natural incubation. The meat has a gamely taste, is leaner than the Pekin, and is highly favoured by consumers. Since these ducks are nearly mute, this breed is favoured because it is not very noisy, but is however prone to praedial larceny. The Muscovy duck has good grazing or foraging habits, and is therefore excellent for small backyard, semi-intensive or extensive production systems.

One disadvantage of this breed is that they exhibit sexual dimorphism. Males are larger than the females, which only attain 60 percent of the weight of males at maturity. The Muscovy is not well-suited to large commercial operations because its level of egg production is lower when compared to the Pekin. The Muscovy can fly well, so it is normally recommended that pinioning be done, particularly where the unimproved strain is being reared. Like chickens, the wild unimproved strain of Muscovy likes to roost at nights. The incubation period for the Muscovy egg is 35–38 days compared to the 21 days the Pekin, as stated above. Because the young take a month longer to come into feather, a longer brooding time is required. Since the plumage is less oily and downy than that of other ducks' feathers, care has to be taken when putting the Muscovy on water, as it is possible that birds can drown, especially the heavy long-winged drake. The claws on the feet are sharper than those of other ducks, so that these birds must be handled carefully, especially the large drakes which are very temperamental and can cause damage to workers.

Sexual dimorphism: differences in appearance between males and females of the same species, such as colour, shape, size, and structure.

Pinioning: the act of surgically removing one pinion joint, namely the joint of a bird's wing, farthest from the body, to prevent flight.

Mule duck

Various strains of this duck, namely multi-coloured and white (which is preferred by commercial producers), can be found (Figures 3.11A and 3.11B). The Mule duck is fast growing and it grows relatively faster than Pekin and Muscovy ducks. Good lines can produce a live weight of 3.7 kg at ten weeks of age and at a FCR of 2.5 (i.e. 2.5 kg feed per kg live weight). This duck does not exhibit sexual dimorphism and produces a good quality carcass that is high in lean meat. The meat also has a soft texture, and similar to that of the Pekin duck. The carcass, while leaner than the Pekin, also retains sufficient subcutaneous fat to produce a succulent flavour following cooking. Mule ducks show good disease resistance, but are sterile.

RESEARCH AND DEVELOPMENT IN TRINIDAD TOWARD A SUSTAINABLE INDUSTRY

Central Farms is the leading duck producer in Trinidad and Tobago, and also is a major partner in the duck research conducted locally. In collaboration with the Department of Food Production, UWI, St Augustine, a programme was developed to test improved duck breeds and strains from a major international duck breeder under our local conditions. In light of this, studies were undertaken on the performance of Pekin, Muscovy and Mule duck breeds from France and North America. The findings of this research are presented in Tables 3.3 and 3.4, which provide summaries of the performance of Pekin and Mule ducks and Mule ducks alone reared at Central Farms, respectively. Based on the results it was concluded that the Mule duck was the best breed to use locally for commercial production.

A major drawback to sustainable duck production however, is the reliance on imported soybean meal and corn. Further, the price increases to which these commodities are subjected, can threaten the sustainability of monogastric animal production in CARICOM (Lallo 1998). Central Farms along with UWI has begun research into this issue since feed costs represent more than 60 percent of total production costs. Work is being done to identify a feed supplement, which is based on by-products from different industries such

as bakeries, snack and cereal manufacturers. The use of ensiled fish waste, protein forages and legumes as a way forward to developing more sustainable feeding systems is also being explored.

Table 3.3: Summary of the performance for Pekin (PK1 and PK2) and Mule (MUC) ducks reared at Central Farms

Parameters	Treatment/Breeds				
	Pekin		Mule		
	PK1	PK2	MUC	±SEM	P-Value
Initial Body Wt. (g)	53.3	66.3	70.7	1.7	<0.001
0-21 days:					
Body weight (g)	1063	1146	1118	26	=0.093
Dry matter feed intake (g)	2119	2522	2549	79	=0.001
FCR (g DMI/g BW)	2.00	2.21	2.29	0.08	=0.099
0-49 days:					
Body weight (g)	2337	2654	2180	60	<0.001
Dry matter feed intake (g)	6157	6514	5634	148	=0.001
FCR (g DMI/g BW)	2.64	2.46	2.59	0.05	=0.067
Carcass yield:					
BW at slaughter (g)	2424	2704	2361	44	<0.001
Eviscerated carcass (g)	1960	2222	1965	37	<0.001
EVC (g/100g BW)	80.86	82.17	83.2	0.34	<0.001
Breast yield (g/100g EVC)	23.7	26.2	19.9	0.4	<0.001
Leg quarters (g/100g EVC)	17.1	17.9	16.9	0.3	=0.020

A local Pekin strain (PK1) (EVC - Eviscerated carcass); Pekin strain imported from USA (PK2); Mule duck strain from Canada (MUC)

Source: Lallo and Ramraj (2008)

Table 3.4: Summary of the performance for Mule (MUC, MUS) ducks reared at Central Farms

Parameters	MUC	MUS	±SEM	P-Value
Initial body weight (g)	70.8	78.1	±1.4	=0.001
0-21 Days				
Body weight (g)	921	998	17.3	=0.005
DM feed intake (g)	1089	2172	73	<0.001
FCR (g DMI/g BW)	1.18	2.18	0.78	=0.005
0-70 Days				
Body weight (g)	3101	2987	97.1	=0.419
Dry matter feed intake (g)	7766	8076	243	=0.376
FCR (g DMI/g BW)	2.51	2.70	0.02	<0.001
Carcass Yield:				
BW at slaughter	2950	2987	120	=0.827
Eviscerated carcass Wt. (g)	2412	2413	99	=0.992
Eviscerated carcass yield (g/100g BW)	78.5	80.8	2.6	=0.516
Breast yield (g/100 g EVC)	23.6	25.7	1.0	=0.125
Leg quarters (g/100 g EVC)	17.0	18.7	0.7	=0.097

Mule duck strain from Canada (MUC); Mule duck strain from USA (MUS)

Source: Lallo and Ramraj (2008)

NUTRITION AND FEEDING

In order for ducks to grow at an optimum rate economically, their nutrient requirements for energy, protein, vitamins and minerals must be met. These nutrients are needed each day to support maximum weight gain in the ducks, and therefore must be present in adequate amounts with no imbalance or excess. As against broilers, the growth of ducks is not influenced by dietary energy concentration and as such, energy must be provided at a level that is most economical (i.e. between 2,890 Kcal/kg and 3,200 Kcal/kg). Since ducks are almost insensitive to excess protein in their feed, the utilisation of diets high in protein is ineffective in attempting to reduce fatness in ducks. Feed restriction may reduce fatness, but will also result in a lower feed conversion. Protein levels in starter rations may range from 18 to 20 percent CP (crude protein) and in grower-finisher rations from 15 percent to 18 percent CP. Scott and Dean (1991) have noted that the ratio of energy to protein (ME: P) is also critical to duck performance. While French researchers have recommended ratios of 17.2 and 20.7 for starter and grower diets (Larbier and Leclercq 1994), the NRC (1994)

suggested values of 13.0 and 18.8 for these various rations respectively. With respect to the vitamin and mineral requirements of ducks, in commercial diets these are supplied by premixes. There may also be differences in the nutrient requirements among the Pekin, Mule and Muscovy.

In intensive systems of production, because the ducks are confined, concentrate feeds are used to supply all their nutritional needs in order to promote a rapid growth rate and high quality carcass. In semi-intensive systems the objective is similar, and while the ducks may forage and consume insects, the contribution of foraging to supplying their nutritional needs is insignificant. In extensive or backyard production systems, the nutritional needs of the ducks are met to some extent by foraging and insect consumption. In such systems however, a large hectareage of land is required, as only 20 to 25 ducks can be supported on 0.4 ha (approximately one acre). Production within this system is also further influenced by the quality and quantity of forage available, and some level of supplementation may therefore become necessary. Generally, large intensive commercial producers use duck feed prepared by feed millers made solely from imported ingredients, thereby posing a challenge to the sustainability of the industry. To address this, locally available agro by-products can be used in the formulation of custom-made supplements, which can not only meet the nutrient requirements, but also reduce feed costs.

Duck feed must be stored away from rodents and insects and in a clean dry place to prevent contamination and mould growth. It should be used within three weeks of the manufactured date or sooner during the rainy season when it is hot and humid, to prevent vitamin loss and mould development. Stale, bad smelling or mouldy feed should never be fed to ducks, as they are extremely sensitive to mould toxins; feed containing as little as 30–40 ppb aflatoxin has been shown to impair protein utilisation. Mould toxins at levels between 60 and 80 ppb can cause damage to the duck's digestive organs, liver, kidneys, muscles and plumage, and reduce growth and feed conversion ratio. Most species of ducks seem very susceptible to heavy metals such as cadmium, lead, and arsenic, which are usually not present at toxic levels in uncontaminated commercial feeds. Because the quality of feed ingredients is also very important, old vitamin/mineral packs should not be used.

Feed form is also important to duck performance due largely to the anatomical structure of the bill. The use of a high quality pelleted feed is important to optimise the growth rate and feed efficiency. Performance will decrease as the amount of fine material increases in a bag of pelleted feed, so that although ducks can be fed mash feed, a reduction in growth performance by approximately 10 percent, will be observed when compared with ducks fed pelleted feed. There will also be an increase in feed wastage. Ducklings should be fed a starter diet consisting of pellets of 3.2 mm in diameter, or as crumbles, and after two weeks of age, a grower diet consisting of pellets of 4.8 mm diameter can be fed.

Feeding and watering equipment

The anatomy and feeding habits of the ducks must be considered when designing or selecting feeding and watering equipment. Ducks use a shovel-like action when eating, which the feeders used should facilitate. An adult duck requires approximately 10 cm of feeder space, and feeders and drinkers should be evenly distributed throughout the pen and provided in quantities that would discourage overcrowding, particularly at feeding time. In production systems where feeders are placed outdoors, the feed may get wet when it rains and if left for extended periods could pose health risks to the ducks. Over exposure to sunlight can also affect the vitamin content in the feed so that it is advisable to place it in a covered area. Because of their susceptibility to mycotoxins, ducks should never be fed old or mouldy feed. Feeders should be emptied, cleaned and feed replaced on a daily basis.

Compared to chickens, ducks eat a lot during a single feeding, as a result of their well-developed oesophagus, which compensates for the absence of a crop. This however could result in birds choking if they do not have easy access to drinking water when eating, which also should be clean and cool. Because of their drinking habits, water spillage from drinkers is quite common, which means that these should be so designed to enable the ducks to easily submerge the tip of the bill in them. Spillage can be minimised by correctly adjusting the water level in the drinkers, and placing drinkers at the appropriate height. Where ducks are reared on deep litter, it is advisable to place the drinkers on wire grids. Nipple drinkers can also be used to help reduce wet litter problems. Where these are used however, they should be checked regularly to ensure that they are all functional.

Nutritional disorders

In ducks, niacin deficiency can be recognised by bowlegs, curled toes and swollen knees. Treatment includes the use of a vitamin supplement rich in niacin. Vitamin D and calcium deficiencies lead to lameness, thereby preventing affected birds from accessing feeders and drinkers, leading to a decrease in feed intake. A vitamin supplement rich in vitamin D₃ can be used to correct this problem. The main symptoms of a vitamin E deficiency are ducks falling on their side and paddle, twisted neck. Cannibalism may be caused by imbalances in certain nutrients, such as methionine, along with overcrowding in pens. Where this occurs, affected ducks should be immediately removed and isolated. To prevent cannibalism, the beaks of Muscovy and Mule ducks should be trimmed at two weeks of age.

SYSTEMS FOR DUCK PRODUCTION AND HOUSING

MAIN FEATURES OF DUCK PRODUCTION SYSTEMS

Ducks can be reared under a number of different production systems, either as a single enterprise or in combination with other livestock, including fish. However, in most commercial farms ducks are reared as a single enterprise. Ducks use water for swimming, wading and mating, but the provision of water for these activities is not absolutely necessary for successful duck production. However, when water is available, it enables the ducks to dissipate an appreciable amount of heat into water via their feet and bills, which aids in reducing heat stress. The type of production system and housing depend on a number of factors such as availability of credit, labour, technology and also the market requirements. The three main systems used for duck production include:

- Intensive system in which ducks are totally confined
- Semi-intensive system in which ducks are partially confined
- Extensive system in which ducks are reared on large hectarages

The two most widely used systems on commercial farms are the intensive (Figure 3.12A and 3.12B) and semi-intensive systems (Figure 3.12C and 3.12D), which to varying extents involve a restriction in the floor space provided for the ducks. Careful attention is also paid to the provision of a high quality, nutritionally balanced diet, in order to attain efficient feed conversion, rapid growth rate and the maintenance of a profitable enterprise. The genetic quality of the stock, as previously mentioned, as well as the health maintenance programme is also important areas of focus. In the extensive system, management of these parameters is not as rigid. Ducks are also kept in integrated systems (Figure 3.13) e.g. in combination with aquaculture or with crop such as rice, commonly seen in Asia. There is also the subsistence or backyard system of production, where ducks are kept mainly for household use and are fed household scraps and sometimes allowed to forage (Figure 3.14).

HOUSING DESIGNS USED IN DUCK PRODUCTION

Many different housing designs are used in both the intensive and semi-intensive systems. Ducks may be housed either directly on a dirt floor or on litter material. Deep litter floors are preferred compared to dirt floors because the ducks are much cleaner and the environment is generally much better for the animals' welfare. They may also be housed in cages with slatted or wire floor. Each of these floor systems has its associated advantages and disadvantages. For example, while the dirt and litter floors are cheaper to establish, they are more difficult to clean and puddles of dirty water can develop. The ducks are also in direct contact with their droppings in this system. Such floors therefore

represent potential sources for the spread of diseases within the flock. Slatted and wire floors on the other hand are more expensive to establish but provide additional benefits, including higher stocking densities, cleaner ducks, and reduced risk of disease transmission due to direct contact with droppings.

The intensive and semi-intensive systems have similarities. They both provide some covered area for the ducks, especially for laying and brooding. They also allow for separation by age or stage of production, whereby for example, the breeders can be separated from those ducks being fattened for market. This is particularly important if the sale of live animal takes place on-farm, as buyers generally want to purchase the larger ducks which are normally the breeders. This practice could however eventually have a negative impact on the quality of the breeding stock, since a number of associated parameters such as growth rate and market weight are influenced by the genetic quality of the breeding stock.

BREEDING STOCK MANAGEMENT

PRODUCTION FOR THE MEAT MARKET

Selection of breeding stock

Ducks for use as breeding stock should be healthy and alert, have good body conformation e.g. be full breasted, have a deep keel and with good width between their legs, and have attained the required weight for age for the given breeds. A major objective of the breeding unit is the production of fertile eggs with high hatchability, but its ultimate objective is to produce healthy ducklings to be reared to give high carcass yield and quality.

Nutrition

Once selected as breeding stock the ducks should be fed with this objective in mind, but not be allowed to become too fat. If the ducks become too fat, this negatively impacts the level of egg production, while in drakes, their ability to mate is affected, something which in turn, affects the hatchability of the eggs produced. The feeding programme and general nutrition of breeders must therefore be carefully monitored in order to maintain this delicate balance.

Duck: drake ratio

A key factor in the achievement of the objective of a breeding unit is the provision of the correct ratio of ducks to drakes, with a range of 5–8 ducks to one drake being usually sufficient. Breeder ducks in intensive and semi intensive systems, as well as in the extensive or backyard systems may be kept for four to five years. Oftentimes, when younger drakes

are mated to older ducks in their first breeding season, because of sexual immaturity egg fertility may be affected, so that egg fertility in the flock should be regularly monitored. As such it is therefore advisable to use older males with older females and younger males with females of their own age.

Lighting and egg production

While ducks may start to lay at 23–28 weeks of age, in a well-managed flock laying can start at 21 weeks. Drakes used for breeding should be at least 27 weeks old. Similar to commercial layers, egg production in ducks could be stimulated by the use of a proper lighting programme, which involves increasing the number of light hours to around 14, approximately three weeks before the onset of laying. During the laying period, light hours should be maintained at about 16 hours. The increase in feed quality and quantity will also bring ducks into lay, and the ration should be changed from one used to support maintenance, to one for breeders. Egg production usually peaks about five to six weeks after the onset of lay, and in most cases if properly managed, is maintained around 50 percent for about five months. Unlike layer chickens, ducks do not like to perch. Therefore nest boxes should be placed at ground level.

Nest facilities for breeders

The provision of adequate nest boxes for breeders is important. A ratio of one nest box for every three ducks is recommended. Nest boxes should be about 35 cm wide x 43 cm deep x 33 cm high) and must allow only one duck to enter and sit. In order to minimise the number of dirty eggs, the nest boxes should be placed in the pens about one to two weeks before the onset of lay, thereby allowing soon to be laying ducks to become familiar with them. A layer of about 10 cm of clean, dry litter should be maintained in the nest boxes at all times. Droppings from the ducks should not be allowed to build up in and/or on the nest boxes, which should be located in a sheltered and isolated area to minimise disturbance, especially during brooding.

Egg collection, storage and handling

It is possible to produce fertile eggs and have a poor hatch, as factors other than fertility, also impact on hatchability, for example, egg collection, storage and handling. Every effort should therefore be made to produce clean eggs and store them properly. Provision of an adequate number of nest boxes, proper nest box management, frequent collection of eggs, proper cleaning of any dirty eggs, reduced length of storage and proper storage conditions for fertile eggs all help to improve hatchability. Frequent egg collection also minimises

soiled and cracked eggs. Proper egg storage is important to ensure that fresh, vigorous embryos are placed in the incubator or under the broody duck. If eggs are to be stored for more than two weeks they should be turned at least three times per day to avoid the yolk sticking to the shell. Eggs should be stored at 13°C, a relative humidity of 75 percent, and with the small end downward.

Artificial incubation

The conditions during incubation impact directly on the percentage hatchability, when artificial incubation is used. It is critical that the manufacturer's guidelines be followed in relation to the maintenance of the correct temperature and relative humidity, regular turning of the eggs, and their timely removal from the incubator to the setter. Most commercial incubators automatically regulate the temperature, humidity and turning of the eggs and are also designed to alert the operator if the equipment malfunctions. Nevertheless, continuous monitoring of the equipment remains critical to the success of the hatch.

Candling of eggs

Not all fertilised eggs develop into ducklings, as some embryos may die right after fertilisation, while others die during various stages of incubation. Candling will help to determine whether there is a fertility or hatchability problem. The best time to candle is between the 17th and 18th day of incubation. With Muscovy ducks candling can be done on the seventh day, and again on the 32nd day of incubation, while for Pekin and other breeds, this can be performed on the seventh and 18th days. When candling, a light is shone through the egg so that the interior of the egg can be observed through the shell. Eggs that appear clean with no signs of embryonic development are called 'clears'. Because some eggs may have been fertilised but the embryos may have died too early to be detected by candling, they will have to be examined ('break-out') for evidence of embryonic development. If 15–20 percent of the clear eggs are "broken out" and show no sign of embryonic growth, the problem is fertility. While a dead embryo will generally show as a dark spot stuck to the shell membrane, a live one will be located near the air space as a dark spot with blood vessels radiating away from it.

Hatchability: the percentage of fertilised eggs that hatch into ducklings.

Natural incubation

Many small farmers use broody ducks to hatch their eggs, so that for these farmers, the brooding tendency is very important. Since the duck usually becomes broody after she lays a clutch of eggs, she can be allowed to sit on her eggs in a nest box in a relatively undisturbed area. She will leave the nest box for food and water, and should have easy access to both. The brooding tendency is therefore an important aspect of the duck's mothering ability, and in this regard, the Muscovy is a much better mother than the Pekin duck, which would seldom sit on her eggs. Some farmers also use broody hens (chickens) to incubate duck eggs. If chickens are used it may be necessary to sprinkle the eggs daily with lukewarm water to achieve a higher humidity. The incubation period for the Muscovy is 35 days while Pekin eggs take 21 days to hatch. Brooding tendency is less of less importance to large farmers who hatch their eggs using incubators, and whose main objective is to have the ducks lay as many eggs as possible without going broody. As such, these producers would prefer the Pekin.

Broodiness: the natural tendency of the duck to set on her eggs until they hatch into ducklings.

MANAGEMENT OF NEWLY HATCHED DUCKLINGS

Minimising mortality in early hatched ducklings

Duckling mortality impacts directly on the profitability of the farm, and should therefore be minimised by farmers as far as possible. A number of factors contribute to mortality levels, including brooding conditions, trampling of early-hatched ducklings by their mothers, feeding and nutrition, diseases and predators. It is advisable to remove early-hatched ducklings from their mother to reduce trampling and mortality of early-hatched ducklings, and also to encourage the mother to sit on the remaining eggs until they hatch.

Natural brooding of ducklings

Brooding refers to the care and management of the newly hatched ducklings for the first few weeks, and can be done naturally. The duck huddles the ducklings under her to keep them warm, especially at nights, and protect them from danger. Broody hens (chickens) also do a good job, but they should be confined since the hens are likely to tire the ducklings by wandering too far. Wandering may also expose the young ducklings to predators.

Artificial brooding of ducklings

Artificial brooding conditions for ducklings are similar to those for brooding layer and broiler chickens and any type of equipment that is suitable for chickens is also appropriate for ducks. Brooding involves the provision of heat to keep the ducklings warm because their temperature control mechanism (i.e. thermoregulation system) is not fully developed, making them susceptible to chills. A 250-watt infrared brooding lamp, hung about 45 cm above the floor can be used in the brooder. If a hoover is used, it should be hung 10 cm to 13 cm higher than the height used for chickens. When infrared brooding lamps are not available, many farmers with small production systems use incandescent light bulbs for brooding. The following are some temperature recommendations for brooding ducklings:

Week 1: 29.4°C - 32.2°C

Week 2: 23.9°C to 26.7°C

Week 3 and beyond: 21°C

It is critical to monitor the ducklings during the first five days post hatch. If ducklings experience heat stress, they will spread out away from the heat source, pant and make a high pitch chirping noise. When they are too cold, ducklings will huddle under the heat source in groups, something that can result in crushing if they pile too high in the groups. It is important to observe the ducklings' response to the heat provided; an even distribution in the brooding area is a good indicator of their comfort.

The brooding area should be dry, well-ventilated, draught-free, protected from predators and provide sufficient floor space for the rapidly growing ducklings. Wire or litter floors should be used during brooding. Wire is preferred because it reduces the risk of aspergillosis associated with the use of some types of litter. Where litter material is used on the floor it should be about 10–15 cm deep. The litter should be treated for fungus, as this grows well on wet litter and ducklings are extremely susceptible to the aflatoxins produced by some fungi. The litter for young ducklings should therefore be kept dry at all times. Aflatoxins could cause high mortality and morbidity, and decreased growth rate of ducklings. In Trinidad and Tobago for example, the best brooding results have been obtained when specially built crates with rubberised or plastic coated wire mesh no more than 2 cm in diameter have been used for this purpose. The crates also provide the ducks with protection against predators such as dogs, cats and rodents, and also prevent aspergillosis since no litter is used.

Feeding the young duckling

Care should be taken with the feeding of ducklings as mortality may result from starvation or from choking on dry feed. Starvation can arise when ducklings receive insufficient feed, are unable to access the feed provided, or if the feed particles are too big for the young duck to consume. If the ducklings do not have enough water to drink while eating the dry concentrate feed they may choke and die. Young ducklings should be fed a duck starter ration in the appropriate feeders, and must be provided with good quality (clean and cool) drinking water. During the first few days, the feed may be placed in flat feeders, which should not be placed on a smooth surface, as this could cause the young ducklings to slip and sustain leg injuries. Drinkers should be placed on wire grids to minimise wetting of the litter. Feeders and drinkers should be adjusted so that ducklings have easy access to them. Ducklings should be given fresh feed each day, and old or mouldy feed must never be fed. Drinkers should be located close to the feeders and should be washed and sanitised daily. The rinse water should not be poured in the house, but preferably into a bucket and removed from the pen to help maintain a clean healthy environment for the ducks. Drinkers and feeders should be checked daily to ensure that they are working properly.

DUCK HEALTH AND FOOD SAFETY

Food quality and human health issues have become more important in recent years, in addition to which, the concept of food value has changed. For example, high energy meat sources are less desirable because of excess calorie, and health concerns about total fat intake in the human diet. In the area of food safety, the primary concerns revolve around the food-borne illnesses caused by chemical contaminants and pathogenic bacteria. It is therefore important to keep ducks healthy at all times. A healthy and disease-free flock will provide good returns to farmers in the long run and a wholesome product to consumers. In order to achieve these objectives, farmers should have a disease-free farm, purchase disease-free ducklings, restrict the movement of visitors, disinfect all shed and utensils after every batch, and follow the advice of a veterinarian to prevent sickness and disease in the flock. The farm should be kept free of any materials that harbour vermin and insect pests. Biosecurity, as with all poultry, is of great importance on the duck farm and the key to maintaining a healthy flock (Box 3.3).

Box 3.3: Biosecurity Measures to be Observed When Rearing Ducks

These include:

- Sourcing or producing healthy ducklings
- Conducting proper brooding by providing a clean, dry and warm brooding area
- Cleaning water tanks, drinkers, and sanitising drinking water
- Employing proper sanitation practices throughout the farm
- Maintaining a closed flock i.e. practice an all-in-all-out system
- Providing a comfortable, stress-free environment
- Rearing ducks on wire or slatted floors wherever possible
- Carefully selecting the location of duck farms
- Minimising the number of visitors
- Providing high quality duck feeds
- Providing facilities for proper feed storage
- Consulting the animal health personnel and established laboratory in cases of infections or diseases
- Increasing your knowledge of the species and training of workers

Ducks raised in small numbers and in relative isolation, suffer little from diseases, but where there are large flocks, diseases may be extremely widespread. Muscovy and mule ducks appear to be resistant to many diseases common to Pekin and mallard-type ducks. The list of common diseases which follows is far from complete both in number and details, and should not be used as a substitute for accurate diagnosis and treatment by competent animal health personnel. Farmers should only administer antibiotics and vaccine when absolutely necessary or on the advice of animal health personnel. Failure to do this could result in the introduction of new pathogenic organisms into the environment.

COMMON HEALTH AND DISEASE PROBLEMS IN DUCKS*Mycotoxins*

These are a group of toxic chemicals produced by moulds or fungi growing on certain feedstuff or litter material. Ducks are extremely susceptible to mycotoxins, especially aflatoxins, and this is therefore a major concern throughout the duck industry, especially in the humid tropics. Recognising this susceptibility and the potential for losses in the duck industry, good feed mill manufacturing practices will prevent the use of sub-optimal ingredients and duck rations are enhanced with both mould inhibitors and mycotoxins binders. Good management, storage and handling and timely usage of feed on the

farm will also go a long way to minimise this problem. Aspergillosis, a fungal infection of the respiratory tract also referred to as brooders' pneumonia, is a common disease in ducks resulting from the inhalation of fungal spores in the air and by aflatoxins produced by fungi of the *Aspergillus* species, such as *A. fumigatus* and *A. flavus*. It is more common in ducklings reared on deep litter, especially on bagasse-based litter. Common signs include: reluctance to move, decreased feed intake, differential growth patterns in flock, ruffled feathers, whitish diarrhoea, difficult breathing or gasping, accelerated breathing, emaciation and death. Treatment of this condition is expensive and usually ineffective. Mortality from Aspergillosis can be quite high, especially in ducklings. Good litter management and a dry brooder house are absolutely essential to help prevent this disease.

Botulism

This disease is caused by the bacterium *Clostridium botulism*, an anaerobic spore forming organism, which grows in decaying plant and animal material particularly in hot humid climates. Stagnant pond water with decaying carcasses and vegetation are sources of the bacteria, which produces toxins that can cause botulism, and may result in high mortality in the flock. Ducks feeding on materials or drinking water containing the deadly toxins produced by the bacteria tend to lose control of their neck muscles and they usually drown if a swimming facility is available. The disease occurs both in young and adult stock. Common signs of botulism are weakness, paralysis of the neck muscles, and death, usually within 24 hours. The removal and/or isolation of birds from sources of contamination such as dead birds, is important in the control of this disease. Maintenance of clean facilities and the quality of the drinking water are very important in the prevention of this disease.

Yolk sac infection

Common signs include depression, septicaemia, navel infection, and some level of mortality within the first week of brooding, and ducklings also look and feel wet. Post mortem reveals the remains of a bluish or blackish yolk sac, something that is commonly observed in ducklings hatched from eggs on the floor or otherwise dirty eggs. While the infection may be caused by different bacteria, the *Escherichia coli* organism, which is normally associated with environmental hygiene, is the common causative agent associated with this disease. Prevention of this disease involves paying attention to good hygiene with respect to housing, nest box management, the hatchery and flock in general.

Coccidiosis

Although not as troublesome as in chickens, this disease causes some measure of distress occasionally in flocks. The organism causing the disease in ducks is different from those causing it in chickens.

External parasites (lice and mites)

External parasites are generally observed in ducks subjected to very poor management. They cause discomfort to the ducks along with varying levels of damage to the feathers. With careful examination, they can be seen at the base of the feathers, and in cases of heavy infestation, can be easily observed.

Hardware disease

While foraging, ducks may ingest undesirable foreign bodies such as nails and small pieces of wire. These items may puncture and cause damage to the internal organs. Affected animals may appear sick and post mortem examination generally reveals the extent of the injury. Similar items may also penetrate the duck's body and cause injury to the skin.

Management-related problems

Blisters – these usually occur on the footpads and breasts, and are usually caused by ammonia emanating from poorly managed deep litter. While the blisters on the footpads cause discomfort to the ducks and affect their access to feed and water, breast blisters affect carcass quality.

Sticky eye - this is caused by dust or feed particles getting into the eyes of the duckling, resulting in around the eyes appearing wet and sticky. Providing the birds with containers of sanitised water to wash their bills assists in alleviating this problem.

Common duck diseases

Duck cholera – this disease causes high mortality in adult and young stock, and can be controlled by strict sanitation.

Duck virus enteritis (duck plague) – an acute fatal disease that affects ducks as well as geese, swans and other aquatic birds. It is caused by a filterable virus that is transmissible by contact, and commonly occurs where water is available for swimming.

New duck disease (infectious serositis) – one of the most serious diseases affecting ducklings, caused by the bacterium *Moraxella anatispestifer*. Symptoms resemble those of chronic respiratory disease of chickens, and stricken ducklings fall over on their sides and backs.

Virus hepatitis – serious outbreaks of virus hepatitis can cause 80–90 percent mortality in flocks of ducklings. This highly contagious disease strikes swiftly and without warning and affects ducklings from one to five weeks of age. A vaccine, which can be administered to female breeding stock is available.

MARKETING

MARKETING AND PROCESSING DUCKS

Ducks are mainly marketed as whole birds in Trinidad and Tobago through pluck shops (cottage processors) or as live birds sold at the farm gate. Recently however, an increasing trend has been observed whereby local duck meat is cut up and sold in ‘tray-paks’ in supermarkets. Eight to ten hours prior to slaughter, feed should be withheld from the birds, but water may be provided up to the time of killing. Clean and un-crowded rearing, transportation and holding facilities will help to prevent bruising, cutting, stress and other factors that cause poor market acceptability. Ducks should be transported in crates or herded into a trailer-type transport, when the slaughtering facility is not done on farm. Construction of elaborate slaughtering facilities is justified only for large commercial operations. If live markets are not available, small farm flocks can be processed by using facilities similar to those used for chickens (i.e. pluck shops/cottage processing) (Figure 3.16).

When slaughtering ducks, birds can either be hung by the feet, or placed in a special slaughtering funnel. Using a long, thin, sharp knife, a cut is made across the outside of the throat high up on the neck and just under the lower bill. This will sever the jugular vein and allow swift and complete bleeding. When bleeding has ceased, birds can be scalded by immersing them in hot water (60°C) for three minutes and de-feathered immediately after scalding. All remaining pinfeathers should also be removed by grasping them between the thumb and a dull knife and pulling sharply. Under local cottage processing it is common to flame off pinfeathers.

In large commercial slaughterhouses, ducks are dipped in a molten wax after they have been de-feathered. The wax hardens when the birds are immersed in cold water, and the pin feathers are extracted when the wax coating is removed from the carcass. The wax can be reused if it is melted and the feathers are separated out. Small quantities of wax can be purchased for use in small slaughtering operations, however it is highly combustible and care must be taken to prevent it from coming in contact with open flames.

After de-feathering, birds must be eviscerated immediately. The eviscerated carcass is then thoroughly washed, and placed in slush ice for rapid cooling, and the giblets placed in the body cavity of the chilled birds. If birds are to be marketed frozen, they should be

packaged in shrinkable plastic bags (Figure 3.17). Protocols and standards are currently being developed for CARICOM with respect to cottage processing that cottage processors of ducks will have to adopt. Further, packaging and labelling requirements are also being developed for farmers' use.

FARM RECORDS AND ECONOMICS

RECORD KEEPING

The three main purposes for keeping records are to: check on performance, guide future decisions, and provide planning data. Farmers must keep proper records if they are to effectively run a profitable duck enterprise, as flock production records are a necessary part of good flock management. Figure 3.18A represents a growing ducks record sheet, and provides a summary of flock behaviour from day old to market. Records on mortality and feed consumption are kept on a daily basis, but summarised on a weekly basis. Body weight of birds is monitored on a weekly basis, and this weekly weight can be plotted to give a visual analysis of how birds are performing, and can be compared with the expected performance based on the breeder's standard.

Records should reveal the strengths of a business that can be exploited and the weaknesses that must be removed. It is therefore important for the duck producer to understand that this enterprise is not only a biological entity but a business and an economic entity. Thus, the cost of production and returns must also be a part of the recording systems, as illustrated in Figure 3.18B, which outlines the parameters to be considered in evaluating the cost of production of broiler ducks.

Figure 3.18A: Flock production record sheet

THE UNIVERSITY OF THE WEST INDIES DEPARTMENT OF FOOD PRODUCTION BROILER DUCK RECORD CHART																
Farmer				Pen No.				Breed/ No. of Ducks								
Date Started				Hatchery				Egg Supplier								
Harvest Date																
MORTALITY								DAILY FEED USE/kg								
Week	Week Starting					Week Ending	Weekly Total	Total To Date	Week Starting						Week Ending	Avg Wts Pen
1																
2																
3																
4																
5																
6																
7																
8																
9																
10																
11																
12																
13																

Figure 3.18B: Template for evaluating the cost of broiler duck production

		\$ Value
INCOME:		
Birds sold		
Manure (if sold)		
Feathers (if sold)		
Total Income		
(a)	VARIABLE COSTS	
1.	Ducklings	
2.	Feed	
3.	Labour	
4.	Litter (if used)	
5.	Medication	
6.	Veterinary Services	
7.	Utilities	
	☐ Water	
	☐ Electricity	
8.	Repairs and Maintenance	
9.	Transportation	
TOTAL VARIABLE COST (add items 1 to 9)		
(b)	FIXED COSTS:	
1.	Salary	
2.	Depreciation	
	☐ Housing	
	☐ Equipment	
3.	Insurance (if paid)	
4.	Miscellaneous cost	
	☐ Bank Charges	
	☐ Land Charges	
5.	Interest Charges	
TOTAL FIXED COST (all items 1 to 5)		
TOTAL COST (Add Total Variable + Total Fixed Cost)		

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Women play key roles in record keeping on livestock farms



Caribbean women are responsible for selling 12-50 percent of the region's local fruits & vegetables.



Marketing has historically provided women and their families with a source of income.



Small producers do adopt safe and regulated practices.



Women dominate in post-harvest and packaging activities.



When given the opportunity women excel in agriculture science.



Attending to seedlings in hydroponics system



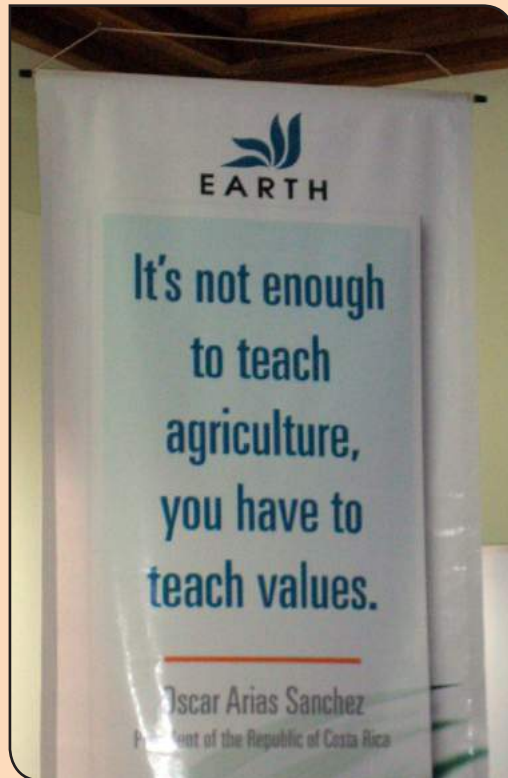
Grafting mango, Nevis



Maintaining drip irrigation line in onion



Pruning tomato under greenhouse,
Jamaica



Banner at EARTH University in Costa Rica.



Young Stars 4H Club members in their hydroponic project in Trinidad.

Figure 3.1: Carcass of a rabbit fed forage with reduced concentrate levels

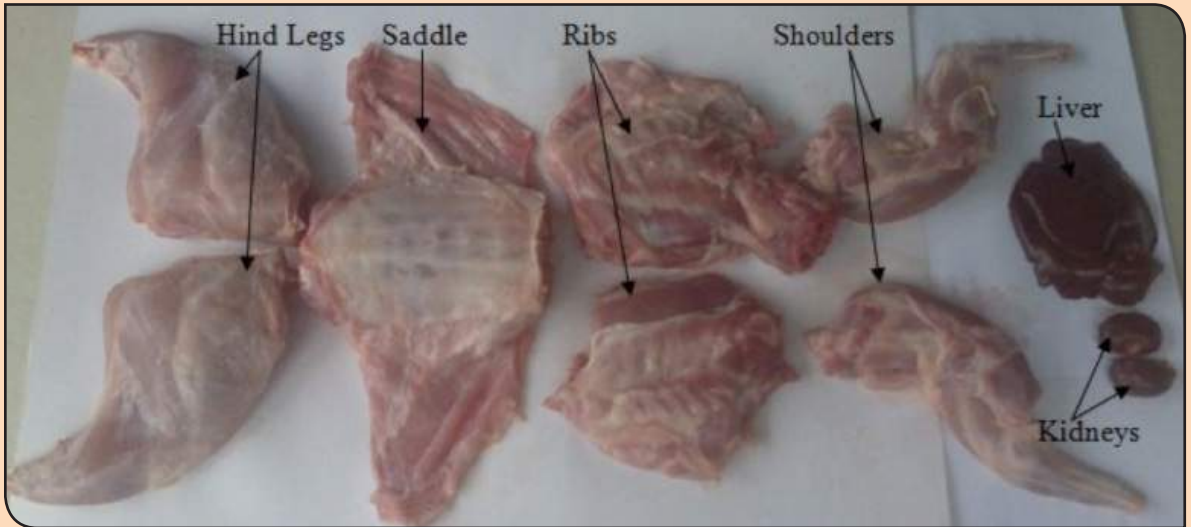


Figure 3.2: Doe accepting male for mating



Figure 3.3: Nest with new born kits



Figure 3.4: Proper method of holding growing rabbits



Figure 3.5: Proper method of holding adult /heavy rabbits



Figure 3.6: Open sided house at Aripo Livestock Station, Trinidad



Figure 3.7: Wire mesh cages with feeding facilities inside



Figure 3.8: Limited feeder space and competition for feed at higher stocking density



Figure 3.9: Pekin breeder ducks at Central Farms, Trinidad



Figure 3.10A: Common Muscovy strain

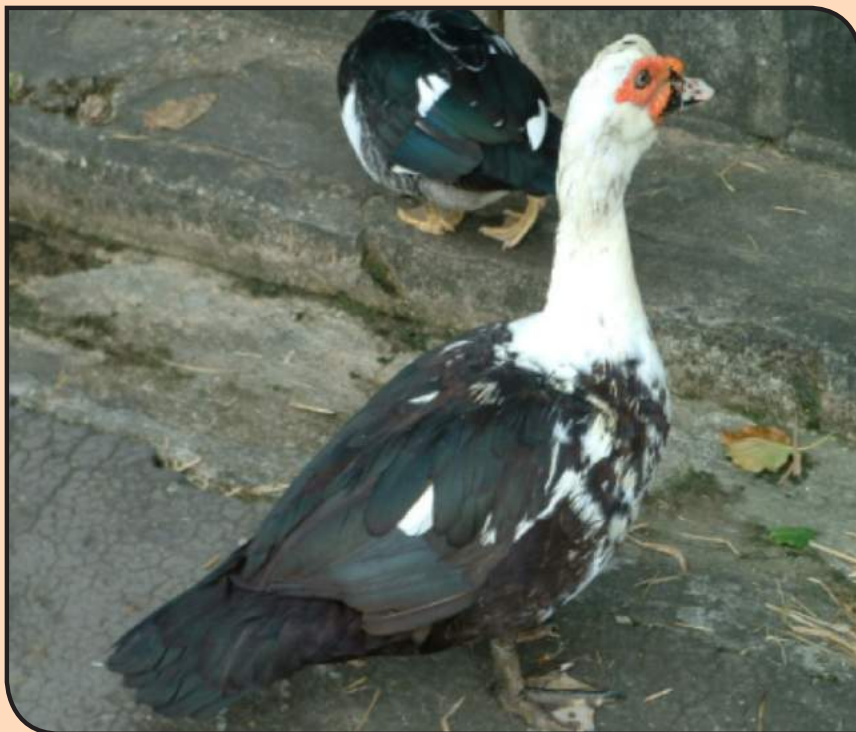


Figure 3.10B: White Muscovy strain used by commercial farmers



Figure 3.11A: Multi-coloured Mule duck



Figure 3.11B: White Mule duck



Figure 3.12A: Intensive system with deep litter floor



Figure 3.12B: Intensive system with solid dirt floor



Figure 3.12C: Semi-intensive system (Guyana)



Figure 3.12D: Semi-intensive system (Trinidad)



Figure 3.13: Integrated duck production system with fish, Sugarcane Feeds Centre, Trinidad



Figure 3.14: Back yard subsistence production system in Trinidad



Figure 3.15: Examples of brooding facilities used in Trinidad



Figure 3.16: Duck processing at Central Farms, Trinidad

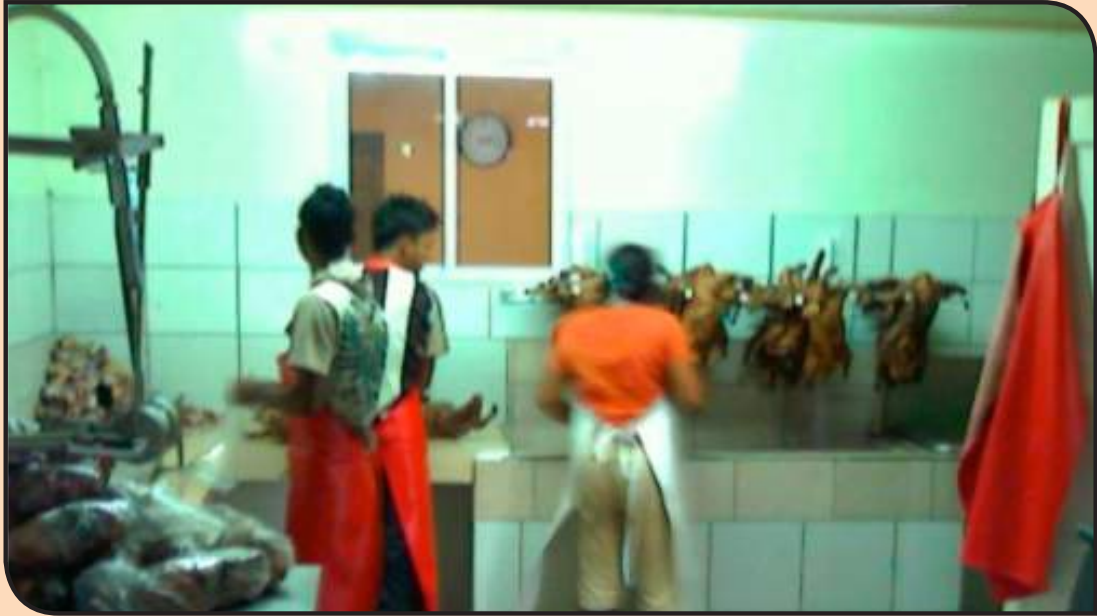


Figure 3.17: Whole frozen duck carcasses on sale in a supermarket in Trinidad



Rain Shelters and Net-houses for Vegetable Production

Chaney C.G. St. Martin

INTRODUCTION

The identification and implementation of technologies and systems with the potential to increase agricultural production and productivity, have been the main strategies used to maximize the value of the vegetable sub-sector of the Caribbean. These strategies are seen as important to satisfy local demands for vegetables, decrease vegetable imports, which amounts to an average annual expenditure of US\$265 Million in the Caribbean (Walters and Jones, 2012), and to increase food security. Protected agriculture is currently viewed as one such strategy, which can be used to profitably produce crops in the region.

Jensen and Malter (1995) define protected agriculture (PA), as the modification of the natural environment to achieve optimum plant growth. It is viewed as a means of addressing the limitations of traditional open-field vegetable production systems, particularly low and inconsistent crop yields and productivity. PA employs technologies such as greenhouses (GH), rain shelters (RS) and net houses (NH), which primarily differ based on the type of protective material used, the size and complexity of the structure, and the degree to which the environment is manipulated or controlled. A greenhouse is a framed or inflated structure, covered by a transparent or translucent material that permits optimum light transmission for plant production and protects against adverse climatic conditions (Jensen and Malter 1995). By contrast, a rain shelter is a greenhouse-like unit, in which, only the roof is covered with a transparent or translucent material that is impervious to rain. It can either have no, or open sidewalls but has no mechanical ventilation or heating system. On the other hand, NH are greenhouse-like units, that are usually covered with insect proof netting that is pervious to rain. The net house may provide some degree of shading but does not normally consist of mechanical ventilation or heating systems.

Regardless of the type of protective structure or the scale of commercial production, farmers are required to have a more comprehensive knowledge of agronomic and crop management principles than for traditional agriculture (Jensen and Malter 1995). Moreover, the success of any of these PA technologies is very much dependent on the level and quality of the applied technology, adequate research, and the provision of efficient technical support systems. The success of PA technologies is also dependent on factors such as local climate, marketing intelligence, and market access.

In the Caribbean, such factors have either been limited or inadequately harmonized, resulting in several failed attempts at adopting PA technologies as a means of profitably producing vegetable crops. Such is the case with the recent re-introduction of greenhouse technology where farmers have not been able to achieve or sustain expected production, productivity, and profitability. This is mainly due to constraints, which have existed since the 1950s across reintroduction cycles of this technology. These include high greenhouse temperatures ($>35^{\circ}\text{C}$) and relative humidity (> 90 percent), pest and disease management challenges, ineffective production systems, and plant growth media and nutrient management issues (St Martin and Brathwaite 2012a; St Martin et al. 2008). All of which often resulted in the abandonment of facilities after a few crop cycles.

This raises the question of which crop production and/ PA technology is most appropriate and sustainable for use under the climatic conditions of the Caribbean. As is evident by the numerous structural modifications made to totally enclosed greenhouses by many farmers, including replacing plastic roof or sidewalls coverings with saran netting or 17–25 or lower-mesh screens and producing in open-sided structures with plastic roof coverings, appropriate and sustainable PA technology is being intuitively defined as RS and/or NH. In fact, many novice greenhouse farmers are opting to establish, RS or NH instead of fully enclosed-plastic roof covered GH. RS and NH are increasingly being viewed as more sustainable than greenhouse because they require a much lower initial capital investment, temperatures in these structures are generally lower than in GH, and if appropriately managed, yields and productivity are arguably higher than in GH or open field production.

In light of this emerging trend, the objective of this chapter is to provide a comprehensive overview of best management practices (BMPs) for sustainable production of vegetables in RS and NH. In contrast to the first volume of this book, focus is placed on the production of leafy vegetables, mainly lettuce, rather than tomato (St Martin and Brathwaite, 2012b). However, owing to similarities among protective structures, some of the principles and practices, which are described in detail in the first volume, have either been summarized into ‘audit verification checklists’, or not included. This is particularly so, for BMPs relating to site selection, RS/NH design and structure, and some cultural practices. These checklists provide a quick and practical means of evaluating the implementation of BMPs.

The collation of information on recommended practices was done using the same methodology described by St Martin and Brathwaite (2012b). This included sourcing information from research done under the climatic conditions of the Caribbean, growers' and the author's experiences/ or on-site research, and RS/NH or GH manuals relevant to crop production in tropical and temperate conditions. All best practices and principles are rooted in, or linked to GLOBALG.A.P standards (GLOBALG.A.P 2011) and are addressed under the relevant subheadings. 'Rules of thumb', which were mainly adopted or modified from Talekar, Su, and Lin (2003) were used to highlight and summarize key points in this chapter.

BEST MANAGEMENT PRACTICES ACROSS THE REGION

BMPs in this chapter will be related only to structural and cultural practices. BMPs for monitoring environmental factors, disaster preparedness, and business will not be discussed in this chapter since they are similar to those for GH production, which were thoroughly discussed in the first volume of this book.

STRUCTURAL BEST MANAGEMENT PRACTICES

These include BMPs relating to site selection, and RS or NH design and structure, which directly or indirectly affect crop performance, hence the profitability of the enterprise. Such BMPs are however, not adequately considered when establishing RS or NH in the Caribbean. Factors that should be considered when selecting a site for the erection of RS or NH are summarized in an audit verification checklist presented in Box 4.1.



A first step to successful rain shelter or net-house vegetable production is a good location. Structures on higher lands are less likely to be flooded and have lower temperatures.

RS and NH design and structure

Many of the rain shelter designs in the Caribbean have been developed “on-farm” by growers, mainly through modifications done to totally enclosed GH. As such, designs and sizes of RS vary, as do the materials used to construct these structures (Figures 4.1–4 – pages 106–7). In contrast, net-house designs are more standard than those for RH, and vary mainly with reference to the type and color of netting used, degree of shading provided, and the size of the structures.

Box 4.1: Audit verification checklist for site selection for establishment of RS/NH*Orientation and light*

- ✓ RS or NH orientation is in any direction that allows for maximum airflow given that neither topography nor canopies do not shade the structure during sunrise and set and/or the orientation of RS or NH is not limited by plot size.
- ✓ Vent openings of NH are oriented in the direction that the wind is coming from rather than against it.

Local climatic conditions, topography and soil quality

- ✓ Mean daily temperatures are not above 35°C.
- ✓ RS or NH are located in areas with cooler temperatures, which in the Caribbean, usually occur at elevations > 500m above sea level.
- ✓ RS or NH structures are sited on soil that is well drained, particularly for crops that are to be cultivated directly in the soil.
- ✓ Soil is amended with organic materials such as mature compost as a cost effective strategy for improving the drainage and fertility of the soil.
- ✓ In the case of soil-less production and in low-lying areas, RS or NH is built on elevated earthen pads that are at least 0.9 m larger than the structure in all directions, high enough to prevent excess rain water from flowing into the structure and with a gentle slope of 1–2 percent to the exterior to allow for good drainage.
- ✓ Soil-less cultivation systems and the establishment of the structure on a gravel base, 15cm to 30cm above grade are used where access to good quality soil is limited or not available.

Water supply and quality

- ✓ Water needs for RS or NH vegetable production were estimated and evaluated against water supply, access, price, and quality in the area, particularly in countries such as Jamaica, Anguilla, Antigua and Barbuda, and St. Kitts and Nevis, where the domestic water supply for the cultivation of crops may not be readily available year round, or the cost is prohibitive. RS or NH operation requires 8,000 liters of water per square meter (196 gallons per square feet) of growing space per year.
- ✓ Water quality analyses were done and the analyses consisted of key variables such as pH (6.5–8.5), electrical conductivity (250–2000 µS/m), sodium content (20–60 percent), sodium adsorption ratio (3–10), *E. coli* (≤77 CFU/100ml), Enterococci (≤20 CFU/100ml), and faecal coliforms (≤200 CFU/100ml).
- ✓ Potable water is used for irrigation, as river and well water are usually less ideal as they may contain pathogens and require filtration to remove silt and particulate matter that might clog irrigation systems.
- ✓ If it is affordable, water used for farming is tested for pesticides, fuel oil, and other contaminants.

Other site selection considerations.

- ✓ Proximity to markets, access to labor and utilities, potential hazards and/or disasters such as land slippage, tall trees, flooding, hurricanes, and industrial pollution have been considered when siting RS/NH.
- ✓ Space for future expansion of the operation as well as the social construct and norms of the neighbourhood where the structure will be established have also been considered.

Source: St. Martin and Brathwaite (2012b), Chandra, Srivastava, and Maheshwari (1982), USAID (2008), Mirza (2008), Torres and Lopez (2010), Kumar, Tiwari, and Jha (2009), Chen, Shen, and Li (1982), St Martin et al. (2008) and Dey (2001)

With respect to the appropriate PA design structure for vegetable production under the climatic conditions of the Caribbean, rain shelter designs with opened sidewalls, definitely address to some extent, the issue of high mean daily temperatures ($>35^{\circ}\text{C}$), which have been observed in totally enclosed greenhouse structures. However, this heat problem may persist in totally enclosed NH that are completely covered with insect-proof netting (50-mesh) and have no vent system. Furthermore, over time, the transmission of sunlight is also significantly reduced due to the blockage of insect-proof netting by dust particles.

Although temperatures are generally lower in opened-sided nethouse designs, these structures provide little or no protection against rains, which may limit vegetable production in the wet season. On the other hand, RS are impervious to rains; however do not limit the entry of pest and pathogens into the structure. Therefore, a more rigorous and/or demanding pest management system, similar to that used in open-field cultivation is needed. However, opened-sided RS or NH may limit the need for hand pollination in crops such as tomato, which may be high cost and time consuming. The substitution of lower size mesh netting (32-mesh) for insect-proof netting (50-mesh) in totally enclosed NH, may result in lower temperatures, while limiting the entry of several insect pests such as aphids and thrips.

In light of these ‘trade-offs’ between types of protective structures and designs, it is recommended that the grower select structures that pose the lowest risk to the production of a specific crop and for which he/she has greater managerial strength. For example, in areas with high rainfall, and the vegetable crop selected for cultivation has a relatively short production cycle (e.g. lettuce) and no or few major pest or diseases, RS are recommended for use rather than NH. In contrast, in cooler areas, where rainfall is low to moderate, and the vegetable crop selected for cultivation has a relatively longer production cycle (e.g. tomato) and is susceptible to major pest or disease infestations, NH are recommended for use rather than RS.

All protective structures, whether RS or NH, should be built to withstand strong winds in locations where severe storms occur. As a result, it is recommended that growers use galvanized iron pipes to construct the frame of these structures. Steel clips should also be used for fastening, where possible. Wood or bamboo should only be used for the construction of semi-permanent RS or NH.

Two critical factors that must be considered when designing totally covered NH are:

1. The choice of mesh size of netting, and
2. The design and location of two double doors to the structure

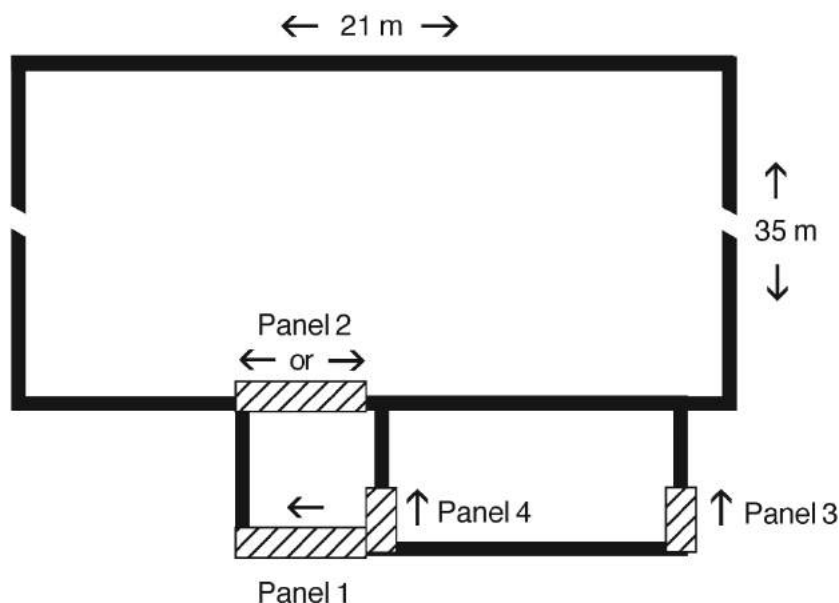
Best-practices relating to these two factors and the issue of proper design and structure are detailed in the audit verification checklist provided in Box 4.2.

Box 4.2: Audit verification checklist for proper design and structure of NH and RS

- ✓ NH and RS are constructed at the recommended height of 3.0–4.5 m. Heights of 5.2–5.8 m are recommended in low lying areas when high mesh size screens (≥ 40) are used to completely cover the NH or the side walls of the RS.
- ✓ NH are constructed at the recommended size of 25–35 m long and 12–21 m wide. In low-lying areas, with high temperatures, the width of the NH is restricted to 10–12 m.
- ✓ RS are constructed at the recommended size of 5 m long by 6 m wide for small-scale production systems. For large-scale production, RS are built using the recommended sizes for NH.
- ✓ A 32-mesh (32 holes per inch or 13 holes per cm or hole size 0.8 mm), which is uniformly weaved, durable quality, nylon netting has been selected for covering NH.
- ✓ Nettings of lower mesh size (< 32) are not used as sidewall coverings because the relatively larger mesh openings readily allow the entry of several pests including diamondback moth, striped flea beetle, leaf miners, and aphids.
- ✓ Finer mesh nets (> 32) are used to restrict the entry of smaller sized pests. However, be mindful that that finer mesh nets provide greater resistance to air flow. Therefore, temperatures inside these NH may rise to levels, which limit crop performance.
- ✓ Mesh nettings allow a minimum air movement of 3.5–5.4 m³/m².
- ✓ A white coloured shade cloth (40 percent) is used for roof covering to allow for proper shading and airflow, which will also help to reduce the temperature in the NH.
- ✓ Two double-doors arranged at right angles to each other are used for entering and exiting the NH (Figure 4.5) instead of single door systems, which allows easy entry of insects when opened.
- ✓ These doors have been erected at the side of the NH, opposite to the direction of the wind encountered during most of the year.
- ✓ Larger double door (Panels 1 and 2 in Figure 4.5) are used only at planting and harvesting to move farm equipment in and out of the structure.
- ✓ Only one door is opened at a time when entering or leaving.
- ✓ Doors are securely shut when not in use.
- ✓ Smaller double door (Panels 3 and 4 in Figure 4.5) are used for entering the structure for daily operations.

Source: Kumar, Tiwar and Jha (2009), Smith and Lopes (2010), Mirza (2008), USAID (2008), Willits and Peet (2000), Willits (1994), Willits (1993), Kamaruddin, Bailey, and Douglas (2000), St. Martin and Brathwaite (2012b) and Palada, Roan and Black (2003)

Figure 4.5: Diagram of nethouse opening; arrows indicate directions that doors (indicated by slanted boxes) slide.



Source: Palada, Roan and Black (2003)

CONSTRUCTION OF RH AND NH

In this section, the focus is placed on the construction of a single-bed rain shelter with an arched roof (Figures 4.2), which is a simple and affordable design. This structure can be made into a net house by using nylon mesh for roof and side-coverings instead of plastic covering on the roof alone. The size of this structure can also be increased to accommodate more beds by incorporating centre posts and more reinforcements in the design (Figure 4.3). The following description of the construction of RS was adopted mainly from Palada, Roan and Black (2003).

Components of RH or NH structures

Components of RS or NH structures are classified as:

- Structural – consisting of pillars, frames, pipes, and side braces (Figure 4.6).
- Covering materials – comprising polyethylene film, polyvinyl chloride, polyolefine, or nylon netting.
- Connecting and fastening accessories – consisting of fastening pins, hooks, clips, and plastic belts (Figure 4.6).

Establishing the foundation posts

The positions of the two corner posts should be firstly marked out at each end of the bed/area (i.e. four-corner posts in total) (Box 4.3 – Step 1A). Holes should be then dug and the posts buried at least 30 cm deep (Box 4.3 – Step 1B). For a more permanent and secure structure, the grower may opt to dig a hole 15cm wide x 15cm long x 40cm deep, split (18–25 cm) then bend end sections of the corner posts and set them in concrete, ensuring that the corner posts are at the same height and level (Box 4.3 – Step 1C). The rest of the foundation posts should be equally spaced (approximately 70cm apart), starting from the corner posts, and buried at least 30 cm deep.

Connecting posts

The arch tops are connected to the foot pipes (foundation posts) by inserting both ends at 5 cm to the pointed end of the foot pipe post (Box 4.3 – Step 2A). Steel clips should be used to attach horizontal and diagonal side pipes to the structure to reinforce the sides (Box 4.3 – Steps 2A, B and D), and the centre top pipe installed into the arch top (Box 4.3 – Step 2C).

Installing the plastic film cover

The UV polyethylene film cover should be carefully cut to fit the arched top roof. To adequately fit a RS with a single bed measuring 5m long (Figure 4.2), a sheet of polyethylene film measuring 5.3 m long x 3.75 m wide is required. Half-inch (1.30 cm) polyethylene plastic clips should be used to attach the film covering to the arch and side brace galvanized iron pipes (Box 4.3–Step 3).

Reinforcing the plastic sheets and cover

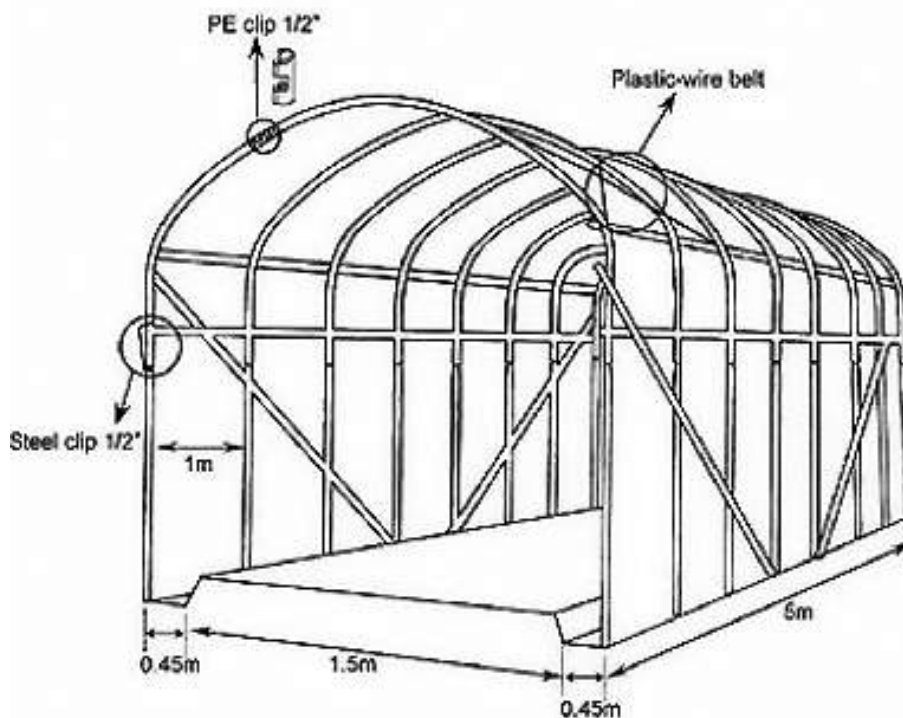
The plastic covering on the side horizontal pipes and upright post can be reinforced using steel clips. Plastic wire belts should be run across the top of the plastic sheet and fastened to upright posts to reinforce the covering against strong winds (Box 4.3–Step 4).

Covering the sides

The use of side-coverings is recommended only if there is a major insect pest problem and to prevent rain from blowing in. In cases, where white-fly transmitted viruses are problematic, and the RS are located at high elevations (>500m above sea level) in a cool environment, a 60-mesh nylon netting is recommended as a side covering. At lower elevations, 32-mesh nylon netting is recommended. The nylon mesh netting should be cut at least six to eight percent longer than the length and height of the side wall to ensure that enough material is present for fastening and securing. For example, for the RS in Figure 4.1, two sheets of

the nylon netting, each 5.3 m long x 1.8 m high are needed to fit two sides of the structure. To cover the front and back ends of rain shelter, sheets of nylon netting measuring at least 11–13 percent greater than the width and height of the rain shelter structure can be used. In the case of Figure 4.1, the nylon netting sheet should measure 2.7 m wide x 2.7 m high. Plastic clips should be used to fasten the nylon netting on all sides of the structure (Box 4.3 – Step 5). The bottom of the netting should be secured by inserting it in the soil to a depth of 10–20 cm, and gently compacting the soil on the netting.

Figure 4.7: Drawing of single-bed rain shelter with an arched roof



Source: Palada, Roan and Black (2003)

CULTURAL BEST MANAGEMENT PRACTICES

This section on cultural BMPs will focus on crop and variety selection, nutrient requirements, pest, disease, harvest, and post-harvest management. Water management and weed control are also categorized under cultural practices. These topics will however not be discussed in this chapter because there is little variation in water management and weed control principles and practices in tomato production compared with that of lettuce under protective structures.¹

Crop and variety selection

The selection of the type of vegetable crops and crop varieties to be cultivated is one of the most important decisions to be made in crop production using RS or NH. Market demand and prices and cost of production are the primary factors which should be considered when selecting leafy vegetables for net-house production. However, growers must also choose leafy vegetables and varieties that are high yielding and most appropriate for the production system employed. Whenever possible, high quality, hybrid seeds from reputable, seed companies, which are bred for greenhouse conditions with heat tolerant characteristics and resistance to multiple common diseases e.g. bacterial leaf spots, bottom rot, and crown and head rots are desired. Information on disease resistance properties can often be found on the label of the seed container. However, growers should be aware that ‘resistance’ labelling does not indicate that a crop will be completely immune to a disease and/or pest. Therefore, selecting a crop variety with high resistance to diseases is no substitute for a good crop rotation system that consists of leafy vegetables from diverse families (i.e. crucifers and non-crucifers) Figure 4.8.

Such a crop rotation system, which is based on the rotation of crucifers such as Chinese cabbage and pak-choi with non-crucifers e.g. lettuce and amaranthus, will assist in minimizing insect and pest damage, and maximize crop performance. This is particularly so for crucifers, where cultivation of these crops season after season in the same substrate leads to poor crop growth and low yield due to the accumulation of undesirable crucifer root exudates (Talekar, Su and Lin 2003). If market demand requires a farmer to grow crucifers continuously, it is suggested that the net-houses be divided into two; one half is planted to crucifers and the other to non-crucifers in each crop cycle (Talekar, Su and Lin 2003). During succeeding crop cycles, the crop should be rotated, and non-crucifers planted

1. For an extensive discussion on BMPs on water management and weed control, it is recommended that the reader consult St. Martin and Brathwaite (2012b).

over the half of the net-houses that was planted with crucifers in the immediate preceding season and vice versa (Talekar, Su and Lin 2003).

Hybrid varieties generally produce stable higher yields with greater uniformity of size, compactness, and yield than inbred varieties (Singh, Dasgupta and Tripathi 2005). Varieties bred to limit physiological problems such as bolting (or, the shooting of seed stalks occurs) and tipburn should also be selected for production in these protected structures. Besides the high cost, the major drawback of hybrid seed is that saved seeds will not produce a 'true to type' plant in the next growing cycle. This means new seeds must be purchased for each season, which will most likely increase production costs.



Rotate the crop and your plants will remain tip-top.

For lettuce production, growers should be familiar with the climatic requirements for different lettuce types such as leafy, head, romaine, or specialty types, which may be red or red and green. For example, some head type lettuce such as iceberg or crisphead, require rather exacting temperatures (10–20°C) to form compact good quality heads (Valenzuela, Kratky and Cho 1996). The formation of heads is limited at 20–27°C. Cool nights are also necessary for good quality head type lettuce, as with high night temperatures, lettuce tends to become bitter. Tip burning also occurs at high temperatures. For these reasons, head type lettuce is recommended for cultivation in NH at high elevations (150–900m above sea level) or in areas with cooler temperatures. In contrast, leafy (Minetto) and semi-head (Green Mignonette) lettuce may be grown year-round at lower elevations (Valenzuela, Kratky and Cho 1996). Cultivars of lettuce that are commonly grown in the Caribbean include Minetto, Mignonette Trini Star, Trinity, and Tropical Emperor. Growers are encouraged to continually search for and test new varieties that provide the best possible advantage in terms of environmental conditions and profitability of the enterprise.

Growth substrate selection and management²

Table 4.1 provides a summary of the key physical and chemical properties, which must be considered when selecting soilless substrates for the production of leafy vegetables. Net-house vegetable production is commonly done in soil-less substrates whereas in RS,

2. Growth substrate selection, handling, disinfecting and managing pH and electrical conductivity have been extensively addressed by St. Martin and Brathwaite (2012b).

production is mainly done in the soil. As it pertains to production in soil, lettuce yield and quality tends to be highest in well-drained, slightly acid to neutral soils (pH 5.5–7) with high organic matter content.

Irrespective of the type of substrate used i.e. soil or soilless, key physical and chemical properties must be assessed before a final decision on a substrate is made. This is important since these properties affect the ability of the growth substrate to effectively perform its basic functions. This not only includes providing the appropriate root environment, plant support and supply of nutrients, but also facilitating water delivery to the crop. A checklist of factors that must be considered when selecting plant growth substrates and recommended practices for managing growth substrates are provided in Boxes 4.4–4.7.

Table 4.1: Key physical and chemical propertiesⁱ of soilless substrates for the production of leafy vegetables

Total porosity	Air space	Water holding capacity	Available water content	Bulk density	pH	Electrical conductivity ⁱⁱ
50–80 percent	10–30 percent	45–65 percent	25–35 percent	0.19–0.70g/cm ³	5–6.0	0.2–1.5 dS/m

i. Physical and chemical properties of soilless substrate listed in the table are after irrigation and drainage, done on a percent volume basis.

ii. For seedling production the ideal electrical conductivity of the substrate is at a lower range of 0.2–0.5 dS/m (Yeager et al., 2007).

Source: Maronek, Studebaker, and Oberly (1985)

Box 4.4: Audit verification checklist for growth substrate selection

- ✓ Cost effective substrates that are preferably locally available in large quantities, renewable, possess good physical, chemical and if possible, disease suppressive properties are selected for crop cultivation.
- ✓ The inherent fertility of soil-less media has not been considered as a primary factor in selecting an appropriate substrate for crop growth, since fertilizer management plans are designed to supply all the nutrients needed by the crop during the production cycle.
- ✓ Soils usually do not provide optimal aeration and drainage required to maximize crop performance and usually need to be disinfected to prevent the build-up of soil-borne disease, insects, and weed seeds.
- ✓ In the event where the use of soil-less media is cost prohibitive, soil that has been amended with well-matured compost, solarized or steam treated is used for crop cultivation. Raised beds have been established for the cultivation of leafy vegetable crops.
- ✓ Ready mix commercial substrates such as PRO-MIX® are used for seedling production, particularly for new vegetable producers.
- ✓ Growers experiment with compost mixes made from locally available material as possible alternatives to peat moss based substrates.
- ✓ Raw bagasse and sawdust or coconut coir that have not been retted (leached), are not used as components of or as substrates as they contain phytotoxic compounds such as phenolics and also immobilize nitrogen.
- ✓ Composted rather than uncomposted coconut coir is used as container substrate for soilless cultivation of leafy vegetable crops, particularly by new growers.
- ✓ Raw or composted coconut coir that has been pre-soaked and leached (retting) over 48 hours is used for crop cultivation unless the raw material has disease suppressive properties, which may be lost through this process.

Source: St Martin and Brathwaite (2012b), Ma and Nichols (2004) and Handreck (1992)

Box 4.5: Audit verification checklist for disinfecting growth substrates

- ✓ Chemical methods are not used for the sterilization of growth substrates since the most effective chemicals are highly toxic to humans and animals and have negative effects on the environment.
- ✓ Solarization and steam pasteurization are used for sterilizing substrates.
- ✓ Solarization is used for sterilization, if capital is limited and there is a lag of at least a month or two between the end of one crop cycle and the beginning of another.
- ✓ To increase the efficiency of solarization, two layers of polyethylene, separated by fillers (i.e., PVC pipes) spaced every few feet are used to create an air space.
- ✓ Though faster than solarization, steam pasteurization may be cost prohibitive to producers because it requires investment in equipment and materials such as steamers and thermometers.
- ✓ The steaming process has been done for at least 30–45 minutes, during which time the substrate has been exposed to steam at approximately 100°C.
- ✓ Temperature has been monitored during the process to ensure that uniform heating is achieved and that all sections reach at least 82°C.
- ✓ Substrates have not been over-steamed since this may have killed disease suppressive microbes and may cause the release of toxic substances.
- ✓ Substrates that have had slow-release fertilizer blended into it have not been steam pasteurized.

Source: Sethuraman and Naidu (2008) and Robbins and Evans (2011)

Box 4.6: Audit verification checklist for adjusting pH

- ✓ Adjustments of the pH of media are made when the values are outside the optimum range recommended for the production of leafy vegetable crops.
- ✓ pH most often needs to be raised rather than lowered.
- ✓ Calcitic (CaCO_3) or dolomitic limestone (mixture of CaCO_3 and MgCO_3) in the form of fine powder or pelletized granules have been incorporated into substrates prior to planting, to increase pH.
- ✓ Fine powders calcitic or dolomitic limestone, which are faster acting than coarser prills (pellets), have been thoroughly mixed with media used, as they tend to settle and leach out of the bottom of the pot/container.
- ✓ The amount of lime required has been determined based on the starting and desired pH, the particle size of the limestone (small particles are faster acting than large ones), the type of media and the alkalinity of irrigation water used. Lime rate recommendations generally range from 3–9 kg/m³ with rates below 4 kg most commonly used.
- ✓ If plants are in production, growers apply a flowable limestone drench to the substrate at an average rate of 1L limestone per 400L of water to raise the pH of the substrate.
- ✓ For a cost effective way of increasing media pH over a longer period, the grower has switched from an acid-based fertilizer (high percentage of nitrogen in the ammoniacal form) to basic fertilizers that contain a higher percentage of the nitrogen in the nitrate form.
- ✓ Materials such as elemental sulphur, ammonium sulphate and ferrous sulphate have been incorporated into substrates before planting or applied through irrigation water to lower the pH.

Source: Robbins and Evans (2011) and St. Martin and Brathwaite (2012b)

Box 4.7: Audit verification checklist for managing electrical conductivity of substrate

- ✓ A consistent electrical conductivity value of > 3.0 dS/m before and after the application of fertilizer is a cause for serious concern as it may negatively affect crop performance.
- ✓ To address the problem of high EC, growers have first determined the source of or practices resulting in elevated salt accumulation. If possible, the grower has reduced or eliminated the source of elevated salts, which is usually from irrigation water, the amount or type of fertilizer used, or the media.
- ✓ Manures and compost (immature and mature) usually have high EC levels; therefore they may have to be substituted for peat moss at a rate of 20–40 percent by volume for a growth substrate mix.
- ✓ High EC levels are being managed by keeping the percentage of water that leaves a container relative to what is applied (leaching fraction) at 20 to 30 percent and not allowing pots to dry out.
- ✓ Substrates are not kept too wet as this may lead to the development of secondary problems such root and stem rot.

Source: Ayers and Westcot (1985), Robbins and Evans (2011), St. Martin and Brathwaite (2012b), USAID (2008) and Smith and Lopes (2010)

LAND PREPARATION FOR RS/NH

The grower should prepare the land under the RS/NH by tilling with a tractor or hand tiller. It is recommended that the grower construct raised beds of approximately 30 cm high and 1.5 m wide and at least 2.4 m long (Palada, Roan and Black 2003). Longer beds, extending almost the full length of the RS/NH may be constructed if production is being done on well-drained soil. Hand hoes should be used to straighten the beds before applying basal fertilizer. The use of silver or black plastic mulch (0.01–0.04 mm thick) is recommended as an effective means of weed suppression, retaining soil moisture, moderating soil temperature, and deterring some pests. Plastic mulch should be rolled over the bed and the side edges of the plastic secured by throwing soil on both sides of the bed (Figure 4.9). Drains approximately 0.45–0.6 m wide between beds and running the length of the RS/NH should be constructed between raised beds.

PROPAGATION, TRANSPLANTING, AND PLANT SPACING

To assure a uniform and proper stand establishment, it is recommended that most leafy vegetable crops including lettuce, should be transplanted rather than direct seeded. The amount of seed required for transplanting lettuce is usually lower than that needed for direct seeding. For example, for head lettuce approximately 85–170g of seeds are required for cultivating an acre (210–420g/ha), compared to 454g/acre (1122g/ha) for direct seeding.

For leafy types, approximately 57–142g/acre (141–351g/ha) is required for transplanting compared to 907–1,360g/acre (2240g–3359g/ha) for direct seeding. Apart from requiring less seeds for cultivation, transplanting lettuce also has the advantage of easier weed control, less damage due to birds, and higher water, land and fertilizer use efficiency since the plants are in the RS/NH production system for a shorter period.

Growers should be aware that lettuce seeds germinate best at 15–20°C, and will fail to germinate at > 27°C, if they are not primed to overcome thermo-dormancy (Valenzuela, Kratky and Cho 1996). Therefore, for year-round cultivation particularly at low elevations, growers should purchase primed lettuce seeds from a reputable seed company. High quality seed generally emerges three to five days after sowing. Except when planting, lettuce seeds should be refrigerated at all times as they quickly lose viability when exposed to high temperatures and humidity. Open-pollinated seed requires a dry storage period prior to sowing.

Slow release starter fertilizers can be incorporated in the substrate before trays or containers are uniformly filled with the seedling starter substrate. If a slow release fertilizer was not incorporated in the media, seedlings should be fertigated once at the two true-leaf stage with 6 grams of an 8-32-8 homogeneous fertilizer per litre of growing media, plus 200 ppm of a 13-24-24 plus micronutrients foliar fertilizer applied in the irrigation water. Growers may also apply suitable commercial fertilizer at a rate and time as guided by the label and other factors such as properties of media and the crop type. Growers should ensure that the seedlings are not excessively fertilized, particularly with nitrogen, which will result in soft-tissued seedlings. On the other hand, under fertilization will result in nutrient deficient seedlings.

As a general rule, vegetable crop species should be ready to be transplanted at the four to five true leaf stage, which usually occurs four to six weeks after sowing. However, for cultivation in raised beds under RS/NH, transplanting of lettuce can be done as early as two to four weeks after sowing. For novice growers, it is recommended that head type lettuce transplants be spaced at 38–45 cm between rows and 30–38 cm between plants and semi-head types, 20–30 cm between rows and plants. For leafy type lettuce, 38–45 cm between rows and 25–30 cm between plants should be used. These spacings usually result in three to four rows per bed. For production in soilless substrates, transplanting can be done earlier at one to three weeks after sowing depending on the sturdiness and health of the seedlings. Transplants should be cultivated at a planting density of two seedlings/0.1m². The time from transplanting to harvest ranges from four to seven weeks depending on the variety and type of lettuce. Audit verification checklists for propagation, transplanting, and spacing practices are presented in Boxes 4.8 and 4.9.

Box 4.8: Audit verification checklist for propagation practices

- ✓ All propagation is done in an appropriate sheltered structure separate from the RS/NH, where production will take place.
- ✓ For ergonomic reasons and to improve productivity, all propagation is done on benches and/or tables that are at least 1m high with solid netted or meshed surfaces consisting of apertures approximately 2 to 3 cm².
- ✓ All tools, supplies including new seedling trays as well as the propagation area have been disinfected following the instructions on the label of a suitable sanitizer, such as bleach.
- ✓ A contingency 3–10 percent has been factored into the equation when calculating the number of seeds needed per area. This is done to allocate for losses due to pest and diseases.
- ✓ Seeds have been placed in the centre of the cell containing growth media, and lightly covered with the substrate.
- ✓ Seeds have been sown at a depth of approximately 2.5 times the average length of the seed.
- ✓ Seedlings have been very gently watered until water drops are seen coming from the holes in the bottom of the germination tray.
- ✓ Germination trays have been wrapped completely with a black plastic (germination chamber) and placed in a cool area.
- ✓ Seedlings have been regularly monitored (at least 3 times/ day) to avoid etiolation.
- ✓ Germination trays were unwrapped as soon as the first seed germinates.
- ✓ Seedlings were kept in an area with optimum conditions (11–16 klx and a temperature of 24–29°C).

Source: St Martin and Brathwaite (2012b), USAID (2008), Smith and Lopes (2010) and Valenzuela, Kratky and Cho. (1996)

Box 4.9: Audit verification checklist for transplanting and plant spacing in a containerized-production system

- ✓ Preparations for transplanting started at least 12 hours before seedlings are removed from seedling trays.
- ✓ Irrigation systems were made operational and plant containers appropriately arranged, spaced, and filled with growth substrate.
- ✓ Growth substrates were pre-moistened before receiving transplants.
- ✓ Seedlings were transplanted in the late afternoon when it is not very hot (24–29°C) so that they can adjust to temperature and substrates changes overnight.
- ✓ Growth substrates were firmly pressed around the root of the transplant, and then lightly irrigated after transplanting.
- ✓ Since light is generally not a limiting factor to vegetable production in RS/NH in the Caribbean, selection of plant density was primarily based on the potential effect on ventilation rates on crop performance and the resources available to produce the crop.
- ✓ The experienced growers has decided to adhere to, or further adjust transplant spacing to the production systems and planned economic goals.
- ✓ Caution was taken to avoid overcrowding as it will result in decreased yield per plant and also tends to promote disease development due to high relative humidity and the inability of pesticides to easily penetrate the thick foliage.

Source: St Martin and Brathwaite (2012b) USAID (2008) and Hanson et al.(2000)



Plant uniformity starts in the germination tray.

NUTRIENT MANAGEMENT

To effectively employ BMPs for nutrient management, growers must be knowledgeable about the nutrient requirements and growth pattern of the crop cultivated. A good starting point is to obtain information on the amount of nutrients that a crop removes from a growth medium (Table 4.2). Such information can be used to estimate crop nutrient requirements, and develop an appropriate fertilizer programme (St Martin and Brathwaite 2012b). The focus of this integrated nutrient management programme will be to:

- match fertilizer application with the nutrient requirements of the plant across growth stages;
- limit the loss of nutrients from plant containers to rain shelter or net-house floors during top-watering or from the soil; and
- limit nutrient and water loss from irrigation and leaching by containing the effluent.

Table 4.2. Recommended nutrient ranges for lettuce

Nutrient	Range	Target level
N	2.5–4.0%	3.5%
P	0.4–0.6%	0.45%
K	4.0–7.5%	5%
Ca	0.9–2.0%	1.0%
Mg	0.3–0.7%	0.35%
S	0.1–0.3%	0.1%
Fe	50–150 ppm	130 ppm
Zn	25–50 ppm	40 ppm
Mn	30–55 ppm	50 ppm
Cu	5–10 ppm	8 ppm
B	15–30 ppm	20 ppm
Mo	0.1–2.0 ppm	0.6 ppm

Source: Valenzuela, Kratky and Cho (1996) and A & L Canada Laboratories (2006)

The fertilizer programme developed should take into account: fertiliser type, application method, fertilization rate and frequency, volume of fertiliser solution, leaching fraction, plant growth rate, and environmental conditions. An audit verification checklist for nutrient management is presented in Box 4.10.

Box 4.10: Audit verification checklist for nutrient management

- ✓ Tissue and soil analyses were used to help determine the amount of fertilizer to apply to complement the nutrient levels already available in the soil or soilless substrates.
- ✓ Integrated nutrient management, which focuses on optimising and harnessing the full potential of available biological and organic sources and using chemical fertilizers only to supplement the gap in the nutrient requirements of the production system, was included in the production of the crop.
- ✓ Recommendations from soil scientists or technicians on appropriate fertilizers to be used in the production of vegetable crops are followed.
- ✓ At least two different fertilizer sources were used to supply each nutrient.
- ✓ Ammonium nitrate was used in crop production because a large amount of N is normally recovered by plants with slight to moderate amount of leaching.
- ✓ No more than 50 percent of the total nitrogen supplied to plants grown in soilless media was in the ammonium form.
- ✓ Vegetable crops were not excessively fertilized i.e. application beyond crop needs, as this can result in soluble salt build-up, phytotoxic effects on plant growth, groundwater contamination, and capital losses due to purchase of unneeded fertilizer.
- ✓ Fertilizer programmes consisted of a combination of fertilizer application types including pre-plant, foliar and fertigation.
- ✓ Solid organic materials such as compost were incorporated at the pre-plant stage.
- ✓ Fertigation was used during all stages of plant growth.
- ✓ Fertilisers were mixed using an injector system, with an adjustable rate injector designed to inject calcium nitrate.
- ✓ With the adjustable rate injector, the same fertiliser concentrate was applied at different concentrations.
- ✓ Long periods of fertigation were avoided. Instead, pulse irrigation (brief periods of fertigation), which has been shown to be the best for efficient application of water and nutrients, was used.
- ✓ The effectiveness of fertilizer programmes on crops and their impact on the environment was monitored through water, substrate, and tissue analysis as well as by the observations of the growers.

Source: St Martin and Brathwaite (2012b) USAID (2008), Smith and Lopes (2010), Valenzuela , Kratky and Cho (1998), Talekar, Su, and Lin (2003) and Cox (1985)

Growers should pay particular attention to phosphorus availability since it has been shown to account for the single largest variation in lettuce yield production among various substrate types (Valenzuela, Kratky and Cho 2003). Moreover, substrates deficient in phosphorus may result in increased bacterial infection rates in lettuce, and in some cases, harvest delays by several weeks compared to well fertilized plants (Valenzuela, Kratky and Cho 1996). The only symptom of a P deficiency in lettuce is stunted growth, and not the reddish pigmentation and leaf ‘feathering’, which are characteristic of phosphorus deficiency in other vegetables crops.

Growers should also ensure that adequate levels of nitrogen are available in the substrate for plant uptake since nitrogen levels are associated with the formation of solid heads, as well as size, colour and earliness of maturity in lettuce (Valenzuela, Kratky and Cho 1996). Nitrogen deficiency in lettuce appears lighter green and often results in delayed harvest and/or in failure of heads to achieve marketable size and quality. Growers should be aware that while corrective nitrogen applications are effective during the early vegetative stages of the crop, they often result in a 3–10 days delayed harvest (Valenzuela, Kratky and Cho 1996). However, corrective nitrogen applications made during the head-formation stage will not result in increased head size or final yields.

PEST AND DISEASE MANAGEMENT

The recommended approach for pest and disease management is the formulation of an integrated pest management (IPM) programme, which includes crop, pest and disease identification and monitoring, the use of resistant cultivars, sanitation, and appropriate cultural, chemical and biological control strategies (Smith and Lopes 2010; St Martin and Brathwaite 2012b). A summary of the key points for the respective components of this programme is presented in Boxes 4.11–13 and the key disorders and diseases of lettuce in the Caribbean are discussed. Important pests of lettuce include caterpillars, aphids, leaf miners, leafhoppers, mites, thrips, and whiteflies. These pests can be successfully managed using most of the strategies and protocols described for disease control in Boxes 4.11–13.

Box 4.11: Audit verification checklist for pest and disease identification and monitoring

- ✓ Information on the major diseases that affect the crop, particularly in the area where the RS/ NH are established, was obtained before cultivating the crop.
- ✓ The assistance of suitably trained personnel to help design and implement an effective IPM programme was solicited.
- ✓ The IPM programme consists of a monitoring or scouting plan, which should form the basis of IPM decision making, regardless of the control strategies used.
- ✓ A scouting plan consists of a pre-crop site evaluation, inspection of incoming plants, the use of sticky cards and indicator plants.
- ✓ The pre-crop site evaluation was done at least 4-6 weeks prior to the introduction of a new crop or at the beginning of another cropping cycle.
- ✓ An evaluation of the surroundings of the RS or NH extending at least 8 m from the structure, was done by collecting information such as, types of weeds, crops growing in the field, soil type and drainage problems and methods used to control pests.
- ✓ One-third to all the plants were thoroughly examined for signs of insect and disease before being introduced into the RS or NH, or not more than 48 hours after they have been introduced into the RS/NH.
- ✓ This examination was done before the plants were transferred to the main growing space in the RS or NH, or in a separate receiving shelter.
- ✓ Once the crop has been established, numbered yellow sticky cards were spaced equally throughout the RS or NH in a grid pattern at the minimum recommended rate of 90 m². These cards are used to monitor infestations of adult flying insects.
- ✓ The cards were also placed near all entryways and vents. They were replaced weekly unless the level of infestation is so high as to demand an earlier removal.
- ✓ Threshold levels for particular crops are being developed with the assistance of suitably trained personnel, using data collected from these cards, such as the number and type of pest and beneficial insects.
- ✓ A scouting unit is not > 370m². Large RS or NH can be divided into several scouting units of ≤ 370m².
- ✓ Diseases are being monitored using similar inspection systems, record keeping and a selected decision-making process.
- ✓ Every attempt has been made to accurately identify diseases so that appropriate treatment or action can be taken. This has been done using diagnostic laboratory services or specialized consultancy services.

Source: St Martin and Brathwaite (2012b), Smith and Lopes (2010).

Box 4.12: Audit verification checklist for sanitation, resistant cultivars and environment

Sanitation:

- ✓ Plant debris, weeds, benches, and troughs were cleared before introducing another crop in the RS or NH.
- ✓ Tools, plant containers, and shelves were washed and disinfected.
- ✓ Recontamination was avoided as much as possible after sanitizing the NH or RS.
- ✓ Antechambers are being used to help control insect pest entry into NH through the door.
- ✓ A footbath is located in the antechambers and filled with a commercial surface disinfectant or a ten percent chlorine bleach solution (enough to cover the entire sole of a shoe). A washing station was established inside the NH for workers who will be in direct contact with plants and supplies.
- ✓ Hose nozzles are not kept on the floor of RS or NH, as these are potential sources of recontamination. Appropriate hooks are provided for hanging hoses.
- ✓ Cleaning and propagating work was done in individual planting blocks or sections and hands and tools cleaned and disinfected, or gloves changed between planting blocks or sections.
- ✓ The reuse of the same growth substrate across crop cycles was avoided as much as possible even if disinfection of growth substrate is practiced.

Resistant cultivars:

- ✓ Varieties resistant to multiple common diseases of the crop have been used, where possible.

Environment:

- ✓ The focus has been placed on lowering relative humidity and minimizing temperature differentials and cold spots in RS and NH.

Source: Valenzuela, Kratky and Cho (1996), St Martin and Brathwaite (2008) and Smith and Lopes (2010)

PHYSIOLOGICAL AND PHYSICAL DISORDERS

Brown stain

Brown stain is caused by excess carbon dioxide (>2.5 percent) in storage. Some cultivars seem to be more susceptible than others. Symptoms include superficial brown spots on the midrib or the surface near the lower part of the midrib, which enlarge and coalesce over the leaf as the disorder progresses. The incidence and severity of brown stain is significantly reduced by storing lettuce in low CO₂ (< 5 percent) and O₂ (<1 percent) environments (Valenzuela, Kratky and Cho 1996).

Box 4.13: Audit verification checklist for cultural and chemical practices

Cultural practices:

- ✓ Crop barriers and trap crops such as corn outside the RS or NH are established.
- ✓ Repellent or companion crops such as marigold, chive, and rosemary are established in and around the RS or NH.
- ✓ Well-drained substrates are used to prevent root diseases.
- ✓ Appropriate plant spacing is used to allow for good air movement, lower humidity levels, and better pesticide coverage.
- ✓ Irrigation is appropriately done to prevent puddling or excess water on the floor.
- ✓ Irrigation is done early in the day to allow foliage to remain dry overnight.

Chemical practices:

- ✓ Chemical pesticides are used as the last resort for the control of pests.
- ✓ 'Green chemicals' such as bio-pesticides and bio-fungicides are used in RS or NH, on a disease preventive basis.
- ✓ Fungicides are only applied on a preventive basis to valuable crops when conditions are favorable for the development of a prevalent disease.
- ✓ A broad-spectrum fungicide is used on a preventive basis to control root diseases.
- ✓ For foliar diseases, pesticides are applied when the disease is first evident.
- ✓ For effective foliar disease control, foliage is thoroughly covered with pesticide.
- ✓ To prevent or minimize the development of resistance by the pest, pesticides with different modes of action, chemical groups e.g., systemic/contact fungicides are used.
- ✓ All Good Agricultural Practices (GAPs) related to pesticide use, handling, storage, and disposal are employed when dealing with chemical pesticides.
- ✓ Copper-based pesticides approved for use in RS/NH are used to control bacteria and most fungi.
- ✓ Diseased plants are removed or isolated from healthy plants.
- ✓ Viral diseases are controlled by controlling the insect vector, removing the diseased plants from the RS/NH and burning them, eradicating host plants such as weeds, and starting with virus-free seeds or propagating materials. There are no effective chemicals for the control of plant viral diseases.
- ✓ Sterile growth substrate is used to prevent nematode problems.
- ✓ Botanicals such as neem-based products are used as a chemical strategy for nematode control.
- ✓ Growth substrates containing nematodes are not used for another cropping cycle.

Source: Valenzuela, Kratky and Cho (1996), St Martin and Brathwaite (2012b) and Smith and Lopes (2010)

Russet spotting

Symptoms of russet spotting include small olive brown spots on the lower midribs of the outer leaves. The symptoms develop at least four days after exposure to excessive ethylene levels of 20-35 ppm at 2–15 °C, and are visible on both sides of the leaf (Valenzuela, Kratky and Cho 1996). However, the inner leaf side is mostly affected and symptoms tend to be more severe on over-matured lettuce or lettuce produced in hot, dry areas. To reduce russet spotting, growers should maintain storage temperatures just above freezing, and ventilate properly. Harvested lettuce should also be kept away or separated from climacteric fruits e.g. bananas and pineapples, and other sources of ethylene or ethylene derivatives such as gasoline engines.

Premature bolting

When exposed to high temperatures and dry conditions lettuce tends to bolt or flower. Cultivars vary in their tendency to bolt. Therefore, premature bolting can be managed by selecting a variety that has a low tendency to bolt, cultivating lettuce in areas with cooler temperatures, and by the use of best practices for water management.

Tipburn

Initial symptoms include small translucent spots close to the leaf margins, which eventually result in darken lesions and death of leaf margin tissues. These spots and lesions, which arise due to localized calcium deficiency in the foliage, provide openings for secondary bacterial pathogens. Tipburn, which can be controlled to some extent by planting tolerant cultivars, is particularly severe under hot weather and fast growing conditions. Increasing soil calcium supply prior to planting, liming highly acid soils, foliar calcium sprays on leafy-types, slowing growth through lighter fertilizer application (particularly N), keeping the soil sufficiently moist, and shading with up to 35 percent shade cloth, are some strategies that can be used to manage tipburn (Koike and Davis 2014; Valenzuela, Kratky and Cho 1996). For best results, growers should use a combination of these strategies and not rely only on one practice. The use of calcium sprays alone is often ineffective, especially on head lettuce, because calcium is inefficiently translocated to those leaf tissues deficient in calcium (Koike and Davis 2014). Head types are generally more susceptible to tipburn than leafy lettuce.

DISEASES

Bottom rot

Bottom rot is a fungal disease caused by *Rhizoctonia solani*. Early symptoms include slimy rotting of the lower leaves in contact with the soil and rust-coloured, sunken spots

on petioles and mid-ribs (Koike and Davis 2014). Eventually, the lesions expand, spread, become darker, and result in decay of the entire plant (Koike and Davis 2014). Control is difficult. However, it is recommended that the grower do the following, as suggested by Koike and Davis (2014):

1. Keep the foliage dry and the fertilizer level low so that foliage growth is not overly succulent.
2. Plant on raised beds to improve drainage as bottom rot is more severe under moist and warm conditions.
3. Avoid flooding as a means of controlling the disease.
4. Rotate crops.
5. Direct fungicide applications towards the base of the plants.
6. Avoid disturbing the soil after application of protectant fungicides for bottom rot management.

Bacterial leaf spot

Bacterial leaf spot is caused by *Xanthomonas campestris* pv. *Vitians*, a bacterium, which is highly dependent on wet, cool conditions for infection and disease development (Koike and Davis 2014). Early symptoms of bacterial leaf spot are small, water-soaked leaf spots on the older leaves of the plant (Koike and Davis 2014). These lesions, which are typically bordered by leaf veins and angular in shape, quickly turn black. This is a diagnostic character of the disease. To manage the disease, it is recommended that the grower do the following:

1. Use pathogen-free seed.
2. Avoid using sprinkler irrigation, whenever possible.
3. Practise crop rotation.
4. Destroy alternate hosts such as weeds.
5. Use can be made of copper-based bactericides, but these are not very effective, and should be applied before infection occurs. Spreader-stickers should be used with bactericide treatment, particularly during rainy weather.

Downy mildew

This fungal disease is caused by *Bremia lactucae*, a complex organism consisting of multiple races (Koike and Davis 2014), which require damp, cool conditions and moisture on leaves to infect lettuce. Symptoms include light green to yellow angular spots on the upper surfaces of leaves, with white fluffy growth of the pathogen on the lower sides of these

spots. Lesions eventually turn brown and dry up (Koike and Davis 2014). The pathogen can become systemic and cause dark discoloration of stem tissue. The grower should manage the disease by using resistant cultivars with fungicide (applied before the development of the disease), crop rotation, and sanitation.

Pink Rib

This bacterial disease, which is caused by *Pseudomonas marginalis*, usually occurs on over-mature heads, causes a diffused but distinct pink area at the midrib base (Koike and Davis 2014). The symptoms intensify during shipping and storage extending toward the leaf veins (Koike and Davis 2014). Growers can manage this disease by not harvesting and packaging over-matured lettuce, good sanitation practices, crop rotation, and providing optimal storage conditions.

HARVEST AND POST-HARVEST

Harvest time and maturity and quality indices

Harvest time for lettuce, which usually occurs four to seven weeks after transplanting, should be informed by consumer preferences, distance, and time needed to market the produce. Maturity is often judged according to the number and colour of leaves and/or by head development in semi-head and head type lettuce. For example, lettuce heads with <30 leaves before trimming are considered immature, whereas mature heads have approximately 35 leaves (Valenzuela, Kratky and Cho 1996). Nonetheless, both immature and mature lettuce generally have a better flavour and fewer post-harvest problems than over-mature heads, which tend to be bitter. Head-type lettuce with a very loose or easily compressible head is generally considered immature, whereas over-mature lettuce have very firm or hard heads (Kader, Lipton and Morris 1973). What is critical however, is that the grower should harvest the lettuce before the heads bolt, crack, yellow, or turn bitter. With improved cultivars and cultural practices, uniformity of the crop yields and quality have increased, therefore growers can harvest up to 90 percent of their crop in one harvest. In most cases, this has resulted in > 5 harvests per year, with an average yield of 3 kg/m²/crop (300 grams/sq. ft. crop).

Lettuce should be harvested when leaves are bright to dark green, crisp and turgid and free from insects and decay, as consumers often perceive higher nutrient content and overall better quality in such leaves. Lettuce without discoloration at the butt and signs of mechanical damage are also perceived as fresh and safer to eat by consumers (Kader, Lipton and Morris 1973).

Harvesting operation

In non-containerized-soil production systems, growers should cut the lettuce at soil surface, with a sharp, sterilized knife, leaving the roots in the soil. This minimises the removal and transportation of soil to unintended areas, which in turn significantly reduces the risk of spreading pathogens or pests to other fields. However, the land should be cleared of all plant debris immediately after harvest. This will reduce carryover of pests and diseases to subsequent crops.

In containerized- soil-less production systems, lettuce should not be cut at the surface of the soil-less substrate since it is may be difficult and require additional labor and costs to remove or clear roots and other plant debris from each container. The root system can be cut off some time after the entire planted is uprooted from the substrate, usually before washing or cooling the lettuce.

For head-type lettuce, the heads should be harvested leaving as many of the wrapper leaves uninjured as possible. That is, at least four to five wrapper leaves on each head of lettuce. To minimize wrapper leaf damage, lettuce should not be cut when the heads are wet. Before packing or immersing in water for cooling, growers should remove soiled and spoiled leaves at the base of the lettuce head. All lettuce heads showing traces of disease infection or any other disorder should be discarded.

Handling and storage practices

Lettuce is a perishable commodity, has a high respiration rate, is sensitive to ethylene, and is readily susceptible to damage due to wilting because of its high surface to volume ratio. Therefore, the key guidelines in maintaining post-harvest crop quality are:

1. avoid mechanical injury such as those resulting from impact, puncture, compression, vibration, and abrasion;
2. promptly and thoroughly cool lettuce;
3. maintain the optimum storage temperature (0°C to 2°C) and relative humidity (95– 100 percent) for lettuce; and
4. avoid water loss.

Vacuum cooling is the recommended method for promptly cooling lettuce. However, in the Caribbean, where small-scale production vegetable systems are predominant, cold water (4–12°C) can be useful in pre-cooling lettuce. As such, in rain shelter or net-house systems, containers with potable cold water can be brought directly into the RS or NH and used by the harvester as a field container. Alternatively, large containers with potable cold

water can be strategically located in RS and NH, at points which minimise the time between harvest and pre-cooling (preferably <20 minutes). The harvester should use clean water with each harvest of lettuce. Lettuce should be packed in stackable containers, which allow for maximum air circulation around pre-cooled lettuce, and reduce mechanical injury.

At the recommended temperature of 0–2°C and relative humidity storage conditions of 95–100 percent, leaf type lettuce has an expected storage life of one to two weeks, and head-type lettuce two to three weeks. Harvesters and packers should avoid storing lettuce next to climacteric crops and in low CO₂ (< 5 percent) and O₂ (<1 percent). Under such conditions, lettuce tends to develop off-flavours and various disorders, including russet spotting and brown stain. An audit verification checklist for harvest and post-harvest is provided in Box 4.14.



Keeping the product cool is the most important rule.

POST-HARVEST CARE OF STRUCTURE

Maintenance of RS or NH

The grower should disassemble and safely store the components of rainshelter or net-house structures if they will not be used for an extended period (> 6 months). Plastic roof and side netting coverings should be washed with a detergent solution, using a high-pressure hose to remove dust, insect eggs, and algae. If compatible with the detergent solution, bleach should be added to the detergent solution, to kill algae. Cleaning the plastic roof and side netting will increase the transmission of sunlight in the rainshelter and net-house structures. Growers should clean the net from the inside-outside direction, as this will reduce accumulation of water inside the NH and facilitate the planting of crops without delay. The grower should promptly repair any damaged parts of the structure.



Top profits are seen when rain shelters and net-houses are kept clean

Box 4.14: Audit verification checklist for harvest and post-harvest

Before harvest:

- ✓ Good agricultural practices (including sterilizing harvesting tools) are employed to ensure the highest acceptable food safety and quality standards.
- ✓ Harvesters have cut sharp and long fingernails, as these may damage produce.

At harvest:

- ✓ Produce was harvested in the early morning or late afternoon, during cool temperatures, and when transpiration rate is low.
- ✓ Utmost care was taken not to cause injury to the produce or to mix damaged and undamaged produce.

On the way to packing shed/area:

- ✓ Produce is shaded to prevent sunburn and overheating.
- ✓ Bumpy drives avoided.

In packing shed and packaging:

- ✓ Produce was washed with potable water, placed in stackable crates or containers, and moved to a shaded cool place where the temperature is < 25°C and humidity is 85–90 percent. The use of packages that reduce air movement or exchange to the extent that the quality of the produce quickly deteriorates even under optimal storage conditions is avoided.
- ✓ Produce is covered with an appropriate material such as tarpaulin to prevent water loss.
- ✓ Stacking crates or containers have been packed to immobilize, cushion, and avoid impacts.
- ✓ Packing containers such as boxes and crates are not over- or under-filled.
- ✓ The package, not the produce, bears the stacking load.

Storage life:

- ✓ The shelf life of most produce is extended by storing at 10–15°C and a 95 percent relative humidity.
- ✓ For most produce, chilling injury occurs below 7°C.
- ✓ Most storage diseases such as rots are significantly reduced by quick cooling of harvested produce and by avoiding fruit injury during harvesting.

Source: Kitinoja and Kader (1994) and St Martin and Brathwaite (2012b)

SUMMARY OF KEY POINTS

As it relates to PA technologies, RS and NH are increasingly being viewed as more appropriate and sustainable than fully enclosed GH, for vegetable production under the climatic conditions of the Caribbean. This is so, mainly because:

1. The establishment of RS or NH requires a significantly lower initial capital investment.

2. To some extent, RS or NH addresses the major factor that limits crop performance in totally enclosed GH, i.e. high mean daily temperatures ($>35^{\circ}\text{C}$).
3. The level of knowledge and skills required for agronomic, crop, environmental and technological management in totally enclosed GH, is arguably higher than what is required for operating RS and NH.

In an effort to avoid the technical pitfalls at adopting rain shelter or net-house technologies in the Caribbean, therefore, the following key summary points are presented:

1. Avoid locating RS and NH on flood prone land or areas that are below or near sea level (<100 m above sea level).
2. There are 'trade-offs' between the types of protective structures and designs utilized, therefore growers should select structures that pose the lowest risk to the production of a specific crop and for which he/she has greater managerial strength.
3. All protective structures, whether RS or NH, should be built to withstand strong wind in locations where severe storms and environmental conditions occur.
4. When selecting crops for production in RS or NH consider market demand, prices, and cost of production.
5. Net-house designs should include two double doors systems as a means of restricting the entry of pest and diseases into the NH. This is an important preventive strategy in pest and disease management in NH.
6. Use should be made of an integrated nutrient and pest and disease management systems in crop production.
7. Avoid continuously cultivating the same crop in the same substrate or area of land. Use a crop rotation system in the RS and NH.
8. Identify and monitor pest and diseases.
9. Reduce post-harvest damage by harvesting the crop at the appropriate maturity index, cooling produce promptly and thoroughly, and storing it under the recommended conditions.
10. Keep proper and accurate records.

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Natural Crop Protection Methods in the Caribbean

Wendy-Ann P. Isaac and Ayub Khan

INTRODUCTION

With the ever increasing population throughout the Caribbean, satisfying the demand for food becomes the very basic goal of regional agricultural production efforts. Crop production is, however, particularly at risk as substantial losses may occur due to high infestation of insect pests, diseases, weeds and other potentially harmful organisms. For crop production to meet food security objectives, there must be marked improvement in insect pest, disease and weed management. During the 1970s and 1980s, crop protection experts advocated the increased use of broad-spectrum synthetic pesticides to promote crop production. Consequently, the majority of small, resource-poor farmers throughout the Caribbean have developed an unhealthy reliance on pesticides which has become a crucial component towards achieving optimum farm productivity. Fernandez et al. (2007) noted that increased pesticide use results from poor land management practices together with loss of agricultural lands to other economic activities. The resulting massive pest outbreaks from this unhealthy reliance on pesticides therefore demands reconsideration of crop protection approaches throughout the Caribbean.

Before the advent of synthetic pesticides, most farmers and agricultural practitioners throughout the Caribbean relied entirely on local or natural crop protection methods. Crop protection methods were based on natural products which were not only environmentally friendly, but also culturally acceptable, affordable, cost effective and sustainable. Cultural control measures are knowledge-based and the methods and practices associated with this type of control are easily accepted and adopted. Natural and/or cultural control strategies are very diverse and practices are complementary in most cases. For clarification, some cultural control strategies include:

- Use of disease free plant material and seeds
- Practice of crop rotation as this interrupts the life cycle and feeding habits of insects
- Intercropping and multi-cropping for control of weeds and insects
- Use of plants as sources of bio-rational pesticides (e.g. marigold, neem)
- Field sanitation - keeping fields clean at all times

Contrary to widespread beliefs, the use of natural, non-chemical crop protection evolved mainly as a result of socio-economic constraints, environmental conditions, natural habitat and the determination to survive (Stoll 1988). Stoll (1988) further stated that ‘non-chemical protection practices by small holders and organic farmers attempt to make maximum use of local knowledge resources’.

Local knowledge is defined as the knowledge of a person or people within various communities that is considered holistically correct. This local knowledge has been developed over centuries. Local knowledge is not confined to specific areas. It can be rural or urban. All developing communities possess local knowledge. It is knowledge that has been tested and proven by past experiences and then adapted into culture and rituals. Local knowledge is passed from one generation to the next by word of mouth. It has its uniqueness in certain geographical areas. It is not uncommon to find different people in different countries who share the same practices.

According to Warburton and Martin (1999), local knowledge relates to the entire system of concepts, beliefs and perceptions that people hold about the world around them. This includes the way people observe and measure their surroundings, how they solve problems and validate new information. It includes the processes whereby knowledge is generated, solves problems and transmitted to one another.

Indigenous knowledge on the other hand is a knowledge system that is unique and sacred to a particular society. Its movement or passage between generations occurs through what is known as oral traditions. The preservation of various customs and beliefs through this type of knowledge system enabled the conservation of agricultural practices, health benefits and environmental protection. This knowledge is often compared with local knowledge and often times the definition is used interchangeably. According to one writer, indigenous knowledge is local knowledge that is unique to a culture or society. Indigenous knowledge has also been referred to as ‘folk knowledge’ or ‘people’s science’ (Senanayake 2006).

Indigenous knowledge systems have played important roles in the debate on cultural policies and developmental planning in some countries. Warren et al. (1995) noted that ‘local people know a great deal about their environment in which they have lived for generations.’ Darkoh (2009) stated that a blend of modern science and local knowledge will be required

to face the challenges of the environment on a sustainable basis in the decades ahead for many in Africa. Certainly, this view is relevant not only for Africa, but for most developing countries, and in particular the Caribbean region.

Local knowledge must be preserved to promote sustainable agriculture. Within the confinements of agriculture and food security, the incorporation of local knowledge would impact the dependency on synthetic chemical methods of crop protection. Communities have successfully utilized local knowledge for centuries and its worth should never be underestimated.

Prior to synthetic chemical inputs, farmers and practitioners relied entirely on natural protection methods. Today however, there is a grave risk that much local knowledge is being lost and, along with it, valuable knowledge about ways of living sustainably.

This chapter focuses on local and natural, non-chemical crop protection practices used on various crops throughout the Caribbean region. It will detail the significance of promoting and supporting these ecologically based strategies for the sustainable production of food for small producers to ensure food security in the region. It will provide a compilation of surveys conducted among aging farmers of successful practices used throughout the Caribbean and will also explore other examples which could be successfully adopted from other countries. It attempts to not only to promote the use of local knowledge of small farm holders but also to strengthen it with external knowledge and scientific references. Research has shown that an integrated or holistic approach to crop protection is recommended. For such an approach, it is clear that appropriate crop protection strategies for small farmers can only result from a thorough understanding of the interrelationships between the natural, technological and socio-economic conditions. It is therefore important for farmers to understand the principles of crop protection and then adapt, rather than adopt, promising pest management techniques to their unique situations.

OVERVIEW OF LOCAL AND NATURAL CROP PROTECTION PRACTICES THROUGHOUT THE CARIBBEAN

Pest management presents one of the greatest challenges to farmers throughout the Caribbean region. Collectively, a group of farmers interviewed to assess their local crop protection knowledge experienced the same types of pest problems. Pest damage caused by insects included damage to leaves, stems, fruits, tubers, and even entire plants. A wide range of non-chemical, natural materials and methods are employed for pest management across the region. Some of the more important ones include:

Ash: which is obtained by burning of leaves, branches, parts of trees and grasses is sprinkled on plants to prevent damage by pest insects. Ash is also placed around the roots

of plants, trees and other crops showing signs of insect damage. This is a very common practice on banana and plantain (*Musa* spp.) farms in the Caribbean. Most farmers believe that it is the best remedy for nematodes and weevils which attack these crops. Ash is also used as a protective covering against biting insects in particular on some vegetable beds. After harvesting of some crops (eg. yams (*Dioscorea esculentum*), the exposed area is dipped into ash before storing to protect against post-harvest storage insects. Dried seeds and beans are also stored with a mixture of ash and ground black pepper (*Piper nigrum*). The use of ground bay leaf (*Pimenta racemosa*) leaves together with ash was reported to be effective against stored pest insects.

Soapy water: The use of soapy water is also very common among farmers. This solution was made primarily with “blue soap” (detergent bar) and is sprayed or sprinkled on insect affected plants. This practice was used to control aphids, mealybugs and scale insects.

Marigold: Grainge and Ahmed (1988) noted that a variety of plants and their extracts can also be used against many pest organisms. The planting of marigold (*Tagetes* spp.) between certain crops reduces the incidence of insect damage. Marigold flowers produce an unpleasant odour which acts as an insect repellent. The leaves and flowers are crushed and soaked either overnight or for a few days in water. The mixture is then strained to remove the solid parts and the remaining mixture is used to spray vegetable and other food crops for the management of various caterpillars and aphids.

Garlic: The use of garlic either alone or in combination with other plant extracts (eg. hot pepper (*Capsicum* spp.) as an insect deterring agent is quite common. Like marigold, it has an unpleasant odor that repels insects and produces a burning sensation on contact with the skin. Two bulbs of garlic, crushed and soaked in about 2 litres of water would make a strong enough concoction that can be applied to plants and other infested crops.

Neem: Some farmers also experiment with neem (*Azadirachta indica*). The leaves and seeds were either crushed and soaked in water for several days or boiled to make a strong solution which is then used to protect crops against insect damage and infestation. The use and effectiveness of neem is highlighted by Stoll (1988).

Urine: Both human and cow urine are also commonly used in crop protection throughout the region. They are either administered in their fresh or stale form by collecting urine from the household or farm each morning. The urine is then poured into cut bamboo joints (about 9 joints in total) and left for seven to nine days to ferment, producing a very pungent scent. The resulting fermented urine can be diluted or used as is. The stale solution is believed to be a good insect repellent. The use of urine is particularly prevalent among farmers who cultivate banana, plantain, vegetables and citrus. The application of urine to

plants is usually done during the evening time as most insects pests associated with these crops feed at night.

Kerosene: Both kerosene and diesel are also utilized as pest management options in the destruction of ant nests by burning and also along the crop field perimeter or along fences to avoid the intrusion of pests. Disinfectants (e.g. 'black disinfectant' or Jeyes Fluid) are also used in the same manner as kerosene and diesel.

Larger pests: Most studies of natural pesticides are concerned with their effects on insects. However, in many cases, the management of larger pests including birds, lizards, rats, squirrels and snakes also present a serious challenge. In some instances, farmers have reported using substances such as diesel and kerosene around the boundaries of their fields to restrict to the entry of snakes, lizards and rats in particular while others are destroyed by the use of shot guns or homemade devices (e.g. slingshots). Despite its significance as Tobago's national bird, the Cocrico (*Ortalis ruficauda*), is considered a pest by some farmers and home-based practices such as soaking fruits in alcohol to cause intoxication of the birds is also utilized. Scarecrows are sometimes also utilized to control the Cocrico. Farine, a local product made using cassava is soaked in water and then left in the field as a trap for birds. When eaten, it chokes the birds and allows them to be easily caught and destroyed. Traps are made for some types of birds using the latex from the outer bark of selected trees, especially breadfruit (*Artocarpus altilis*) and locally referred to as 'laglee'. This is then left to 'set' and becomes very sticky. This sticky substance (laglee) is then spread over very thin pieces of sticks and placed in strategic locations in the field to trap birds. Various traps are made to capture mammalian pests including rats (*Rattus* spp.), manioc (*Didelphis marsupialis*), agouti (*Dasyprocta leporina*) and squirrels (*Sciurus granatensis*) in particular.

Uncultivated sites can provide refuge for weeds during the non-crop period. Traditionally, most weeds are controlled physically by 'cutlassing' or burning. Some Caribbean farmers practise mulching or intercropping of cover crops as a form of, or to facilitate weed control. Intercropping also minimizes the incidence of insect pests as the case of *Thrips palmi* Karny (Thysanoptera: Thripidae) in Cuba where damage to vegetable and row crops is reduced when they are intercropped with corn (Venotola 2013).

Farmers in some Caribbean islands practise biological control on their farms. Cuban farmers are an excellent and successful example of the use of this form of pest management. Venotola (2013) stated that Cuban farmers use the natural enemy, *Trichogramma* spp. (Hymenoptera: Trichogrammatidae). These are small wasps which parasitize the eggs of a range of crop pest insects including the cassava hornworm (*Erinnyis ello* L. (Lepidoptera:

Sphingidae), the tobacco budworm (*Heliothis virescens* F. (Lepidoptera: Noctuidae) and the sugarcane borer (*Diatraea saccharalis* F. (Lepidoptera: Crambidae). Additionally, farmers also use homegrown biopesticides including *Bacillus thuringiensis* (Bt) to control mosquitoes and lepidopterous pests which affect crucifers and corn, citrus, potato leafminers and mites. A local strain of the entomopathogenic fungus, *Beauveria bassiana*, is used to control the sweet potato weevil *Cylas formicarius* F. (Coleoptera: Curculionidae) with much success. Farmers also use the carnivorous bighead ant, *Pheidole megacephala* F. (Hymenoptera: Formicidae) which is found in banana plantations to kill the sweet potato weevil. Korada (2010) described the Cuban farmers' technique of rolling these ants in banana leaves for transport to sweet potato fields. The whitefly *Bemisia tabaci* Gennadius (Homoptera: Aleyrodidae) which is a pest of a range of crop plants is controlled by farmers who spray a suspension of the fungus *Verticillium lecanii* on their crops, particularly tomatoes and beans (Nicholls et al. 2002).

Table 5.1: Management of field and storage pests in the Caribbean

Crop	Problem experienced	Pest	Local Protection Method(s)
Cabbage	Browning of leaves, blackened cabbage and bitten leaves	Bacterial attack, caterpillars and bachacs (leaf cutting ants)	Treat with garlic and pepper solution
Corn	Damage to young cobs and leaves	Armyworms	Place dry soil / ash in 'heart' of corn plant
Cowpea	Damaged leaves	Bachac	Spray with garlic and/or neem solution
Cucumber	Holes in fruits, insect damaged leaves	Worms, fruit flies	Spray with neem solution
Lettuce	Damaged leaves, holes in leaves	Bachac	Sprinkle with ash
Ochro/Okra	Deformed fruits and leaf spots	Caterpillars	Sprinkle with ash
Peppers	Fruits burnt or sunburn, leaves eaten by ants	Bachac and caterpillars	Sprinkle with ash
Pigeon pea	Damaged pods and ant infestation	Worms	Sprinkle with ash
Pumpkin	Mildew on leaves	Fungus	Remove leaves and sprinkle ash, spray with baking soda
Tomato	Stunted growth, curling leaves and damaged fruits	Fruit flies and caterpillars	Drench with marigold water / plant marigold around crop
Watermelon	Mildew, Insect bites	Bachac and ants	Spray with neem

Table 5.2: Insect and disease problems in crops and local crop protection methods used and knowledge source

Crop	Problem	Insect/ pathogen	Local protection method(s)
Root Crops	Wilting of tips; stunted growth	Shoot flies	Remove affected plants by hand and spray with soapy water
Cassava	Cutting of leaves and stalks	Bachac /Ants and mole cricket	Spray bed with neem solution. Drench roots with diluted urine late evening 3 times/week
Dasheen	Heart or middle of tuber eaten and holes on leaves	Beetle, Bachac, Ants	Spray with soapy water, black disinfectant and neem solution separately each time
Yam	Leaves of vine eaten	Bachac	Spray with neem and ash solution
Sweet potato	Stem, leaves and tubers eaten, leaving holes	Bachac	Spray separately each time with soapy water, black disinfectant and neem solution
	Hollowing of stems; Damage to tubers and leaves are eaten	Stem borer	Spray with soapy and garlic water
Vegetable crops	Sticky leaves and deformed fruits, brown marks on leaves	Aphid, Thrips	Spray with neem and garlic solution weekly. Spray marigold crushed in water and left to soak overnight
Watermelon	Drastic wilting of leaves and veins and eventual death of plant	Fungus (Bacterial wilt)	Drench with urine and sprinkle ashes on leaves
	'Bad eye' or 'Maljoe'		Place blue bottles in field on sticks
Pumpkin	Mildew on leaves; White powdery spots on leaves, gradually turn completely yellow and leaves fall off and vines eventually die	Fungus (Powdery mildew)	Remove leaves and sprinkle ashes on
Peppers	Wilted plants, stunted growth	Small worms (Nematodes)	Plant marigold as a cover crop between and around beds. Sprinkle ashes on bed and plants
	Wilted plants and extensive lower stem rot causing eventual death	Fungus (Southern blight)	Mulch with grass clippings. Rotate crops to avoid planting peppers in the same plot 2 years in a row
	Seedlings suddenly fall over and rot	Wilting (Damping off)	Do not over water plants especially at young stage
	Fruits burnt or sunburnt, leaves eaten by ants	Bachac and caterpillars	Sprinkle ashes

Crop	Problem	Insect/ pathogen	Local protection method(s)
Tomato	Large holes in leaves and young plants completely stripped	Fruit flies; Caterpillar	Kill when seen. Spray plants with crushed marigold in water after leaving to soak
	Curling and yellowing of leaves and immature fruits	Whiteflies	Plant marigold around beds and spray with soapy water. Spray with black disinfectant in late evenings
	Dark brown or black spots on the bottoms of immature fruits	Blossom end rot	Do not over water plants especially at young stage and drench soil with black disinfectant before planting
Melongene	Cutting of leaves and in some cases stalk by insects	Bachac, Ants, Mole cricket	Bed sprayed with neem solution. Drench roots with diluted urine late evening 3 times / week
	Lesions on leaves, wilting and eventual death	Blight	Sprinkle ashes on leaves and drench roots with diluted urine and other times with black disinfectant
Cabbage	Black rot on cabbage and in heart when cut	Fungus	Treat with garlic and pepper solution; Drench bed with black disinfectant before planting; Sprinkle ashes on bed
	Large holes on leaves	Caterpillar; Ants	Handpick and drop them in soap water. Plant marigold in between beds
Cucumber	Holes in fruits, leaves are damaged	Worms	Spray bed with neem, soapy or pepper solution; Sprinkle ashes on bed before planting
	Plant turns yellowish, looking like it was sprayed with herbicide, plant eventually wilts and dies	Fungus	Drench bed with black disinfectant before planting and sprinkle ashes on bed
Cowpea	Damaged leaves	Bachac	Spray with garlic solution along with neem solution
Lettuce and Pakchoi	Melting of leaves	Fungus	Drench soil before planting with black disinfectant
	Leaves curl with light brown discoloration along parts of the leaf	Aphids, Virus	Drench soil before planting with black disinfectant
	Damaged leaves, holes in leaves	Worms	Spray with neem and nutgrass root solution
Corn	Brownish spots on leaves	Fungus	Drench soil before planting with black disinfectant and urine. Use ashes on young leaves
	Heart of corn eaten	Worms	Use sand and ashes in heart of corn

Crop	Problem	Insect/ pathogen	Local protection method(s)
Tree crops	Root damage, tree collapsed and wilted leaves	Beetles and nematodes	Spread ashes around root of plant. Drench root with urine
Banana/plantain	Reduced plant growth, choking of the bunch in the trunk, yellow leaves and weak or dying suckers	Beetle	Drench root with black disinfectant. Drench root with urine. Spread ashes around roots
	Leaves dry out	Fungus (Panama wilt)	Drench roots with urine and sprinkle ashes around roots of plant. Cut down infected tree and burn it
Citrus	Curling of leaves; Brown spots on leaves	Aphids	Spray with soapy water and other times with neem solution
	Holes in fruits	Black bee	Spray with neem
	Fruits become damaged and fall off tree. Leaves eaten by insects and later become covered with ants and remain stunted	Bachac, biting ants	Spread soapy water around root and sprinkle ashes on leaves
Cocoa	Unevenness and premature ripening in both the young and mature pod	Cocoa pod borer	Spray trees with soapy water and neem solution
	Small, hard, dark spots on any part of the pod	Black pod	Drench around roots with urine
	Affects shoots, flowers and pods. Patches that give the appearance of uneven ripening	Fungus	Drench around trees with black disinfectant from early stage. Keep field clean by pruning trees and weeding around trees
Coconut	Leaves become red and fall off pre-maturely	Coconut beetle	Use table salt in "heart" of leaves

Table 5.3: Non-chemical methods used to prevent insects during post-harvest including storage

Crop	Initial treatment	Post-harvest protection
Cassava	Leave tubers on stem	Tubers should be stored in damp area for not more than 2 days.
Sweet potato	Clean to remove dirt	Keep in cool dry area and dust with ashes
Yam	Remove excessive dirt	Dust cut surfaces with ashes
Cocoa	Sweat beans and sundry then wash beans	Lemon juice can be added to protect beans

Table 5.4: Non-chemical storage of vegetative plant parts

Crop	Method used
Yams	Hang yams on tree in field till sprouts emerge. Store in cool area under tree
Potato	Slips or plant part should be stored in cool area, (e.g. in banana stool root)
Cassava	Cuttings are stored in upright position in cool, dry area at home or in field
Dasheen, tannia and eddoes	Cormels and heads are stored in moist area until needed
Corn	Shell and dry grains in sunlight. Remove unwanted spoilt grains. Store in bags using black pepper. Dry cobs are tied together and are hung over a fireside to be smoked. This protects corn from weevil attack.
Pigeon pea	Sun dry and shell pods. Store in cloth bags after dusting with ashes, clove and grounded bay leaves
Yams	Dusting - Dust top or head with ash and store in cool area

NATURAL CONTROL OF SELECTED INSECT PESTS

VEGETABLE CROPS

Diamondback moth (DBM)

Plutella xylostella L. (Lepidoptera:Plutellidae)

Main crops affected: *Brassica* spp. – Cabbage, broccoli, cauliflower, pak choi

Control measures:

Preventive practices:

- Control all whitetop (*Parthenium hysterophorus*) in area around the crop
- Scout field regularly (at least twice weekly) to look for incidence of pests
- Practise crop rotation. Avoid planting the same crop family for a second cycle

Cultural practices:

- Intercropping cabbage with tomato and the application of neem extracts has shown promising results (Shankar et al. 2007)
- Planting marigold (*Tagetes* spp.) as a trap crop has given 30–50 percent reduction of the larval population (Stoll 1988)

- Early morning overhead irrigation reduces egg laying and causes adults to fall to ground where they are consumed by predators (e.g. ants)
- Field sanitation – removal and destruction of crop residues reduce incidence of diamondback moth in subsequent crop

The use of insect repellent plants is also recommended (Stoll 1988). These include: *Annona* spp., Chilli, *Mammea americana*, Neem seed extracts, *Tephrosia candida* and tumeric. Other methods include the use of *Bacillus thuringiensis* and saturated green sticky traps (Hallett et al. 1995)

Leaf miner fly

Liriomyza sativae (Blanch.) and *Liriomyza trifolii* (Burgess) (Diptera:Agromyzidae)

Main crops affected: cabbage, cucumber, legumes, tomato

Control measures:

Preventive measures:

- Use non infested planting material
- Scout field regularly and remove and destroy infested plants and/or leaves immediately
- If possible, use resistant varieties
- Remove any plant debris at the end of the growing season

Natural enemies:

Parasitoids such as *Diglyphus minoeus* (Walker) (Hymenoptera:Eulophidae) and *Opius* sp. (Hymenoptera:Braconidae) can provide as much as 50–90 percent parasitism for these leafminers (Cock et. al. 1985). Use insect controlling plants/plant extracts such as neem, quassia and hot pepper. Aqueous quassia extract gave better control than the synthetic insecticide malathion (Pluke et al. 1999). Other methods of control include the yellow leafminer sticky trap and ash.

Whitefly

Bemisia tabaci Gennadius (Homoptera:Aleyrodidae)

Main crops affected: Tomato, sweet pepper, melongene, sweet potato, poinsettia, crucifers

Control measures:

Cultural practices:

- Use of disease free plant material as infected plants may spread viral diseases
- Encourage natural enemies (parasitoids – *Encarsia* spp. (Hymenoptera:Aphelinidae)

and *Eretmocerus* spp. (Hymenoptera: Aphelinidae) and predators – ladybird beetles, syrphid fly, lacewing insects).

- Entomopathogenic fungus, *Paecilomyces fumosoroseus* – kills the whitefly adults but has no effect on the plants (Matthew and Khan 2013)
- Use yellow sticky traps hung just above the crop canopy
- Other traditional methods (e.g. the use of kerosene-soap emulsion and milk powder spray to keep the adults from flying).
- Intercrop vegetable crops with corn (Venotola 2013)

ROOT CROPS

Sweet potato weevil

Cylas formicarius (Coleoptera: Curculionidae)

Main crop affected: Sweet potato

Control measures:

Preventive measures:

- Frequent scouting of fields for adult weevils and remove and destroy
- Planting in late rainy season, as practised in Kenya. Pest attack is high on the foliage before the onset of the dry season. The tubers begin to enlarge when it rains again, but few soil cracks are present. As a result, weevils cannot gain access to the tubers and their numbers diminish.

Cultural methods:

- Crop rotation or fallow to reduce the weevil population
- Manage host weeds belonging to the Morning Glory family
- Thick skinned, early maturing varieties and those which form tubers deeper in the soil should be planted
- Use clean, uninfested cuttings as planting materials to reduce incidence of pests (weevils, moths, diseases)
- Practise field sanitation by removal of crop residue as this reduces weevil populations
- Moulding vines fills cracks in the soil and prevents access to tubers by weevils
- Pheromone traps should be used for early detection and mating disruption
- Tubers for storage can be covered with a layer of sand (at least 5cm) or dusted with ash

FRUIT CROPS

Banana weevil

Cosmopolites sordidus (Germar)(Coleoptera: Curculionidae)

Main crops affected: Banana and plantain

Control measures:

Several natural enemies have been introduced into the Caribbean to control *C. sordidus* including *Plaesius javanus* Erichs (Coleoptera: Histeridae), *Dactylosternum hydrophiloides* (Macleay) (Coleoptera: Hydrophilidae) and *D. abdominale* (F.) (Coleoptera: Hydrophilidae) from South-East Asia and *Hololepta quadridentata* (F.) (Coleoptera: Histeridae) a native species of Trinidad (Cock et al. 1985). Entomopathogenic fungi such as *Metarhizium anisopliae* and *Beauveria bassiana* can also be used and provide some degree of control (Khan and Gangapersad 2001).

Cultural methods:

- Use of clean planting material (infestation drops from 24 percent to five percent)
- Cutting old pseudostems off at ground level
- Removal of old pseudostems at regular intervals reduces continuous breeding of the weevil
- Removal or destruction of stumps of wind-damaged plants
- Treatment of infested suckers with hot water
- Use pseudostem traps to collect then destroy adult weevils. Entomopathogenic fungi can be combined with these traps (Khan and Gangapersad 2001)

Pineapple mealybug

Dysmicoccus brevipes Cockerell (Hemiptera:Pseudococcidae)

Main crops affected: pineapple, sugarcane, coffee, plantain

Control measures:

A number of natural enemies attack this mealybug in the Caribbean including *Hambletonia pseudococcinna* Compere (Hymenoptera: Encyrtidae) which is found in several islands of the Lesser Antilles (Cock et al. 1985). Management of this pest is essential not only due to crop losses as a result of direct feeding but also because of its ability to spread pathogens. This pineapple mealybug spreads the associated wilt viruses which have recently been detected in the Caribbean (Cuba) for the first time (Hernandez et al. 2010). A hot water treatment of pineapple crowns at 50°C for 30 minutes gave complete control of the

pineapple mealybug associated wilt virus and also allowed 100 percent plant survival (Ullman et al. 1993)

Cultural methods:

- Bait made of powdered skimmed milk, wheat flour, wheat middling and insecticide was attractive to ants tending pineapple mealybug. Death of ants after feeding on bait caused 75 percent reduction in mealybug population (Rai and Sinha 1980)
- Removal and burning of crop residues before replanting reduces ant and mealybug population in new crop

Fruit flies

Anastrepha spp. (Diptera:Tephritidae)

Main crops affected: guava, (*Psidium guajava* L.), sapodilla (*Manilkara zapota*), and numerous soft fruits

Control measures:

Management of *Anastrepha* spp. requires a multi-pronged approach (i.e. IPM). Several natural enemies have been introduced into the Caribbean for management of these fruit flies but limited success has been recorded (Cock et al. 1985).

Cultural methods:

- Regular collection and destruction of fallen fruits
- Bagging of individual fruits may be an option for small farms and backyard gardens
- Extracts from the plant, *Piper auritum* can kill 78 – 90 percent of larvae (Perales-Segovia et al. 1996)
- A fruit fly trap attractant was developed in Guyana for trapping sapodilla fruit fly *Anastrepha serpentina* (Pluke et al. 1999):
 - 2 litres of water
 - 20ml vanilla extract
 - 1 green, grated sapodilla
 - 30ml honey
 - 240ml diluted human or cattle urine

Box 5.1: Other pests and diseases which can be managed using some common insect repellent plants found throughout the Caribbean:

- Cowpea weevil (*Callosobruchus chinensis/maculatus*) – can be controlled by using custard apple, neem, Christmas bush (*Chromolaena odorata*) and marigold.
- Thrips (*Thrips palmi*) – can be controlled using fresh red chili, garlic, pepper, bitter gourd/carille (*Mormodica charantis*), custard apple, billy goat weed (*Ageratum conizyoides*) and Christmas bush.
- Damping off – moringa leaves and garlic can be useful
- Fusarium wilt – moringa root, celery and seed under leaf (*Phyllanthus niruri*) can be useful
- Fungi – can be controlled using aloe vera (*Aloe barbadensis*) and garlic (*Allium sativum*).
- Root rot – can be controlled using seed under leaf, citronella and eucalyptus.

PHYSICAL CONTROL OF PESTS

There are several ways in which a farmer can manage agricultural pests and diseases without relying on chemicals. The following is a list and brief description of some of these methods:

PREVENTION THROUGH GOOD SANITATION PRACTICES

Improving and changing the conditions of the garden area can make it difficult for pests to survive. This can be achieved through destruction of food sources and habitats and breeding areas for pests, controlling weeds, practising crop rotation, using companion crops that attract beneficial insects, proper water and fertilizer management and using plant species that are tolerant to pest and disease attack. Such an integrated crop management approach is considered as one of the easiest and cheapest methods that the farmer can adopt without the use of chemicals.

Box 5.2: Prevention and control methods for insects and diseases

For insect control:

- Regular field scouting is recommended to look for insect pests and infected plants. Where there are low cases of insect or disease incidence, remove pests manually from infested plants and burn to avoid further infestation and contamination. Spraying with concentrated lime water mixed at a ratio of one part per lime water to three parts water, or use 0.5 kg, plus 0.5 kg of ashes from hardwood trees mixed with 20 litres of water may also be useful. Mix together, filter and then spray over the collected, infested plants.
- Practise companion planting using plants such as marigolds, tomatoes and chive with vegetables. The smell of these plants serves to repel insects when their leaves are crushed.
- Use of colour and light to trap and trick insects. Insects can be attracted to various colours such as blue, red and yellow. Yellow sticky traps can be used to capture insects while insect-luring lights can be used using blue light. A simple insect-luring light can be made as follows:
 - Place a big bowl of water under a light source. Add petroleum oil to the water to entrap any fallen insects. If a blue light is not available, you can wrap the bulb with blue paper or tape. Take all necessary precautions.
- Use sulphur powder for mite outbreaks by diluting 75 ml in 20 litres of water. This solution can be sprayed over and under the leaves of infected plants. Diluted fermented cow urine can also be used as a substitute for sulphur sprays.

For disease control:

- Adjust soil pH before planting using dolomite, egg or sea shells or burned animal bones pounded and mixed into the soil. This will also help to reduce disease and water logging in the soil. For sandy soil, add 250 kg of dolomite mixture per acre (617 kg/ha); for loam soil, add 500 kg of dolomite mixture per acre (1,235 kg/ha) and for clay soil, add of dolomite mixture 700 kg per acre (1,729 kg/ha).
- Avoid application of too much nitrogen fertilizer as plants will grow too quickly, use too much water, and their cell walls will become susceptible to the penetration of fungi.
- Remove infected plants immediately when discovered and spray trees with fermented bio liquids such as compost teas.

Box 5.3: Advantages of natural plant insecticides

- There are about 2,500 different plants with insecticidal properties. Many of them contain potent substances such as alkaloids, ricin, capsaicin, rotenone, thiopene, terpenoids, phenols, azadirachtin, pyrethrum, nicotine, solanine, etc.
- Natural plant substances are usually safe and non-toxic to humans and animals.
- They do not leave any toxic residues.
- Chances of insect resistance are minimal compared to synthetic chemicals.
- They are cheap to produce and readily available or can be easily made by the user.
- They have huge economic potential and can be used in extract form.

Source: Tancho, 2013

SELECTED PLANTS USED TO CONTROL INSECT PESTS

There are several plants which may have natural pest repellent properties. The use of plant extracts is not new and extracted plant compounds such as rotenone, nicotine and pyrethrins have been used by small-scale subsistence and even commercial producers.

Collecting extracted substances from plant parts

There are a few things to consider before collecting parts of desired plants. The age of the plant will affect how much substances can be extracted. The time for collection is also very important because each substance will be available in varying amounts depending on the season and time of day. The effective substances originate from the plants' own biochemical processes and are stored in specific places as part of their own defense system. In some plants such as tobacco, it is found in the leaf. For peppers, it is located in the fruit. Neem and custard apples store their insecticidal substances in their seeds. Lemon grass provides the maximum effects at 7–11 months. Collection from leaves should be done during the day in dry weather. It is necessary, therefore, to know each type of plant and where their effective substances are stored in order to be able to collect them correctly for use against pests. For plants which contain volatile oil, such as basil and Christmas bush, the maximum amount can only be collected in the morning. In these plants, sunlight reduces the amount of volatile oil in the leaf. The most common extraction methods include: fermentation, steam distillation, compression and extraction using solvents. Table 5.5 offers some useful generalizations on the best time to harvest plants.

Table 5.5: Harvesting plant parts

Part of plant	Time to be harvested
Flower	When the flower starts to bloom
Fruit	Before the fruit becomes ripe and the substances transfer to the seeds
Seed	When fruit is fully ripe
Root / tuber	Start of flowering in winter and dry season
Peel	During summer or early in the rainy season before new leaves
Leaf	Daytime in dry weather
Leaf (Volatile oil)	Dawn

Source: Tancho, 2013

The following common plants found throughout the Caribbean have been reported as having pest repellent properties:

Ackee (*Blighia sapida*)

Family: Sapindaceae

Ethanol and acetone extracts of ackee were also recorded as repellent to three pests (Khan and Gumbs 2003) while extracts in hexane were toxic to the sweet potato weevil *C. elegantulus* (Wilson and Mansingh 2004). Wilson (1993) also concluded that ethanolic extract from ackee gave better control of diamondback moth 2 weeks after field application compared to neem extract.

Powdered seeds of ackee were toxic to three stored product pests – cowpea beetle *Callosobruchus maculatus* F. (Coleoptera:Bruchidae), Rusty grain beetle *Cryptolestes ferrugineus* (Stephens) (Coleoptera: Cucujidae) and maize weevil *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) (Khan et al. 2002).

Annona – soursop (*Annona muritica*), sweetsop (*Annona squamosa*), custard apple (*Annona reticulata*)

Family: Annonaceae

The unripe fruit, seeds, leaves and roots have been found to have potent ovicidal, insecticidal, repellent and nematocidal properties. Compounds isolated from *A. montana* have been shown to possess powerful antifeedant activity (Mootoo et al. 2000). The active chemical is called, acetogenin.

Grind seeds into powder and soak one kg of the powder in 10 litres of water, leaving undisturbed for 12–24 hours. Filter with a thin white cloth.

Before using, mix the solution with a sticking agent such as powdered detergent or dishwashing liquid at a rate of one tbsp. detergent to ten litres of solution.

The dark green leaves can be ground or crushed before soaking in water for 24 hours. Mix the solution before using and add a sticking agent at the same rate as above.

Powdered seeds of custard apple have also been used to control lice (Ayensu 1981), aphids, diamond back moth caterpillar, leafhoppers and various types of grasshoppers.

Basil – *Sweet basil (Ocimum basilicum) and Holy basil or Tulsi (Ocimum sanctum)*

Family: Lamiaceae

The plants have insecticidal, fungicidal, repellent and molluscicidal properties. *O. sanctum* seeds are used as a mosquito larvicide. It can also be effective against the housefly larva and the sweet potato weevil (Sujatha et al. 1988). Essential oil can also be extracted from the leaves. About 20 mls of the essential oil of basil mixed into 1 litre of water can be sprayed onto vegetables to control pest and diseases.

Berry leaf – *Jamaican gooseberry (Phyllanthus acuminatus)*

Family: Phyllanthaceae

A powder of its roots is used to control melonworm (*Diaphania hyalinata*) and diamondback moth (*P. xylostella*) (Pluke et al. 1999).

Black pepper (*Piper nigrum*)

Family: Piperaceae

Contains essential oils that repel insects.

Grind dried black pepper fruit then soak in rice whisky. Filter out the solids and spray the remaining solution. Effective against aphids and the cabbage-heart caterpillar (Tancho 2013).

Castor oil plant (*Ricinus communis*)

Family: Euphorbiaceae

Can be grown around the garden to keep away pests. The active chemical is called ricin. The leaves and seeds are effective against termites, crickets, nematodes and rats.

Chilli – *pepper, hot pepper* (*Capsicum frutescens*)

Family: Solanaceae

The skin and seeds of ripe fruits contain active insecticidal substances. Its actions include – stomach poison, repellent, antifeedant, fumigant and viroid. It is listed as being effective against ants, aphids, rice weevil and other beetles (Pluke et al. 1999). Amoabeng et al., (2013) conclude that field application of *C. frutescens* extracts provided better control of diamondback moth than some synthetic insecticides and also had less detrimental effects on natural enemies including ladybird beetles, spiders and wasps which continued to feed on the pest after application

Christmas bush (*Chromolaena odorata*)

Family: Asteraceae

Contains eupatal which is a natural insecticide.

Grind the dried leaves and stems into a powder and soak 400g of the powder in eight litres of water. Shake the mixture thoroughly before filtering. Spray the solution every seven days for a total of six applications (Tanco 2013).

Can be used for the control of aphids, common cutworm, diamondback moth and grain storage pests.

Eucalyptus (*Eucalyptus spp.*)

Family: Myrtaceae

Contains essential oils that effectively repel and control many insects.

Combine one kg of eucalyptus leaves with two tbsp. of ground ginger. Boil the leaves for 15–20 mins and filter. The stock solution can be used with other sprays (Tanco 2013).

Effective against diamondback moth, common cutworm and grain storage pests.

Fever grass – *lemongrass* (*Cymbopogon citratus*)

Family: Poaceae

Lemongrass extracts have been reported to possess powerful insecticidal and repellent properties (Anon 2014).

Grind the dried lemongrass and soak in water (400gm ground leaves to eight litres of water) for 24 hours.

The ground dried lemongrass can be blended with mung bean.

Both the oil and dry powder is efficient at protecting stored seeds against the cowpea beetle *Callosobruchus maculatus* by inhibiting oviposition on the seeds (Ketoh et al. 2000).

Extracts from lemongrass were also toxic and repellent to the maize weevil *S. zeamais* (Ramlal 2014). Also effective against the common cutworm and diamondback moth.

Garlic (*Allium sativum*)

Family: Amaryllidaceae

Alicin, which is a compound derived from garlic is effective against many types of fungi and can also be used as an insecticide and repellent as it inhibits feeding.

To 150 gms of crushed garlic, add half litre of hot water and leave undisturbed for 24 hours before filtering. Add another four litres of water and mix with a sticking agent such as dishwashing liquid before spray. Spray at least twice a day.

Effective against beetles, aphids, nematodes, white flies, downy mildew, leaf rusts, fleas and ticks (Tancho 2013).

Gliricidia (*Gliricidia sepium*)

Family: Fabaceae

The active ingredient in gliricidia is coumarin and rotenone. The leaves, bark and fruit of this plant all have insecticidal properties.

Leaf extracts of *G. sepium* in ethanol were shown to cause high mortality and reduced egg laying in the carmine spider mite *Tetranychus cinnabarinus* (Sivira et al. 2011). The smoke from burning leaves and branches of *G. sepium* is used in the Philippines as a repellent against blood feeding insects (Obico and Ragragio 2014).

Lantana (*Lantana camara*)

Family: Verbenaceae

Contains lantadine and lantamine which is toxic to the nervous system of insects

One kg of the lantana seeds can be ground and then soaked in two litres of water and left for 24 hours. After filtering, spray as an insecticide.

Can be used for the control of the army worm in corn. It also repels insects that lay eggs in vegetable gardens (Tancho 2013).

Mammey (*Mammea Americana*)

Family: Guttifereae

The seeds of the mammey can be finely ground and four kgs dissolved in 400 litres of soapy water or kerosene. This can be used to control caterpillars.

225 gms of the leaves of the mammey can be soaked in 1.2 litres of kerosene. This is effective against cockroaches, houseflies and ants.

Powder from the dried seeds has insecticidal properties with stomach poison, contact and repellent activity against aphids, diamondback moth, beetles, banana borer weevil and acoushi ants (*Atta cephalotes*). Dusting cabbage with the dry powder early in the morning to allow it to stick on the leaves (wet with dew) and effects good control of diamondback moth (Pluke et al. 1999). The powder from dried leaves of mammey gave 59 percent and 75 percent control of *S. frugiperda* and *D. hyalinata* respectively (Morton 1987). Wrapping young tomato plant stems with a mammey leaf and then planting so that half is covered with soil and the other half exposed above ground prevents damage by mole crickets (Morton 1987).

Marigold (*Tagetes spp.*)

Family: Compositae

The active chemical is called thiopene. 500 gms of marigold leaves can be boiled in four litres of water. Allow to cool then filter. Add another four litres of water and spray onto infested plants.

The extracts of the leaves are effective against the diamondback moth, nematodes, beetles, aphids and cabbage heart caterpillar (Tanco 2013).

Milk bush (*Euphorbia tirucalli*)

Family: Euphorbiaceae

Stems of the milk bush can be crushed and about 1 kilogram can be soaked in 15–20 litres of water. Leave for a day. Filter out the liquid and spray onto infested plants.

The crushed stem can be used to control cowpea weevils, common cutworms, aphids and grain storage pests (Tanco 2013).

Moringa (*Moringa oleifera*)

Family: Moringaceae

Contains substances that kills fungi and bacteria. Both seeds and leaves are effective.

Mix moringa leaves with soil being prepared for sowing seeds; leave undisturbed for one week.

Effective against root and stem rot of cucurbits, tomato fruit rot, and damping off.

Neem (*Azadiractha indica*)

Family: Meliceae

The leaves and seeds of the neem tree are known to possess insecticidal compounds, some of which is commercially available. The active chemical is called azadirachtin.

Grind the dried seeds and soak in the water in the proportion of one kg of neem seed to 20 litres of water. After leaving undisturbed for one to two days, spray onto infested crops.

For dried neem fruit, soak one kg in ten litres of water.

Aqueous extracts of either the seed or leaves provide good control of both lepidopterous and coleopterous larvae as well as leafminers, aphids and grasshoppers (Pluke et al. 1999). Dried seed powder can also be used effectively to control stored product insects.

Nutmeg (*Myristica fragrans*)

Family: Myristicaceae

Nutmeg oil extract was both toxic and repellent to adult maize weevils *S. zeamais* (Ramlal 2014). Nutmeg oil has strong insect feeding deterrent properties against stored product insects (Parthasarathy et al. 2008).

Papaya (*Carica papaya*)

Family: Caricaceae

The leaves of the papaya can be finely chopped and about one kg placed in one litre of water. Separate the liquid by filtering with a cloth. Combine the liquid with four litres of water and then mix in 16 gms of detergent and spray onto infected plant.

Can be used to manage rusts and powdery mildew (Tancho 2013).

Physic nut (*Jatropha curcas*)

Family: Euphorbiaceae

The whole plant, particularly the seeds have insecticidal properties.

Both the dried powder and oil from the seeds of physic nut are known to be insecticidal. The oil has been recorded as having low environmental persistence and non-toxic to beneficial insects (Pluke et al. 1999). Physic nut seed oil reduced the hatching of eggs of the sugarcane borer *Diatraea saccharalis* Fab. (Lepidoptera:Crambidae) (Oliveira et al. 2013).

Pursley (*Portulaca oleracea*)

Family: Portulacaceae

Pursley has been reported to contain insecticidal compounds which are toxic to diamondback moth (Grainge and Ahmed 1988; Iwu 1993).

Quassia – quassia, bitter ash (*Quassia amara*)

Family: Simaroubaceae

Contains quassin, a natural insecticide.

Boil small pieces of the plant (500 gms) in 10 litres of water and leave undisturbed for 24 hours. Filter out the solids before dissolving two kgs of soap in three litres water to the solution. Add more water for a total of 100 litres.

The bark of bitter ash is known to have insecticidal and nematocidal activity. Bark extract acts as a contact insecticide, a stomach poison and also systemically and hence can be applied to plant roots for protection against sucking and chewing insect pests. Aqueous extracts applied to plants also deter insects (e.g. sweet potato whitefly *B. tabaci*) from feeding on the treated plant parts Flores et al. (2008). Bitter ash extracts have also been used in organic agriculture (Psota et al. 2010). Can be used to control aphids, diamondback moth, leafminers, mites and cucumber worms (Tancho 2013).

Tomato (*Solanum lycopersicum*)

Family: Solanaceae

Repels insects and inhibits feeding and egg laying.

Grind three gms of fresh tomato leaves and add five litres of water or grind 50 gms of fresh leaves and add to two litres of warm/hot water. Allow to soak for five hours then filter with a thin white cloth. Add sticker to mixture such as dishwashing liquid at a rate of one tbsps per ten litres water. Spray every two days in the evening.

Effective against the flea beetle (*Phyllotreta sinuata*), stem borers, houseflies, the diamondback moth, nematodes, cockroaches and red mites (Tancho 2013).

Vervine (*Stachytarpheta jamaicensis*)

Family: Verbanaceae

Ethanollic extracts from the leaves of *S. jamaicensis* had antifeedant effects against the fall armyworm *Spodoptera frugiperda* in Trinidad (Moustache and Khan, 2012) while extracts from the leaves of another species (*S. mutabilis*) in Guyana exhibited antifeedant effects against locusts and armyworms (Pluke et al. 1999).

Wild chataigne (*Pachira insignis*)

Family: Bombacaceae

Used for trapping the cocoa beetle *Steirastoma breve*. Branches are cut and placed in wire baskets, beetles are attracted to it to lay eggs. Branches are burned every few days and new traps set up (Hall 1914).

Wild coffee (*Cassia occidentalis*)

Family: Leguminosae

Leaves of wild coffee are used as a seed protectant against the cowpea beetle *C. maculatus* (Lienard et al. 1993) and also against termites which can be a serious problem in agriculture (Abdullah et al. 2012). Leaf extracts were also toxic to mosquito (*Aedes aegypti*) larvae (Chariandy et al. 1999).

Box 5.4: Other plants with naturally-occurring insect repellent properties

- Amaranthus, bhaji or callaloo (*Amaranthus* spp. - stems, flowers and leaves used),
- Annatto (*Bixa oreliana* – fruits and roots used),
- Bougainvillea (*Bougainvillea glabra* – leaves and flowers used),
- Cashew (*Anacardium occidentale* – leaves, seeds, seed oil used),
- Fish bean (*Tephrosia* spp. – whole plant, leaves, twigs and roots contain rotenone),
- Goat weed (*Ageratum conyzoides* – all parts of plant used),
- Jimson weed (*Datura stramonium* – whole plant, especially leaves used),
- Oleander (*Nerium oleander* – all parts of plant used),
- Onion (*Allium cepa* – bulb and leaves used),
- Pyrethrum (*Chrysanthemum cinerariaefolium* – flowers contain pyrethrum),
- Soyabean (*Glycine max* – stems used),
- Sweet potato (*Ipomoea batatas* – leaves and starch water used),
- Tamarind (*Tamarindus indica* – leaves and fruit used),
- Tobacco (*Nicotiana tabacum* – leaves and stems contain nicotine).

CONCLUSION

A combination of local and natural crop protection measures blended with certain aspects of modern agriculture is recommended to achieve sustainable agriculture practices. In order to ensure the adoption and continuity of some of these ecologically friendly practices, researchers, scientists and extension workers must ensure that this knowledge is disseminated effectively. The focus on one or two plant species used as pesticides could be expanded since there are diverse plant species that possess pesticidal properties. This will require further validation trials and basic research. To avoid ad hoc application of non-chemical pesticides, appropriate testing of materials and ingredients should be done to avoid toxicity. This would ensure that the correct amounts are applied to crop and insect pests. The effectiveness of each application of pesticide due to its active ingredients on each specific type of insect should be tested and documented. This would result in grading of the various formulations according to strength. Information on non-chemical crop protection methods must be reliable and made easily available through workshops, books, journals, media and the internet. The adoption of these indigenous and natural crop protection practices should be encouraged and considered a priority in the region in order to curb the heavy dependence on synthetic pesticides.

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Sustainable Water Management Practices for Food Production in the Caribbean

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INTRODUCTION

Water is one of the most valuable resources on the planet earth. Three-fourths of earth's surface is covered by water, which constitutes 60-70 % of the weight of the living world. Water is used for many purposes including drinking, domestic and industrial use, and agricultural production. Water also determines the density and function of vegetation and biodiversity richness in an ecosystem, making it ecohydrologically important. It is implicated in many biogeochemical processes exerting a strong control on microbial activity, nitrogen mineralization, and biogeochemical cycling of nitrogen and carbon (Robinson et al. 2008). Water is also important for many physical and chemical weathering processes on earth and transportation of large amounts of sediments. As a fundamental raw material in photosynthesis, it is central to acid-base neutrality and enzyme function. Therefore, the state of this resource, with respect to its quality, and availability (i.e. whether there is 'too much' or 'too little'), can have economical, biological and ecological implications.

In spite of the large volume of water on the planet earth, only three percent is fresh water and 0.06 percent easily accessible for human use (Ekwue, Dhanraj and Birch 2013). Professor Henry Lin of Pennsylvania State University (Schneider 2013) in describing the dwindling nature of this important resource, asserted that 'if a beer barrel – 13 gallons – represents all of the water on earth, the total amount of fresh water is just ten drops. Not only that, but out of that ten drops, only one-tenth of one drop is surface water that we can see and directly access' (Schneider 2013). With the expected increase in the world's population to nine billion people by the year 2050, demand for food will increase. In order to meet the food demand for this teeming population, food production will have to increase correspondingly by

about 70 percent (Schneider 2013). Presently, irrigated agriculture which uses 70 percent of fresh water produces 40 percent of the world's food. With an increasing demand for food, coupled with competing demands from industries, urbanization, recreation, continuing pollution and climate change, the world's water resources will become even more strained (Schneider 2013). This situation will have a more precarious impact where land is limited as in the case of small island developing states (SIDS) like those of the Caribbean region, which are already densely populated, limited in reservoir storage facilities, vulnerable to climate change impact, and with agriculture that is estimated to utilize 60–70 percent of the total fresh water resources (Farrell, Nurse and Moseley 2007).

The quality and quantity of available water resources in the Caribbean are already being strained. Climate change is having a strong impact on the water resources. Intense rainstorm activities have increased over the years resulting in colossal runoff generation and flooding problems, causing a decrease in groundwater recharge and aquifer depletion. Concomitantly, sea level rise due to climate change has increased the proneness of lowlands to flooding and salinization, and saltwater intrusion into coastal aquifers. In addition to climate change impacts, population growth and urbanization have put more strain on the existing water resources through agricultural chemicals and human waste which pollute both aquifers and surface water. There is also the problem of over abstraction, which depletes aquifers and changes in land use, which increases runoff and decreases recharge to aquifers. Soils in the Caribbean, except in islands with volcanic soils, are mostly medium to heavy in texture, with impeded drainage. Most of the soils have a restrictive layer that can easily develop a perched water table with attendant waterlogging issues that significantly affect plant water relations. The soils can therefore be exposed to prolonged waterlogging and high water tables under intense rainfall. This lowers the productive capacity of the land for food production. Sustainable water management must therefore address water issues related to its scarcity and excess.

As Caribbean nations seek to attain food security, therefore, adequate water of good quality is required to maximise both yield and quality. Consequently, there is heavy reliance on fresh water for domestic, agricultural and commercial uses. However, sustainable management of water resources has not been given the priority it deserves in many Caribbean islands. Unsustainable use of water resources will intensify our water woes leading to food insecurity and slows the advancement of the Caribbean region towards meeting poverty and hunger reduction targets. The following economic, social and environmental impacts have been identified as repercussions for failure to sustainably use and manage our water resources (Taylor, Stephenson and Rankine 2011):

- Degradation of water quality which accentuates water scarcity
- Overburdening of the sensitive environmental and human systems
- Increasing frequency and risks of soil erosion, coastal erosion, flooding and inundation
- Dwindling safety in potable water and other water supplies
- Reduction in subsistence and commercial agricultural production of such crops as vegetables, bananas, and coconut with attendant food insecurity issues
- Increasing dry spells and sea level rise, intensifying the risk of saline water intrusion into river estuaries and coastal aquifers compromising both the quality of surface and groundwater sources
- Increased risk of dengue fever, malaria, cholera, typhoid fever and diarrhoeal diseases
- Increasing human conflicts and sufferings.

Therefore to achieve a sustainable functioning environment and a food secure Caribbean region, appropriate and sustainable water management practices must be an integral part of the way we use our water resources. Adopting sustainable water management practices will assist in alleviating the economic, social and environmental impacts listed above and will have far reaching benefits to cope with the myriads of constraints that are inimical to achieving food security in the Caribbean region.

CARIBBEAN CLIMATE AND WEATHER

The Caribbean region is essentially characterized by a humid tropical climate. Rainfall is almost bimodal with two distinct seasons; a dry season from January to May and a wet season from June to December. The rainy season coincides with the hurricane season of June to November, with peak rainfall occurring at the start and end of this season (Cashman, Nurse and John 2010). The mean annual rainfall is large and varies from 1127mm in Antigua and Barbuda to 4500mm in Dominica (Ekwue et al. 2013). Roughly 20 percent to 25 percent of the rainfall received in the Caribbean falls in the dry season, with 75–80 percent falling in the wet season months. The major water management issue in the Caribbean, therefore, is really how to cope with excess water in the wet season to ensure adequate supply all-year round (Ekwue et al. 2013). Even though the Caribbean does not have a steady spatio-temporal rainfall trend, projections reveal that there will be more pronounced dry days and fewer successive wet days, which will become more intense. The annual precipitation,

however, is not expected to change drastically; day and night time temperatures are however expected to increase.

The hydrological cycle inextricably links climate to water resources. It defines water transfer from bodies of water to the land for storage. Essentially it involves the movement of water from different reservoirs by the physical processes of evaporation, condensation, precipitation, infiltration, run-off and sub-surface flow. The following equations (1 and 2 respectively) are used to calculate the water balance for ground water and surface water respectively:

$$\Delta GW = P - ET - RO + GW_i - GW_o \quad (1)$$

$$\Delta SW = P - ET + SW_i - SW_o + G_i - G_o \quad (2)$$

P is precipitation in the form of rain, ET is evapotranspiration, RO is surface water runoff, GW_i and GW_o are groundwater inflows into and groundwater outflows from the system respectively and ΔGW represents change in subsurface storage. ΔSW represents the change in surface water storage, SW_i represents the surface water inflows into the system, SW_o represents surface water outflows from the system, G_i represents groundwater inflows into the system and G_o represents outflows from the system to the groundwater system.

Water resources management is strongly influenced by the water balance equation, which in turn is determined by the impact of climate on the hydrological cycle. This is shown by the fact that the interactions between the different variables in the water balance equation can be very intricate and are largely dependent on climate. For instance, temperature and humidity can affect water loss via evaporation and transpiration, while rainfall intensity can affect surface run-off.

Climate and weather have many significant impacts on food production within the region. Plant growth and thus yields in the Caribbean are a consequence of the climate experienced in the region. Temperature, precipitation, soil moisture availability, humidity, radiation intensity, day length and wind all vary with latitude. The atmospheric conditions experienced in the region are therefore an expression of our unique location in the world. Climate can also have an effect on livestock. Increases in temperature can cause heat stress to animals thus reducing productivity, increasing animal diseases and altering the quality of food. The increase in invasive species of weeds can also be an effect of climate and weather patterns. An increase in temperature and precipitation can favour one species of plant over the next causing certain species of weeds to out-compete agricultural crops for limited resources thereby reducing crop yield and productivity. Pests and diseases also respond to increased temperature and precipitation favourably, something which may influence their distribution and development. Humidity and evaporation can also play a role in increasing

some pest and disease activity. Most processes that occur in the soil are largely influenced by temperature and precipitation and changes in CO₂. These can affect soil development and therefore determine its characteristics.

WATER RESOURCES IN THE CARIBBEAN

‘Water is not a commercial product like any other but, rather, a heritage which must be protected, defended and treated as such’ (Water Framework Directive 2000). The total amount of water on the earth today is nearly the same as 1000 years ago. However, threats of water crisis continue to loom on us. Billions of people lack basic water services, and millions die each year from water-related diseases. This is partly due to the increasing unsustainable use of water resources that degrades the quality of easily accessible fresh water converting it into forms that require expensive technological treatment for remediation.

The Caribbean region is endowed with an abundance of water resources (Table 6.1) so that the availability of fresh water should currently not be an issue. However, threats from population growth, unsustainable agricultural practices, and climate change have highlighted the issue of accentuated water insecurity in the Caribbean. Based on Table 6.1, the water resources in the Caribbean are adequate to meet the current water demand for domestic and industrial purposes, except in the low-lying more arid islands of Barbados, Antigua and Barbuda, the Bahamas, and the Virgin Islands, where surface free-flowing water is scarce. The limited data on water resources presented in the FAO Aquastat database (FAO 2013) indicate the critical role of rainfall in determining a nation’s water resource supply system. For instance, the lack of perennial rivers in the drier Caribbean islands of Barbados and Antigua and Barbuda as a result of mean annual rainfall that is <1500 mm, indicate that these islands are water scarce. Here, the recharge of ground water as the sole source of water supply by precipitation is critical or else precipitation is lost to the ocean. Therefore, the use of surface ponds and reservoirs as storage facilities is important in alleviating shortages. Sea water desalination has become an important source of water in these islands. Nonetheless, the increased frequency of intense weather conditions, sea level rise and population growth, with their associated decrease in ground water recharge, reduced water quality due to saline intrusion and pollution, pose a serious threat to the continuous supply of water in adequate amounts and quality from these ground water sources.

Caribbean countries such as Trinidad and Tobago, Dominica and Jamaica on the other hand, have mean annual rainfall values of > 2000 mm and a water resource supply that is well above the water scarce threshold. These islands have multiple water sources and their water withdrawal is below available resources. Increased water withdrawal via irrigated agriculture in some countries such as Guyana,

Table 6.1: Water resources in selected Caribbean countries and water supply situation

Country	Water Supply Situation
1. The Bahamas	In New Providence Island (with 67 percent of the population), water supply is from local groundwater and 30 percent of water barged from Andros Island, 75 km to the West. All water is from groundwater except small supplies from roof catchments and desalination of seawater. New Providence alone has a projected demand of 64,500 m ³ /d in 2000 but has only a safe yield of 9100 m ³ /d from its water sources, a depressing serious shortage of water. There are no major surface water sources because of the porous nature of the soil and rock. No major irrigation is carried out.
2. Barbados	Public water supply is from groundwater reservoirs. Water from well sources is either pumped directly to transmission and distribution mains or otherwise to 24 service reservoirs varying in capacity from 900 m ³ to 6800 m ³ . Irrigation water is provided in the public water supply system (23 percent). Shortage of water is envisaged in the near future, but measures are in place to prevent this.
3. Belize	Public water supply is obtained from 9 rivers, springs and wells. Surface water requires the removal of turbidity, tastes and odours through sedimentation, filtration and chlorination. The Department of Agriculture drills wells for agricultural use in farming communities, separate from the public water system. Enough water is available for the near future for irrigation and other purposes.
4. Dominica	Abundant rainfall, coupled with steep relief and valleys lead to abundant surface water for domestic, industrial and hydro-electricity. Surface water is collected in five new reservoirs constructed with welded steel. The capacity of developed water sources estimated at 45,500 m ³ /d, greatly exceeds the forecast demand of water up to the year 2005. Not enough water for irrigation.
5. Guyana	Public water supply is obtained from groundwater (84 percent) and surface water (16 percent). Quality of groundwater is good except for the relatively high iron content of 1.5 to 2.5 mg/L in sand aquifers. Treatment of surface water is necessary because of the high turbidity, colour, odours and tastes caused by decaying organic matter. Only 40 percent of produced water is treated. Supply is unreliable. 98 per cent of water is used for irrigation.

6. Jamaica	Public water is from surface (eight percent) and groundwater (92 percent) scattered in different parishes. An estimated 2,542,465 m ³ /d is withdrawn from developed sources. About 11.2 x 10 ⁶ m ³ /d of water is still available for further development. The quality of groundwater is good requiring only chlorination. Surface water is conventionally treated to remove turbidity, tastes, odours and hardness. No problem of water scarcity is envisaged in the near future. 74 percent of water use is for irrigation.
7. St. Kitts	Both surface water tapped from high elevations and ground aquifers (which occur in formations of volcanic origin) are used. There are 16 distribution reservoirs. Raw water quality of surface and groundwater is good. One third of water supply sources are treated by sedimentation, rapid sand filtration and chlorination. Developed water supply sources with a safe yield of 27,100 m ³ /d can meet local needs for the next ten to 15 years. Not enough water for irrigation.
8. St. Lucia	Water supply is drawn from 33 surface water sources, the most recent being the Roseau River on which a dam and a storage reservoir have been constructed to augment supplies to the Castries area. All supplies are disinfected but some require additional treatment through coagulation, sedimentation and sand filtration. Turbidity levels of water rise because of increased erosion in catchments as a result of removal of forest cover. Present water sources are enough for the forecasted future demand, but not for irrigation.
9. Suriname	Public water supply is from groundwater extracted from ten well fields in three major aquifers. Water is stored in reservoirs. Presence of carbon dioxide, iron, ammonia and chlorides from sand aquifers require treatment. Principal treatment methods are aeration, sand filtration and chlorination. Water is abundant for irrigation and other purposes.
10. Trinidad and Tobago	Water is supplied from surface sources (79 percent) and groundwater (21 percent). A total of 97 sources are involved. Caroni-Arena, Navet, Hollis and Oroupouche resources supply 64 percent of total production. The first three have earth dams and impounding reservoirs. There are 76 distribution reservoirs ranging in size from 45,500 m ³ /d to less than 45 m ³ /d. The Desalination Company of Trinidad and Tobago supplies 109,589 m ³ /d. The present safe yield of identified water supply sources will take care of the projected water demand. More land could be brought into irrigation if more water can be exploited.

Source: Ekwue (2010)

Belize, Jamaica and Trinidad and Tobago, however, indicate an increased demand on water resources. Consequently, shortfalls have been experienced during the dry season. Drought episodes were very severe in Trinidad and Tobago among other Caribbean countries in 2009 extending to 2010 (ODPM 2013). To sustain water supply, water for domestic, agricultural and alternative uses was regulated. The accompanying ills of the drought episode, such as forest fires, incidences of crop failure and flash flooding caused by rainfall events following the drought, were severe. Therefore whether too little or too much, the demand for water will increase, requiring us to sustainably manage water resources.

Water resources usually take three main forms in the Caribbean region; groundwater, surface water (rivers, springs, lakes, and reservoirs), and sea water. Ground and surface water are the primary sources used to meet public and industrial demands. Desalinization of sea water has, however, become an important supply of potable water to a number of Caribbean Islands (Table 6.1). Water resources may vary among islands depending on geology and topography. For instance, for the islands of Barbados and Antigua with calcareous geology, ground water is the principal natural source of water with desalination supplementing these natural sources.

Groundwater constitutes 30 percent of global fresh water stocks, making it by far the largest freshwater resource on earth other than water stored as ice. Groundwater resources are relatively clean, reliable and a cost-effective resource as a source of drinking water, for agricultural irrigation and for maintenance of surface water systems, biodiversity and habitats of sensitive ecosystems (Tharme 2003). Groundwater is water located beneath the earth's surface in aquifers. An aquifer is a layer of porous substrate that traps groundwater in amounts which can then be available to the population. Groundwater resources are an important source of water in the Caribbean, the quantity and quality of which are influenced by a number of factors, including: the location of the aquifer (coastal or inland), whether it's confined or unconfined, the size of the aquifer, the characteristics of the soil around the aquifer, the geology, climate change and variability. Caribbean islands, for example Barbados depend heavily on groundwater for their national supply (Table 6.1).

Surface water resources in the Caribbean region take the form of rivers, small lakes and small impoundments. This water resource is the primary source of potable water in most Caribbean countries and is an important component of a nation's water supply system. It is influenced by precipitation, run-off, evaporation and exchanges with the underlying groundwater system. Countries such as St. Vincent, St. Lucia, Dominica, and Trinidad and Tobago all rely on surface water resources to meet the national demand (Table 6.1).

Saline bodies of water through the process of desalinization contribute to the water resources of the Caribbean region. Desalinization is the process where salt and other minerals

are removed from saline water. It is considered to be one of the few rainfall independent water resources. Salt water is desalinated to produce fresh water for human consumption or irrigation. In Trinidad and Tobago, desalination plants are used to provide fresh water suitable for industrial use as a good alternative of supplementing the country's supply of fresh water leaving more naturally-occurring water for domestic purposes.

ROLE OF SOIL WATER

Soil water is the amount of water that is stored in the soil from rainfall after losses via evapotranspiration, runoff and deep drainage. Soil water is an important water resource particularly because of its role in the ecosystem, the hydrological cycle and in modulating other critical elements of the hydrological cycle. Ecohydrologically, soil water is a vital ecosystem resource that provides the transpiration water needs of plants. It controls the structure and function of vegetation, and diversity in ecosystems. In spite of its overall small amount (~0.05 percent) in the global hydrological cycle, it plays the vital function of regulating the global energy balance and the distribution of precipitation. Soil water governs microbial activity affecting vital biogeochemical processes such as nitrification and CO₂ production via respiration (Robinson et al. 2008).

Soil water is important in determining the profile storage for determining antecedent conditions, thereby controlling rainfall-runoff response in systems where saturation excess runoff dominates (Robinson et al. 2008). Soil water performs a critical hydrological role in an ecosystem by controlling infiltration and water recharge to aquifers. By influencing infiltration, runoff generation, evaporation and exchanges with the underlying groundwater system, it determines the quantity and quality of both surface and groundwater.

Soil water can be expressed as the soil water content (equation 3) on a mass (gravimetric water content) or volume basis (volumetric water content).

- Gravimetric water content (θ_g) is the ratio of the mass of water (M_w) relative to the dry mass of soil (M_s):

$$\theta_g = M_w / M_s \quad (3)$$

or, volume basis (volumetric water content)

- Volumetric water content (θ_v) is the ratio of the volume of water (V_w) relative to the total volume of soil (V_t):

$$\theta_v = V_w / V_t \quad (3)$$

$V_t = V_a + V_w + V_s$; $V_t = V_f + V_s$ since $V_f = V_a + V_w$, indicating that air and water in the soil occupy the soil pores.

Where V_a is the volume of air, V_s is the volume of solid particles and V_f is the volume of pores.

To fully characterise soil water, however, the amount of water in the soil (soil water content) and the matric potential (the force by which water is held in the soil matrix) are key factors. Both matric potential and soil water content are related to each other via a function referred to as the soil water characteristic. The status of soil water determined by soil water content and matric potential affect among other things the water available for plant use, rate of exchange between liquid and gaseous phases, the hydraulic conductivity in the soil and exchange between the soil water and groundwater.

Available soil water is used by plant for growth and development. Under drought conditions there is less available water for plants, which results in reduced productivity. Under intense rainfall, soils may become waterlogged resulting in transient low aeration. Also soil aggregates are degraded resulting in high runoff generation and erosion reducing the productivity of agricultural crops (Wuddivira, Ekwue and Stone 2010). Consequently, soil and water management practices are required to maintain this pool of water for sustainable food production in the Caribbean.

VULNERABILITY OF THE REGION TO WATER PROBLEMS

The Caribbean region is extremely vulnerable to water scarcity. Too much or too little rainfall can pose a serious effect on surface and ground water resources in the region. Increased rainfall intensity can result in increased surface runoff reducing recharge into aquifers, while, a reduced rainfall amount coupled with increased temperatures and evapotranspiration rates reduces soil moisture, infiltration and aquifer recharge. It has been shown that in the tropics, approximately 90 percent of net radiation produces evaporation over the oceans (Budyko 1974). Net radiation over the continents heats the surface driving evaporation of water from surfaces of water bodies, soil surfaces and providing energy to plants to remove water from soils. Inconsistent rainfall patterns coupled with high evapotranspiration rates create a water deficit within the region. This occurs especially during the dry season.

With the expected impacts of climate change, decreases in crop yields are anticipated with reductions in surface water causing less water to become available for irrigation. Prolonged high temperatures can also cause cracking in heavy clay soils which can also cause soil loss. Higher ocean levels will lead to salt water intrusion in groundwater supplies, threatening the quality and quantity of freshwater access to large populations. Saline water intrusion percolating through underground channels can affect the quality of fresh water in aquifers.

Saline water intrusion usually occurs as a result of sea level rise, which is a consequence of climate change and can be devastating to a country's economy, as a substantial portion of most islands' economic activity occurs a few kilometres inland. Saline water intrusion is already a problem in many countries including small islands in the Pacific and Indian Oceans and the Caribbean Sea.

Increased rainfall intensity and poor irrigation practices which characterize the Caribbean region can also cause excess water to accumulate in the root zone, causing waterlogging damage and a decline in the vigour and productivity of crops. This often occurs in soils with poor natural drainage caused by restricted layers beneath the root zone. Additionally, soils found in low elevations and flat landscapes are prone to excess water accumulation in the root zone. Therefore, effective water management should include the drainage of the excess soil water from the root zone in poorly drained soils and using appropriate water conservation measures to protect water resources from pollution and loss of water from the root zone.

SUSTAINABLE WATER MANAGEMENT PRACTICES IN THE CARIBBEAN

Water is one of life's most valuable resources. As such, responsible and efficient water management practices are mandatory to alleviate the increasing pressures on our water resources. One significant way to reduce the threats that water insecurity presents in the Caribbean is through an integrated water management plan. This plan involves differentiating water into different shades (blue, green and grey) and ranking its importance for human use. Proper management that involves the use of blue, green and grey water can improve water security in the region. As we look for new ways of preserving water for future generations, these three categories of water when used in an integrated management plan can lower energy costs, recycle nutrients and increase water security. They are:

- i. Blue water: refers to surface and groundwater in lakes, rivers, reservoirs and aquifers. In terms of importance to humans, blue water is the most vital for drinking purposes, water for homes and businesses and for irrigation. Agricultural irrigation uses 70 percent of the blue water in the world. In the Caribbean, the primary source of blue water is precipitation which feeds all sources of ground and surface water resources. An increasing demand for food results in a heavy dependence on blue water. This situation is further worsened by over-abstraction and increased discharge of pollutants into groundwater and surface water resources thereby decreasing the fresh water quality and quantity in the region's watersheds and coastal zones. Urban expansion that results in paving of the ground surface also

affects the recharge of blue water and replenishment of ground water supplies. Pollution degrades the quality of surface and groundwater resources and climate change in the form of flash floods or droughts can also threaten both water and food security within the region. Water management that is sustainable must therefore employ practices that increase the storage of blue water, protect blue water from pollutants, increase groundwater recharge and increase water security by integrating green and grey water resources into the water supply chain. Some of the practices are discussed below.

- ii. Green water: this is the water available in the soil for plants and soil micro-organisms. 90 percent of the water used by plants is green water. Green water sustains terrestrial ecosystems. Through the processes of transpiration, evaporation and surface run-off, green water is lost. Green water, however, is only considered productive for plants when it increases plant growth and crop yield. While only 15–30 percent of water is used for transpiration, a greater amount is lost (30–50 percent) via evaporation and 10–25 percent as run-off. Sustainable water management to prevent green water loss must therefore include soil and water conservation practices. Increasing plant water use efficiency can also help reduce water loss by increasing the productive use of green water, decreasing evaporation and increasing the rate of transpiration. By better utilizing available water, resources can be secured for increased crop production thereby reducing the strain on blue water. Sustainable soil water conservation practices that minimize soil water loss are discussed in the following section.
- iii. Grey water: can be described as treated wastewater and may contain impurities. It is used mainly for cities, households and industries. Waste water is largely produced by households and industries. The amount of waste water increases as the population grows; according to United States Environmental Protection Agency (USEPA), in 2025 wastewater inflows can amount to 52 trillion gallons per day (Schneider 2013). The use of grey water saves blue water and creates more green water for plants as well as providing other benefits such as nutrient recycling. Great care, however, is needed when using grey water to avoid salinization or other environmental problems. Permits regulating the use of grey water are therefore necessary to avoid environmental degradation. Sustainable practices will involve encouraging household water conservation by using grey water for washing, bathing, to water gardens and for livestock purposes.

RAINWATER HARVESTING AND STORAGE

Harvesting and storage of rainwater is an important practice which ensures water security particularly in the Caribbean region where there is an abundance of rainfall but concentrated between June to December. Rainwater harvesting can be described as the accumulation and deposition of rainwater before it reaches aquifers or other forms of ground and surface storage. Some of its uses within the Caribbean generally include water for plants, livestock, irrigation, drinking water. Efficient harvesting and storage of rainwater is a sustainable water management practice that provides an independent water supply that often supplements the main supply. This practice should be promoted in the Caribbean to augment existing supplies. The advantages of rain water harvesting is that it can provide water during periods of dry spells, reduce flooding in low lying areas, replenish groundwater and surface water storage, and is an excellent source of uncontaminated water that does not contain fluoride, chlorine or dissolved salts, minerals and chemicals (CEHI 2009).

Within the Caribbean, rainwater harvesting is mostly done through the roof catchment, where the size of the roof and tank must be large enough to maintain adequate flow and storage. The size of the rainwater system is usually set up to meet the individual farmer's demand or household demand throughout the dry season. Apart from rooftop harvesting, the use of contour bunding, gully plugging, and check dams and dykes to catch rainwater can also be efficient ways of sustainable water management. In many of the drier Caribbean islands such as the Grenadines, the Virgin Islands and the Bahamas, with annual rainfall of <1500 mm, free-flowing water is scarce. As a result rain water harvesting remains the main source to meet water needs. Due to seasonality of rainfall, rainwater harvesting is also an attractive low-cost option to meet shortfalls in water supplies during dry months even in the wetter islands (i.e. >2500 mm per annum of rainfall). CEHI (2009) provides a comprehensive overview of typical rainwater harvesting systems found in the Caribbean. According to CEHI (2009) the typical rain harvesting system comprises four main parts:¹

1. Other relevant websites on rainwater harvesting include: <http://www.chennaietrowater.com/rainwatermain.htm> (Chennai Metro Water – Rainwater Harvesting); <http://www.rainwater-toolkit.net/index.php?id=75> (eToolkit on Rainwater Harvesting); <http://www.eng.warwick.ac.uk/jircsa/> (International Rainwater Catchment Systems Association); http://www.rainharvesting.com.au/rain_water_harvesting.asp (Rainwater Harvesting); <http://www.rainwaterharvesting.org/> (Rainwaterharvesting.org); <http://www.sear.net.org/sear.netfinal/home.asp> (SearNet – Southern and East Africa Rainwater Network); <http://www.tideindia.org/products/o6polyhouse.html> (example of RWH for agricultural greenhouse); <http://www.gdrc.org/uem/water/rainwater/rain-web.html> (The Web of Rain - Online resources on rainwater harvesting); http://www.youtube.com/results?search_type=&search_query=rainwater+harvesting (YouTube videos on rainwater harvesting).

- Catchment area: usually a roof surface or pavement with applications that can range from agricultural or commercial uses with large water requirements.
- Conveyance system: this is a network of guttering and pipes to transfer the rainwater from the catchment to the storage tank.
- Storage device: This is usually a tank situated above, underneath or partially below the ground.
- Distribution system: this ranges from a simple container to extract the water from the storage tank, or a pipe functioning solely as an outlet or a complex network of pipes serving multiple users. The distribution of the water can be assisted by using a pump.

RE-CYCLING OF DRAINAGE WATER

Recycling of drainage water can be described as the storing of run-off water from agricultural farms and after heavy rainfall for reuse as irrigated water into these farms. The water collected passes through a controlled irrigation system. This system requires a suitable area for the collection and storage of run-off and rain water. The advantages of this system are that it returns nutrients to the soil, a positive economic benefit, and it also supplements the use of fresh water, which is becoming more limited. Care must be taken to ensure that the quality of drainage water is good enough to prevent contamination of the soil and ground water supplies.

USE OF EFFLUENT AND WASTEWATER

The use of effluent and wastewater can be described as the recycling of water previously used by industries and households. This water includes sewage effluent, storm water runoff, and industrial discharges (OAS 1997). Water recycling has created a new and reliable source of water without compromising environmental, public health or agricultural resources. The advantages of using recycled water are that it provides an additional source of water, it reduces the diversion of water from river and wetland ecosystems, it decreases wastewater discharge into waterways and it can be used as irrigation water for agriculture. Effluent and waste water must be treated adequately to ensure water quality is appropriate for the intended purpose. Effluent can pose environmental, public health or agricultural resource risks if not managed appropriately. Urbanization and industrial development have led to the production of large amounts of wastewater in the Caribbean. The integration of this grey water into the water supply chain will help alleviate the water woes of the Caribbean. Countries around the world have included treated wastewater to supplement their water

supply particularly for agricultural and industrial purposes. Although in some countries wastewater has been treated to drinking standards, public health, religious and cultural concerns among consumers poses a hindrance to this use of wastewater.

Essentially in the Caribbean, wastewater reuse has been restricted to irrigation and industrial applications. Wastewater treatment effluent in Jamaica has been used for golf course irrigation, in some hotels and for the industry, as in the case of extensive recycling in the bauxite/alumina companies. In Barbados and Curaçao, extended aeration sewage treatment plants supplies water for lawn irrigation and hotel use. Large-scale wastewater treatment plants in Trinidad and Tobago have been used to treat wastewater to industrial standard for industrial use. For instance, the severe drought in 2009/2010 in Trinidad and Tobago left the Water and Sewage Authority (WASA) with no option but to significantly reduce supply to industries to meet the need for domestic use. As a result treatment plants like the Beetham Wastewater Treatment Plant have been used to supply water to the Point Lisas Industrial Estate, Trinidad. Also in Trinidad, river water fed by wastewater treatment plants is actively used by farmers to irrigate crops in areas like Caroni (Central Trinidad) and Maloney (East Trinidad). However, in order to expand the irrigated acreage to attain food security, large-scale treatment plants must treat grey water to agricultural standards in Trinidad.

WATER CONSERVATION SYSTEMS

Water conservation systems are necessary tools in light of a growing population and changing climate. These systems are essential for the Caribbean region to ensure viability of its agricultural sector. Water conservation systems involve the preparation of fields for efficient water use, for example, conservation tillage, scheduling irrigation and efficient irrigation systems such as drip irrigation. The advantages of water conservation systems are that they help to preserve the quality of water, reduce or eliminate drainage problems, conserve energy, increase food production and save money.

INCREASING IRRIGATION EFFICIENCY

One of the ways to ensure sustainable water management is to increase the efficiency of irrigation systems. Irrigated agriculture uses 60–70 percent of fresh water resources globally. With population growth, competing demands and climate change impacts, available water resources will become scarcer, therefore more emphasis must be given to efficient use of irrigation water for maximum economic return and water resources sustainability. Irrigation efficiency requires that appropriate methods of measuring and evaluating how effectively water extracted from a water source is used in crop production. It avoids crop water stress

and yield reduction from inadequate irrigation application and also the pollution of water sources from the loss of plant nutrients through leaching, runoff, and soil erosion due to excess irrigation application.

Increasing irrigation efficiency helps to get ‘more crop per drop of water’ (Kranz 2013). Surface irrigation which constitutes about 90 percent of irrigated agriculture is poorly controlled and does not result in uniform distribution of water to the field, leading to heavy water wastage. Pressurized irrigation facilities that ensure uniform distribution of water in the field, result in less wastage. Drip (micro) irrigation is highly efficient, as almost every drop of water from the source can reach the root system with minimum water losses. Drip irrigation is the process whereby small amounts of water are frequently dripped onto the soil area surrounding the plant roots through tubing with built in emitters. This system allows for a carefully managed amount of water to be applied, thereby avoiding deep percolation and run-off. The advantages of drip irrigation is that it reduces salt build up, plant stress, farm operations and maintenance costs, increases crop yield and enables efficient water use on steep slopes.

ENHANCED SURFACE WATER STORAGE

Enhanced surface water storage within the Caribbean usually takes the form of damming and water catchment. Examples of where this was successful are the Roseau Dam in St Lucia, which is also the last relatively large water catchment project in the Caribbean. Enhancing the surface water catchment does not only take into consideration its size but also the number of water catchment facilities that are able to improve the water quality supply of the country. Recently, the Government of Trinidad and Tobago constructed over three hundred (300) on-farm irrigation rain-fed ponds to serve as an incentive to increase irrigated acreage and encourage agricultural production to meet the food needs of the nation.

SALT WATER INTRUSION CONTROL TECHNIQUES

Saline water intrusion into fresh surface water and groundwater systems can decrease the quality of fresh water resources for drinking and agriculture. It can also increase the area of marginal unsuitable lands for agriculture. Therefore, measures to curb saline water intrusion can result in sustainable supply of fresh water from surface and groundwater sources, and can sustain the agricultural productivity of wetlands. In the Caribbean, sluice gates have been used to regulate the flow of salt water at high tides into river channels and adjoining wetlands, thereby protecting the sensitive wetland ecosystem and surface and groundwater resources. Sluice gates efficiently drain upstream lands, preventing saline water intrusion and back flooding during high tides. The use of sluice gates therefore prevents the conversion of fresh water systems into saline/brackish systems.

SOIL WATER CONSERVATION TECHNIQUES

Soil and water conservation methods help in increasing the amount of green water for crop production and ecosystem diversity and protect surface and groundwater resources from pollution hazards. Some soil and water conservation practices that are relevant to sustainable water management in the Caribbean are already discussed elsewhere (Wuddivira and Atwell 2012). Soil conservation practices include:

- i. **Cover cropping:** an effective method of soil and water conservation, which decreases water loss from the soil surface and increases the quantity and quality of green water. Cover crops protect the soil from the elements of soil erosion and evaporation. They therefore prevent soil erosion and runoff and encourage water to soak into the soil instead of running off the surface. Cover crops also increase soil organic matter content which improves and maintains soil fertility, conservation of soil moisture and soil structural stability. Cover crops capture, recycle and promote nutrients in the soil profile, suppress weeds and improve soil quality and thus greatly influence water storage and use.
- ii. **Conservational tillage:** a soil and water conservation system that promotes reduced frequency of tillage and the retention of crop residue at, or near the soil surface. This practice significantly alleviates soil susceptibility to erosion under intense rainfall. Crop residues retained at or near the soil surface usually dissipate raindrop energy by providing surface protection against the direct impact of the raindrops. This minimizes aggregate breakdown and surface sealing and retards surface water flow, thus providing more time for infiltration into the soil.
- iii. **Mulching:** soil and water conservation are achieved by using or applying a layer of plant residues or other suitable material on the soil surface. Instead of leaving the soil in between crop stands unprotected; residues are applied as mulch on the soil surface to enhance soil water infiltration and storage. This is achieved by stabilizing the soil temperature and moisture, and preventing sunlight from germinating weed seeds. Mulches also warm the soil by helping it retain heat that is lost during the night, and additionally minimise the effect of soil erosion, runoff, aggregate slaking forces and raindrop impact by improving soil structure. Mulching protects the soil surface from direct impact of weather elements such as the sun thereby reducing evaporation. In an environment like ours, characterised by intense and energetic rainfall, a layer of residue on the soil surface acts as an “impact absorber”, reducing direct hitting of the soil by raindrops. Mulches also modify temperature and moisture regimes thereby increasing the activity of soil fauna and flora, and suppressing weed growth.

- iv. **Crop rotation:** under a continuous cropping management system, soil and water conservation are achieved by growing crops in a planned sequence on the same field. This planned sequence of growing crops is referred to as crop rotation. A crop rotation system that includes the rotation of annual crops with grasses and legumes, improves soil structure, reduces erosion and increases soil fertility. The benefits of crop rotation include the improvement of soil structural stability, the reduction of erosion, improvement and maintenance of soil fertility, reduction of the build-up of pests, reduction of the risk of weather damage and reduction in the reliance on agricultural chemicals. These promote green water storage and the quality of surface and groundwater resources.
- v. **Conservation vegetative barriers:** the use of vegetative barriers as a soil and water conservation practice involves planting strips of rigid, dense vegetation mostly of bunchgrass and shrubs on the contour. Vegetative barriers drastically reduce runoff velocity and thus prevent potential pollutants from running off into surface waters. In addition, vegetative barriers control overland water flow, trap sediments and reduce pollution in the surrounding environments.
- vi. **Contour farming:** this is a good conservation practice for water management on sloping lands. It involves carrying out farming practices such as ploughing, ridging, planting, cultivating, fertilizer application and harvesting across the slope rather than along the slope. The contour farming practice slows down runoff and increases the detention time of water on the slope, thereby allowing more water to soak (infiltrate) into the soil. When more water infiltrates, sheet and rill erosion are reduced. Reduction in erosion means reduction in the transport of sediments, other solids and associated contaminants to the surrounding environment. Therefore, contour farming conserves soil, water and ensures the preservation of environmental quality.

POLICIES AND LEGISLATIONS

Many sectors in the Caribbean are affected by water scarcity. Inappropriate water management practices, climate change and climate variability impacts, increase rates of abstraction, pollution from agro-chemicals and other contaminants, inefficient and inadequate water storage facilities, failure to exploit recycling technologies and implement water-use efficiency measures all compound water scarcity problem of the region (Farrell et al. 2007). This will go unabated unless by-laws are put in place to deal with water wastage and discharge of pollutants into water bodies.

Currently, policies and legislation for water management are either inadequate or non-existent in the Caribbean. However, legislation is in place in countries like Antigua and Barbuda and Barbados for compulsory rainwater harvesting and storage from new buildings with large floor size (Ekwue 2010). Trinidad and Tobago has developed ad-hoc laws to legislate on water use in times of scarcity during unusually long dry spells. Urgent legislation is however required in the Caribbean to protect water resources from misuse and pollutant discharge.²

PUBLIC ENLIGHTENMENT AND EDUCATION

To achieve sustainable water management in the Caribbean public education on water conservation is essential. Strategies on how to save water from wastage and protect degradation of water quality can be incorporated into posters, leaflets, print and electronic media for the public to read and adopt. Information on proper and efficient irrigation systems, frequency of watering and mulching will go a long way in empowering the public to use water sustainably.

EXCESS WATER (WATERLOGGING) MANAGEMENT

In the Caribbean, there is a preponderance of poorly-drained soils due to heavy clay textures, low elevation, flat landscape, and the presence of a restrictive layer beneath the root zone. With above-average sea-surface temperatures, rainy seasons are expected to be wetter, with waterlogging problems hampering food production. Waterlogging interrupts seeding and germination, increased incidences of crop diseases and increased cost of tillage implements and production. Under waterlogging conditions, farmers must plant crops on raised beds to create a zone of unsaturated soil volume for optimal root growth. This will reduce the harmful effects of waterlogging on crop productivity. Effective water management is also required for profitable crop production, and should include the drainage of the excess soil water from the root zone in these poorly drained soils. Therefore, fields that are prone to water settling will benefit from drains that are dug to move excess water to lower lying areas away from the root zone. Drainage removes excess water and improves the supply of oxygen at the root zone for beneficial microbial activities as well as plant roots growth (Boman and Tucker 2012).

In fields with restrictive layers and those prone to waterlogging, the water table level should be monitored to maintain it at an optimal zone for crop production (Boman and Tucker 2012). There are many devices for monitoring the water table ranging from a

2. Note: there is water quality legislation in some islands.

ruler to electronic sensors. The selection of which device to use should be guided by the level of accuracy required. To deal with waterlogging problems, surface and subsurface drainage will be required in the poorly-drained soils of the Caribbean. Drainage systems to be employed should consist of canals, retention areas, detention areas, open ditches, subsurface drains, beds, water furrows, swales, and pumps to remove the excess water. For the drainage systems to remain effective, proper maintenance must be employed to ensure that the prolonged exposure of roots to waterlogged soils under intense tropical rainfall is avoided. For successful productivity of poorly drained soils, the design of the drainage systems should be such that it permits a daily drop of the water table to between 10 and 15 cm (Boman and Tucker 2012). This will create an optimal zone of unsaturated soil volume sufficient to prevent root damage.

To successfully surmount bad drainage, effective land reclamation, design and installation of adequate water management systems, effective drainage and irrigation systems as well as land layouts that use cambered beds is necessary. The beds can vary in width from 3m to 20m, depending upon the crops to be grown (Ahmad 2011). Ridges that are individually used or constructed on top of already cambered beds are also important to overcome waterlogging problems. These practices have proved successful in those cultural production systems involving sugarcane, in Caribbean countries like Guyana and Trinidad and Tobago. Also growing of crops that are tolerant to poor soil aeration such as dasheen (*Colocasia esculenta*) is an important practice.

SUSTAINABLE WATER MANAGEMENT PRACTICES IN LIVESTOCK PRODUCTION

Livestock production is a vital agriculture sub-sector in the Caribbean. Production and consumption of animal products increases at about 2.5–4 percent per year in developing countries, and 0.5 percent per year in developed ones. Livestock production systems sustain the lives of four billion people globally, of which 32 percent are poor and 13 percent poor livestock keepers. Livestock production systems are heavily reliant on water for feed production, general maintenance and the production of animal products. It has been estimated that one litre of milk requires 3,000 litres of water (Times of India 2004), while producing one kilogram of grain fed beef requires about 100,000 litres of water (Pimental 2000). Compared to the production of potatoes, which only uses 500 litres, it takes much more water to produce animal products than crops. As a result, the sustainable utilization of water within the livestock industry is necessary in the face of uncertain water sources and variable weather patterns. Some sustainable water management practices that will be beneficial in the Caribbean include:

- **Feed sourcing and management:** involving the utilisation of feeds with a low water cost of production. The effective use of food-feed crops decreases the water cost of production. For example, crop residues for livestock feeding and importation of feed places no additional demand for water.
- **Production-enhancing strategies** such as veterinary care, provision of appropriate nutrients and a stress free environment limits the need to use water on sick or dying animals and increases livestock water productivity. By using these strategies one can maximise the benefits derived from animal production per unit volume of water depleted.
- **Water conserving strategies** help to shift evaporation to transpiration, by the implementation of better pasture management in the form of sustainable stocking rates, rehabilitation of degraded areas, replenishing soil fertility and maintaining a critical mass of live biomass. These help to increase livestock water production by fostering higher transpiration rates, encouraging infiltration of rainwater and reducing water contamination by sediments and zoonotic pathogens.
- **Spatial and temporal distribution of livestock, drinking water and feed resources** will improve livestock water productivity. Low to moderate livestock stocking densities and rotational grazing decrease cumulative grazing pressure, soil compaction and decrease the risk of damage to vegetation. Animal movements should be adapted and supplementary feeders and supply of drinking water for livestock should be positioned accordingly to avoid excessive soil compaction. This will reduce soil erosion, runoff volumes and evaporation improving soil water retention and reducing environmental pollution.
- **Protection of water courses:** livestock should be prevented from direct access to surface water at any time. Water courses should be fenced off in fields away from livestock. Grazing of environmentally sensitive areas as well as areas with concentrated livestock wastes should be properly managed. Areas where waste is collected should not be on permeable soils to avoid nitrate and bacterial contamination from leaching into the ground or surface water. Waste collection areas should be located further than 30 m away from waterways and streams and should be regularly cleaned.
- **Minimising and reducing water spillage and contamination:** when rearing livestock intensively, a formal wastewater management plan should be put in place to prevent potential sources of water pollution in storage areas. The installation of stock drinkers for livestock is also important to avoid water spillage.

- Promoting water use efficiency and reusing water whenever possible: water supply systems should be monitored using metering to allow for the rapid identification of inefficiencies in the water system. Breakages (e.g. in troughs or pipes) and leaks in livestock areas should be mended, and potential areas where water can be reused, sought. For example clean rainwater can be channelled and collected from roofs for livestock drinking, if there is no health risk.
- Minimise water wastage by animals: consider alternative drinking water designs such as troughs, nipple and cup or bite-type drinkers in bowls as these can reduce the amount of water wasted by animals.

CONCLUSION

In a changing Caribbean region with mounting demographic pressures and growing threats of water quality degradation, improving the security and resilience of water is vital for the provisioning of good quality water for drinking and agricultural production. Although endowed with an abundance of water resources, the year-round supply of fresh water remains an enormous challenge in the Caribbean. This challenge is worsened by strong competing sectoral demands. Over abstraction and increased pollution of fresh water resources decreases water quality and can exacerbate the scarcity of fresh, easily accessible water. While using our water resources, practices that ensure its continuous supply in adequate and safe amounts to meet the needs of the population for drinking and food production must be adopted.

The adoption of appropriate sustainable water management strategies as suggested above is of paramount importance to meet the water needs and to ensure a water and food secure region. The realities of water quality degradation, increased frequency of extreme rainfall patterns, and dry spells are looming. To have a region that is water and food secure, coping with these threats will involve reducing our regional water footprints through these sustainable water management practices and other suitable treatments that protect our water resources and increase the quality and availability of surface and groundwater resources.

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Figure 4.1.: Flat or slanted-roof



Source: Chandler and Pulehuiki (2012)

Figure 4.2: Single-bed RS with an arched roof



Source: Palada, Roan and Black (2003)

Figure 4.3: Double-bed RS with an A-roof



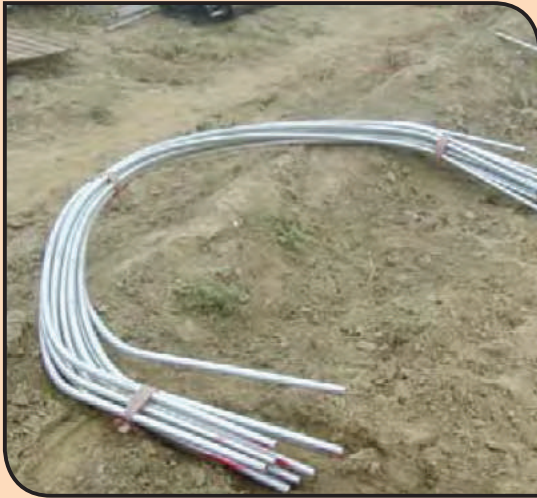
Source: Palada, Roan and Black (2003)

Figure 4.4: Multiple-beds, large-scaled RS with an arched roof.



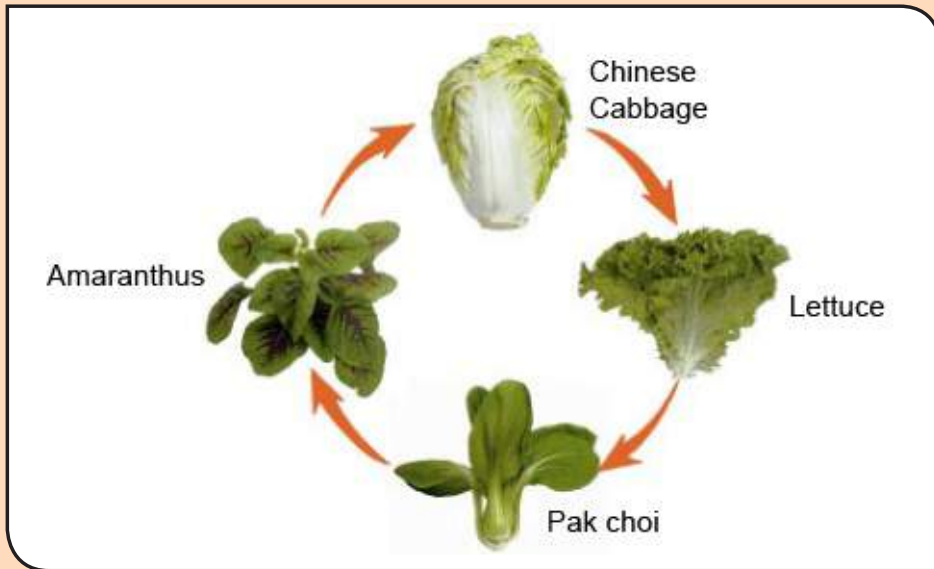
Source: Morris (2012)

Figure 4.6: Structural, covering, connecting, and fastening components of RH/NH.



Source: Palada, Roan and Black (2003)

Figure 4.8: A recommended crop rotation system



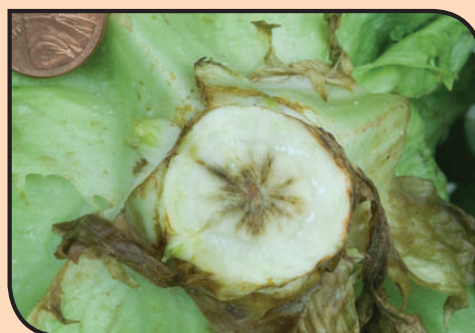
Source: Talekar, Su, and Lin (2003)

Figure 4.9: Plastic mulch being installed manually



Source: Palada, Roan and Black (2003)

Figure 4.10: Bacterial leaf spot and downy mildew of lettuce



Source: Koike (2010) and Smith and Koike (2010)

Box 4.3: Construction process for RH/GH

Step 1



Step 2



Step 3



Step 4





Aphids on Citrus



Whitefly parasitised by
entomopathogenic fungi



Fruitfly on guava



Fruitfly larva in guava



Ladybird larva feeding on aphids



Ladybird pupa



Ocimum sanctum Tulsi



Gliricidia as a living fence



Lemongrass



Pussley



Soursop Leaf



Vervine



Farming on hillslopes



Contour farming on slopes Paramin, Trinidad



Contour farming on steep slopes



Cracking of soil in South Oropouche, Trinidad



Waterlogged soil in South Trinidad



Waterlogged field



Water logged soil in South Trinidad



Rain water harvesting in Moruga, Trinidad



Rain water harvesting in Moruga



Rain water harvesting in rural Trinidad



Water Storage



Desalinization Equipment



Polluted water well



Sluice gate in South Trinidad



Solid waste polluting dammed water supply



South Oropouche river to Gulf of Paria



Surface river water leading to sea



Surface water



Surface river water



Pond in Aranguez, Trinidad



Tributary supply to a dam



Turbid river water after heavy rains

Sustaining The Environment: Farm and Beyond the Farm

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INTRODUCTION

A complex interrelationship exists between food production and the environment. The prevention and control of environmental risks associated with food production is important for the preservation of human health and communities within which they exist. Agriculturists, in addition to their struggle to increase food production efficiencies, must consider environmental preservation to make food production sustainable. The agri or agro environment can simply be defined as the interactional impacts of agricultural practices on the environment. Agricultural Environmental Management (AEM) must be given more importance as countries strive towards food security within the context of promoting sustainable agro-ecosystems. Good Agricultural Practices (GAPs) must be employed to sustain the environment taking into consideration all dimensions of the agricultural production system. However, commitments to the management of agricultural environments must seek to not only include GAPs, but must go beyond and specifically address the associated food safety and environmental risk elements related to the food production and agro-processing sector.

Agricultural intensification has further contributed to environmental degradation since primary production agriculture is known to affect every component of the environment: surface and ground water, agricultural and non-agricultural land surfaces, the atmosphere and biodiversity. The main agricultural pollutants include pesticides, fertilizers, animal waste products and untreated manure. There are intervention and preventative approaches that can go a long way in attempting to safeguard the environment from the negative impacts of food production. Environmental-friendly agriculture, through sustainable agricultural intensification efforts, will ensure minimal contamination and disturbance to the natural environment from farming

and other agricultural related activities. The first step towards achieving agricultural sustainability would be to diagnose the impact of agricultural practices on the environment (Payraudeau and van der Werf 2005).

This chapter focuses on several of the complex interrelationships that exist between food production and food safety within an environmental context. Additionally, the chapter will provide recommendations to reduce the adverse impacts of agro-environmental hazards and food safety considerations which have a direct impact on people and societies in the Caribbean. The sources of environmental impacts from crop (pesticides, toxicity and fertilizers) and animal production (housing and waste management), identification of the key sources of contamination within the food value chain, along with considerations to reduce food safety hazards, food safety regulations and food traceability systems are addressed.

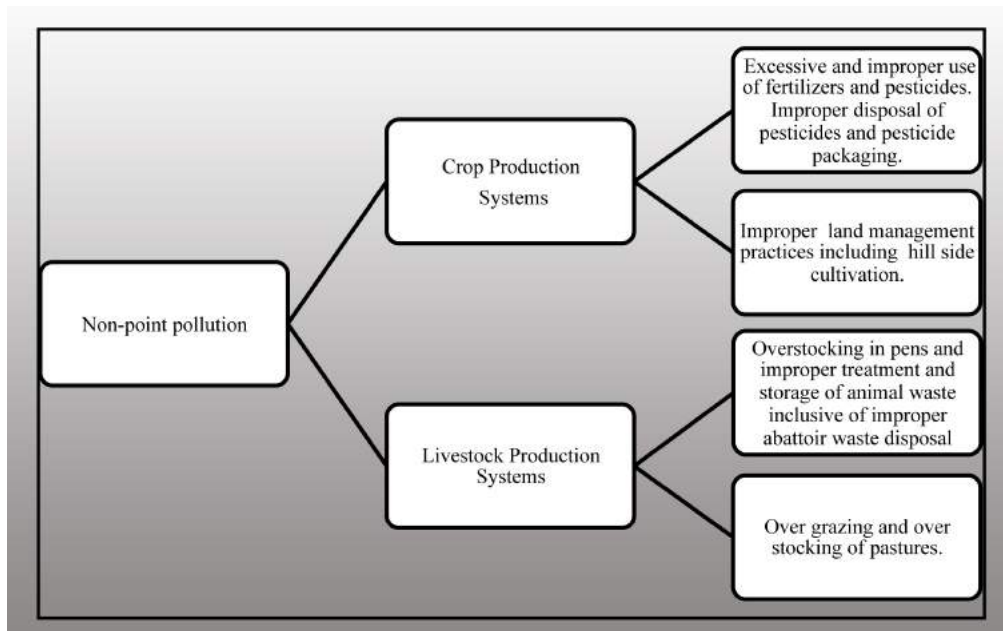
NON-POINT SOURCE POLLUTION (NPS) MANAGEMENT

Non-point source (NPS) pollution refers to the contaminants found in surface and sub-surface soil and water resources that are diffused in nature and cannot be traced to a point location. In contrast to industrial and sewage pollution, it is less toxic and does not have one specific source of origin. Although it is less toxic, it poses serious threat to the health of human beings and their community. NPS pollution is not concentrated within a specific area, but has a dispersed character. It can affect a water body from sources such as run-offs from agricultural areas draining into rivers. The run-off from agricultural areas may contain bacteria, nitrates, ammonia, pesticides, phosphorous, minerals and sediments. Chowdary et al. (2001) for example have suggested that agriculture is the largest contributor to non-point pollution to ground and surface water to the environment.

From a chemical pollutant (man-made) perspective, the sources of non-point pollutants from crop production are seemingly more diverse than from livestock production. Livestock production on the other hand specifically contributes to non-point pollution contaminants from animal waste and from the slaughtering processes. These two (2) types of production systems however, have similar adverse impacts on land surfaces related to: over-cropping, improper land preparation, over-grazing and over-stocking. Figure 7.1 shows the possible sources of non-point pollutants from crop and livestock production systems.

Non-point pollutants from the agriculture include the excessive use of fertilizers and improper fertilizer application; excessive use of pesticides, improper pesticide application and disposal of containers; sediments from hillsides which enter rivers and lakes, resulting from improper land preparation practices including deforestation and 'slash and burn' practices; and bacteria (faecal coliforms and *Streptococci*) from animal waste.

Figure 7.1: Agricultural nonpoint pollutants from crop and livestock production systems



Agricultural NPS pollution is the leading contributor to surface and ground water pollutants, thereby causing the water to become harmful to public health safety, aquatic animals and plant life dependent on water. Non-point pollution also affects water intended for consumption purposes for both humans and livestock.

PESTICIDES

A global estimate of 4.6 million tons of chemical pesticides is sprayed into the environment annually (Zhang, Jiang and Ou 2011). The need for pesticides in agriculture has become the norm to prevent crop loss attributed to pests. Pest injury to fruits, vegetables and cereals can reach 78, 54 and 32 percent respectively without the application of pesticides (Cai 2008). However, the improper use and application of pesticides can cause poisoning to humans and other organisms in the environment. Annually there are approximately 26 million cases of pesticide poisoning resulting in an approximate 220,000 deaths worldwide (Richter 2002). Pesticides and other chemicals released into the environment include the following:

- Weedicides, fungicides and insecticides used in the production and husbandry practices associated with producing food crops
- Chemicals such as copper sulphate used in animal foot baths and those used to sanitise animal pens and surroundings

- Insecticides used to spray animals for external parasites such as ticks. Large volumes of these are used in spray races and animal dips and are discarded into the environment after use
- Detergents and disinfectants that are used in operations such as dairying.

Eleftherohorinos (2008) pointed to the inappropriate use of pesticides which has resulted in adverse effects on non-target organisms (e.g. reduction of beneficial species populations); water contamination from mobile pesticides or from pesticide drift; air pollution from volatile pesticides; injury on non-target plants from herbicide drift; injury to rotational crops from herbicide residues left in the field; crop injury due to high application rates, wrong application timing, or unfavourable environmental conditions at and after pesticide application. The reported impacts of pesticide exposure on human health include the development of cancers, tumours and lesions, disruption of immune and endocrine systems, reproductive impairment and congenital defects and are consequentially the result from long term pesticide exposure, bio-concentration (mechanisms by which pesticides concentrate in fat tissue) and bio-magnification (increase in pesticide concentration throughout the food chain).

Table 7.1: The fate processes of pesticides in the environment and the mechanisms associated with the processes

Fate Process	Mechanism
Adsorption	Positively charged chemical pesticide is attracted to negatively charged clay particles and organic matter.
Transfer	Runoff: the movement of water along a sloping surface.
	Volatilization: the conversion of a solid or liquid into a gas
	Leaching: the movement of the pesticide through the soil rather than over it
	Pesticide drifts: the unintentional airborne movement of droplets during pesticide application.
	Crop removal
Degradation	Chemical degradation: the breakdown of the pesticide by non-living factors e.g. temperature, moisture, pH and the pesticide's chemical characteristics.
	Biological degradation by microorganisms.
	Photo-degradation: the breakdown of the pesticide by sunlight.

Source: Fishel (2007)

Fate of pesticides in the environment

The fate processes of a pesticide when applied to the environment fall into three (3) categories; adsorption, transfer and degradation. What is critical however, is the interaction of each of these factors and their interplay with the particular soil type and environmental conditions that determines the pesticide behaviour within the environment. Table 1 summarizes the fate processes of pesticides in the environment and the mechanisms associated with the processes.

The four major properties that are important to a pesticide's fate after application are:

- i. Vapour pressure** (volatility): relates to the ability of a pesticide to be converted into a gas.
- ii. Adsorption:** the process by which a pesticide is bound to or adsorbed to soil or organic matter within the soil. When pesticides are adsorbed they are less likely to be leached.
- iii. Water solubility:** the more soluble a pesticide is, the greater its mobility within the environment and it is less likely to be leached.
- iv. Persistence:** or the length of time a pesticide remains active in the environment. It is a function of the chemical composition of the pesticide and the chemical and biological degradation processes, which break down the pesticide into a less harmful form.

There are several conditions which will hasten the process by which pesticides volatilize; these include soils of a sandy composition and hot, dry, windy conditions. The size of the droplets being emitted from the spraying equipment also determines the rate of volatilization: - the smaller the droplets, the greater the rate of volatilization. To therefore avoid the hot and windy conditions experienced during the day, it is recommended that volatile pesticides be sprayed late in the evening. The resultant loss of pesticide by this process will be considerably reduced, and there will be a long mode of action during the night time period into the sunrise.

Pesticide toxicity

Pesticide toxicity can either be classified according to the World Health Organisation (WHO) or Environmental Protection Agency (EPA) as shown in Table 7.2.

Table 7.2: WHO and EPA acute toxicity classes for pesticides

Acute* toxicity of pesticides			
WHO Classification		EPA Classification	
Ia	Extremely hazardous	I	Highly Toxic
Ib	Highly Hazardous	II	Moderately Toxic
II	Moderately hazardous	III	Slightly toxic
III	Slightly hazardous	IV	Practically non-toxic
U	Unlike to present acute hazard		

*Any poisonous effect produced from a single or short exposure (24 to 96 hours) resulting in severe biological harm or death.

Adapted: Kamrin (1997)

The assignment of pesticides into toxicity classes will enable the applicator to assess the potential risk using the relationship:

$$\text{Risk} = \text{Toxicity} \times \text{Exposure}$$

Based on the above formula, it can be seen that the level of risk can be predicted such that in the case of a very lethal pesticide, if there is very little exposure to the applicator or handler, the risk will not be great. On the other hand, pesticides of low toxicity with prolonged exposure, can pose a high level risk of harm to the applicator or handler.

The pesticide drift is dependent on the size of the droplets exiting the nozzle of the pesticide application equipment, the wind velocity and the distance between the point of exit from the equipment and target. The greater the distance from the point of exit to the target, the more likely is the potential for pesticide drift. In knapsack sprayers, the pressure of the spray exiting the tank has an impact on the size of the droplets.

The risk of pesticide contamination to ground water contamination is based on the solubility of the pesticide, level of adsorption, degree of persistence, the amount of clay and organic matter present, the size of the pore spaces within the soil, depth of the ground water and the amount and frequency of rainfall and irrigation. Table 7.3 provides a summary of the ground water contamination potential as influenced by water, pesticides and soil characteristics. It should be noted that although botanical pesticides such as pyrethrins, extracted from chrysanthemum flowers are relatively non-toxic to mammals there are highly toxic to fish, tadpoles, aquatic invertebrates and honeys bees. Additionally, pyrethrins are unstable in sunlight and have a half-life of 12 days.

Half-life is the amount of time it takes for ½ of the original material to be broken down or removed. For each additional half-life period, 50 percent of the remainder will be lost.

Table 7.3: Summary of groundwater contamination potential as influenced by water, pesticide and soil characteristics

Risk of ground water contamination		
	Low risk	High risk
Chemical properties		
Water solubility	low	high
Soil Adsorption	high	low
Persistence	low	high
Soil characteristics		
Texture	Fine clay	Coarse sand
Organic matter	high	low
Site conditions		
Pore spaces	Few, small	Many, large
Depth to ground water	Deep, 30.5 m (100 ft.) or more	Shallow, 6 m (20 ft.) or less
Rainfall or irrigation	Small volumes at infrequent intervals	Large volumes at frequent intervals

Source: McBride (1989)

Reducing the pesticide risk to the environment

Pesticides from agricultural and public health sources (eg. mosquito spraying programmes) will inevitably be leached into the environment. The following strategies can be used to reduce the entry of chemicals into the environment.

1. ***Integrated Pest Management (IPM)***: The impact of pesticide entry can be reduced through careful examination of the pest life cycle and implementing an IPM approach, which places focus on knowing the pest's biological characteristics and monitoring the pest behaviour in order to advance a control strategy. The IPM approach uses one or more of the following methods; biological, cultural, mechanical and physical, and chemical control. IPM is used as a long-term approach for controlling, but not eradicating the pest. Chemical control methods are used last in the line of defence.
2. ***Reduce drift***: Spraying should not be undertaken when wind or temperature favours pesticide drift to an off target area. The appropriate spray pressure, nozzle selection and spray shield to minimize drift should be used.
3. ***Avoid spraying near water bodies***: Although agricultural soil is the recipient of most pesticides, adjacent water bodies are also affected. Avoid spraying pesticides along drains and water-ways. Use non-chemical methods of control. Check pesticide

labels for warnings regarding use near bodies of water such as streams, rivers, and lakes.

4. **Pesticide disposal:** Calculate the expected quantity of pesticide required before purchasing to avoid the need to store excess, or incur possible wastage. Empty pesticide bottles should be washed at least three times and the resulting water added to the application mixture. Do not burn pesticide packaging. Contact the relevant municipal authority or national waste management authority for information on the safe disposal of your pesticide packaging.
5. **Application site:** Consider the soil texture, organic matter content, depth to ground water and slope of the site. Soil texture affects the movement of water and the movement of dissolved chemicals such as pesticides. The presence of organic matter will hold water and dissolved pesticides and within the root zone reducing the volume of runoff. The shallower the depth to groundwater, the less soil there will be available to act as a filter. The greater the slope's gradient, the greater the volume of runoff, leaving the pesticide application site. The retention of pesticides within the soil as opposed to runoff pesticides will enable degradation and adsorption processes to occur.
6. **Weather conditions and irrigation:** Avoid applying pesticide (also fertilizers) when rainy conditions are forecasted, during rainfall, or when irrigation can influence runoff into surface water and leaching into ground water.
7. **Mixing:** Carefully mix pesticides according to the rate specified on the label.
8. **Equipment:** Maintain application equipment and calibrate accurately.
9. **Buffer zone:** Establish buffer zones to maintain a safe distance from wells and surface water (a minimum 15 m – 30 m is recommended); do not apply pesticides in buffer zones.

FERTILIZERS

As a consequence of rapid population growth and industrialization, the amount of arable land available for farming is rapidly decreasing. Soils become depleted of nutrients from crop uptake, from harvesting which breaks the natural nutrient recycling, or through leaching and surface run-off. The use of fertilizers therefore has become more or less the accepted practice to ensure the realization of sustainable crop yield. It is also needed to replenish nutrient-depleted soil in order to maintain and enhance soil fertility to ensure food production.

In addition to the need for the use of fertilizers in the agricultural sector, there is an inadvertent risk to the environment attributed to excessive fertilizer application. There has been a projected upward global trend in the use of fertilizers from seven percent per year (Pluncknett 1995), 3.8 percent annually between 1989/1990 and 2010 (Alexandratos 1998) and an expected nitrogen use to grow by 1.1 percent annually from 1990 to 2070 (Frink, Waggoner and Ausubel 1999). The improper use of fertilizers can have several deleterious impacts to the environment, including:

1. **Negative impacts on soil quality:** The improper use of fertilizers can increase the soil acidity and impact the beneficial soil macro and microorganism.
2. **Negative impacts to water bodies:** Excessive and improper use of fertilizers can cause eutrophication, or the process by which nutrients from sediments are carried by runoff water into surface waters providing nourishment for algae in the aquatic ecosystem (nitrates and phosphates). Where excessive plant growth in water bodies is attributed to human activities, it is known as cultural eutrophication, which is the primary environmental concern of surface water today (Yannawar and Bhosle 2013).

Effective fertilizer management

The impact of fertilizer or manure application on the environment is dependent on the fertilizer source, the rate of application, the placement of the fertilizer and the timing of application. Bruulsema (2009) refers to this approach as the 4R nutrient stewardship concept, and underscores the importance of best practices, which require that a soil analysis is always done before implementing a fertilizer programme. Nitrogen (N) and phosphorous (P) are two critical fertilizer nutrients, which can adversely impact the quality of ground and surface water. In this regard, it is very important that these two nutrients are carefully managed in crop production activities.

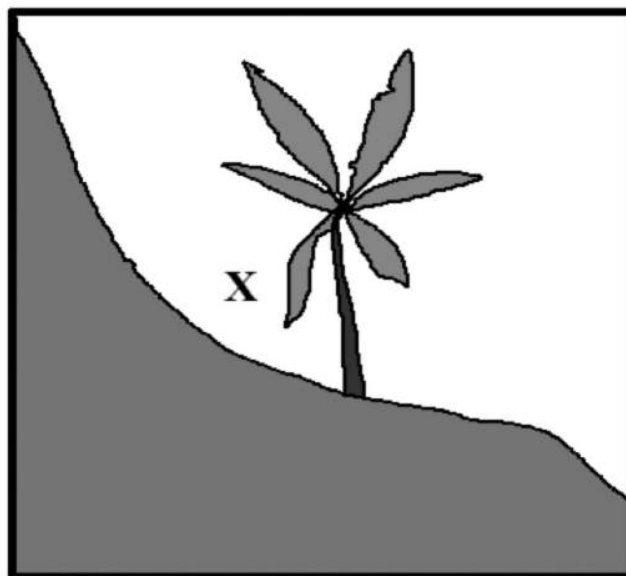
It will also be critical to know when to apply plant nutrients in order to optimize the benefits from the fertilizer application. The recommendation is that nitrogenous fertilizers be applied during the maximum growth phase of the plant, for them to be efficiently utilised. This will ensure that the fertilizer is efficiently used, and that less opportunity exists for residuals in the soil and loss from surface run-off or leaching. Split application of fertilizers will ensure minimum losses resulting from surface run-off and leaching, particularly in the case of nitrogen fertilizer management. Other methods, by which nitrogen fertilizers can be managed, include: the use of slow release fertilizers which can significantly reduce nitrogen losses, and the use of nitrification inhibitors which delay the microbiological transformation of ammonium to nitrates. Iron supplements can be used alone, or in combination with

reduced nitrogen fertilizer to elicit a greening response, thereby reducing the amount of nitrogen leaching from crop production activities. Careful consideration must be given to the application of fertilizers on slopes as this must be kept to a minimum and always placed on the uphill side of the slope, shown as 'X' in Figure 7.2.

The management of phosphorus loss from crop fields into waterways can be prevented by ensuring that it is applied at the recommended rate based on a soil test. The notion that high rates of phosphorus will not be injurious to plants, and as such can be applied in high rates to build up soil levels, is no longer an acceptable practice. Although phosphorus moves very little within the soil, soil erosion and run-off are processes that cause phosphorus pollution of water. The following approaches can be used to reduce phosphorus movement into runoff water: conservation tillage, terraces, contour farming, grasses way, vegetative filter strips, and cover crops. Strips of unfertilized grass or natural vegetation near water channels or water bodies can assist in reducing soil erosion, and behave as a trap for unwanted nutrients, thereby preventing any deleterious impacts to the environment. Grass barriers are narrow strips (approximately 1.2 m) of tall, erect, stiff-stemmed, native warm-season perennial grasses planted on the field contour (Kemper et al. 1992). Grass barriers and strips have proven to be economical means to:

- i. Reduce run-off and promote infiltration (Meyer, Dabney and Harmon 1995)
- ii. Enhance deposition of soil and organic matter (Melville and Morgan 2001)
- iii. Promote degradation of sediment-bound chemicals (Groffman et al. 1991)

Figure 7.2: Placement of fertilizer on the uphill side of slope (X)



The misconception also appears to exist, that organic fertilizers such as manures cannot be detrimental to the environment when in fact, manure application to crop lands contributes significantly to both nitrogen and phosphorus-loaded run-off into streams, rivers and lakes. Figure 7.3 shows algal growth attributed to nutrient rich run-off from animal waste. Additionally, there is a belief that increasing fertilizer use can increase yield. This occurs up to a point, beyond which, any further increase in fertilizer application will not be effective, resulting in economic losses and environmental harm.

ANIMAL PRODUCTION

World population growth along with demographic factors such as age, structure and urbanization has influenced the demand for livestock food products tremendously. In addition to this, economic growth and a concomitant increase in individual incomes and by extension the standard of living, have also contributed to a shift in dietary choices and a subsequent increase in the demand for animal products. The livestock sector has responded to this increase in demand by improving production efficiencies via strategic changes in animal breeding and genetics, reproduction, nutrition, animal health care and housing. These controlled modifications have led to the intensive model of livestock production.

Animal production systems may be broadly categorized as being either intensive or extensive, however it must be noted that some systems show features of both categories and are hence categorized as semi-intensive. Intensification, as it relates to animal production, may be defined as the rearing of many animals in a single location in close proximity to each other. The drastic increase in animal population densities associated with intensification usually result in attending problems associated with the animals' requirement for nutrition and feeding, health and environmental management. In the regional context, because of the relatively small size of states, competing interests for land use, praedial larceny, hilly topography and the need to control the environment for animal production exist, resulting in many of our livestock production systems moving towards the adoption of intensive systems for production. Examples of intensive systems used in the region are:

- i. Large tunnel ventilated houses for broiler production (with bird density of less than 0.09 m² per bird), which utilises the deep litter system of production.
- ii. Open side naturally ventilated houses for broiler production using the deep litter system.
- iii. Slatted floor and deep litter systems for small ruminant (sheep and goats) production.
- iv. Feedlot systems for cattle and water buffalo production.
- v. Intensive swine production facilities.

Industrial farm animal production (IFAP)

The term industrial farm animal production (IFAP) has been used by Halden and Schwab (2010), to describe this type of intensive production on a very large scale in some developed countries. Specifically for the Caribbean, two key features of intensive systems are found, involving the use of relatively small land areas, resulting in high animal to land ratio and the use of housing structures and equipment designed to:

- protect the animal from the environment and predators
- ensure timely and controlled supply of feed nutrients and water
- exclude disease causing organisms and prevent spread of diseases
- facilitate the easy handling of animals
- facilitate timely and efficient removal of waste

The biggest environmental concern with respect to intensive systems, is the timely removal and safe disposal of animal waste. Conversely, within extensive animal production systems, animals are not kept in close proximity to each other and animal production densities are comparatively low. The term range operation is often used to describe the release of animals on large expanses of land where they have to seek their own food and water supplies. Within this type of system, land degradation from overgrazing constitutes a major environmental concern.

In general, animal production operations impact the environment (water, soil and air) due to the large volume of animal waste produced. In situations where there is a lack of adequate regulations and monitoring policies to reduce the incidence of pollution, the environment is negatively impacted. The major effects are as follows:

1. Nutrient pollution of ground and surface water resources from inappropriate management of animal waste (manure).
2. Contamination and pollution of ground and surface water resources by the various chemicals used in animal husbandry.
3. Contamination of ground and surface water resources with microorganisms.
4. Overuse of fresh water resources leading to depletion.
5. Degradation of land from overgrazing.
6. Production and release of odorous gases and toxic substances.
7. Release of particulates and bio-aerosols containing pathogens into the atmosphere.
8. Consumption of non-renewable energy for feed production and transport.

Global animal manure production

Animal production produces much more waste than the amount produced by humans. Notwithstanding this, animal waste is less strictly regulated in terms of its management and disposal. In the past, with traditional extensive systems, manure did not present as much of an environmental problem as it now does, due to much lower animal populations, lower stocking densities and correspondingly, lower animal manure output. As a consequence, the natural cleansing systems found in many ecosystems were not overburdened.

It is essential that the waste disposal from livestock production is carefully managed to prevent harmful impacts on human health, water quality, air quality and soil properties. Large volumes of both solid and liquid waste (Figure 7.4) are produced from animal feeding lots, the major fraction of which is manure, but the waste also contain many chemicals used in modern animal husbandry.

Land degradation from overgrazing

Overgrazing is considered to be the major cause of soil degradation worldwide (Oldemann, Hakkeling and Sombroek 1991), accounting for 35.8 percent of all forms of degradation. Land degradation refers to those processes that render the land no longer useful for agricultural purposes due to deterioration in quality. Grazing livestock can alter and damage the ecosystem of the lands they graze. Overgrazing of an area can lead to insufficient time for grass regeneration, resulting in soil depletion, erosion and desertification. Overgrazing is a function of time and not necessarily a function of animal numbers on a specific area of grazing land. Farmers have moved to reduce overgrazing by rotating livestock in different pastures to allow plant growth to continue. However, this is not always carried out for long enough periods to enable the soil to fully recover. Animals should not be turned out to the pastures before the plants have fully recovered. In many of the Caribbean territories where the extensive/semi-extensive system of production is practiced, the limited acreage of available land for livestock production and the nature of the terrain of available lands often lead to overgrazing and soil erosion. This occurs as the animals are left in a single pasture for an extended period of time. In many situations, small ruminants such as sheep will graze so close to the ground that the soil is left exposed. To prevent the negative effects of overgrazing, the following should be integrated into livestock production systems. These include: land and soil management (e.g. pasture rotation and fertility management), animal management (e.g. managing animal distribution and their proximity to water supply), and strategic marketing to avoid overpopulation of herds/flocks and to reduce herd/flock size in times when forage availability is low e.g. in the dry season. Table 7.4 provides the commonly used stocking densities for livestock and poultry production in the region.

Table 7.4: Commonly used stocking densities for livestock and poultry production in the region

Species	Type of System		Stocking Density
	Intensive	Extensive	
Broilers	Open Ventilated (deep litter system)	–	approx. 0.09 m ² (1.0 ft ²) per bird
Broilers	Tunnel Ventilated houses (deep litter)	–	approx. 0.08 m ² (0.90 ft ²) per bird
Layers	Intensive/deep litter		approx. 0.23 m ² (2.5 ft ²) per bird
Sheep and Goat	Deep litter/concrete floor/earthen floor Ewe/doe with lambs		approx. 1.49m ² -1.85 m ² (16-20 ft ²) per animal
Sheep and Goats		Grazing animals	**1 animal unit per acre
Sheep and Goats	Deep litter/concrete floor/earthen floor Feeder lambs/kids		approx. 0.74m ² – 0.93m ² (8-10 ft ²) per animal
Sheep and Goats	Slatted floor Ewe/doe (35kg)		approx. 0.69 m ² (7.5 ft ²)
Sheep and goats	Slatted floor Ewe/doe (50kg)		approx. 0.90 m ² (9.7 ft ²)
Sheep and Goats	Slatted floor Ewe/doe (70kg)		approx. 1.09 m ² (11.8 ft ²)
Sheep and Goats	Slatted floor Lamb/kid		approx. 0.29 m ² (3.2 ft ²)
Sheep and goats	Slatted floor Weaner lamb/kid		approx. 0.69 m ² (7.5 ft ²)
Sheep and goats	Slatted floor Buck/ram		approx 1.5 m ² (16 ft ²)
Cattle		Grazing	**One animal unit/acre
Cattle	Feedlot system		approx. 11.15m ² (120 ft ²) per animal
Swine	Intensive concrete floor system • Sows and boars • Sow with piglets • Weaner pigs • Growing pigs • Finishing pigs		approx. 2.3 m ² (25 ft ²) animal approx.3.25 m ² (35 ft ²) approx. 0.28m ² (3 ft ²)per animal approx.0.56 m ² (6 ft ²) per animal approx.0.84 m ² (9 ft ²)per animal

**1 animal unit is equal to one adult cow – roughly 450kg or 9–10 sheep/goats

Use of fresh water resources and its depletion from livestock

Agriculture is the largest consumer of fresh water, accounting for 70 percent of total fresh water use (Steinfeld et al. 2006). It also accounts for in excess of 90 percent of total water depletion rates. Some areas where water is specifically used in animal production include:

- Drinking purposes – A large lactating dairy cow that is producing 35 l of milk per day will consume in excess of 120 l of water in hot dry conditions.
- Washing and cleaning – a tremendous volume of fresh water is used in animal agriculture on a daily basis for washing and cleaning feedlot facilities, washing animals, and the managing of animal waste in the form of slurry. A classic example are the large commercial swine units, which often use flushing systems and where water consumption is often several times the drinking water needs.
- Cooling of animals, facilities and products e.g. misting and drip cooling for animals, milk cooling facilities, etc.
- Product processing – such as animal slaughtering and processing of meat and milk processing amongst others. In addition to slaughtering, water use in these facilities includes that which is used for offal processing and rendering.
- Evapo-transpiration losses associated with livestock evapo-transpiration is the main mechanism by which crop and grassland deplete water resources (Steinfeld et al. 2006).

Most of livestock's contribution to evapotranspiration losses is due to the production of corn and soybean. In the Caribbean region, the contribution to water depletion by this means is minimal, since little grain for feeding animals is produced, and pasture irrigation is carried out on a limited scale during the dry season. However, it must be noted that the region imports large volumes of corn and soybean meal which constitute 100 percent of the ration fed to monogastric animals (poultry and pigs in particular), and approximately 40 percent of the ration fed to ruminants. Therefore the regional contribution to the depletion of water resources in this way is indirect.

Nutrient pollution of ground and surface water

Not all the nutrients consumed by the animal are digested, a considerable fraction is undigested and passed out in the excreta. Manure contains solid and liquid animal waste, much of this is returned to the environment when livestock facilities are cleaned. The manure contains a large volume of nutrients such as N, P and potassium (K). In addition to nutrients, drug residues, heavy metals and pathogens are also carried in animal waste and

constitute a pollution concern. Contamination of water sources from animal waste usually stem from runoff from facilities directly in drainage systems, disposal in the waterways or watersheds, and from percolation through the soil and into water sources.

The two nutrients of major concern are N and P, with P tending to be more of a problem with surface water quality and Nitrogen more of a problem with ground water quality when nitrate leaches through soil layers (Steinfeld et al. 2006). High concentrations of nutrients in these water resources contribute as previously stated, to eutrophication. Animal farming therefore markedly increases the quantity of nutrients reaching the water. When these nutrients enter the water systems, algal growth is stimulated and the clarity of the water is reduced. Algal blooms and resulting microbial activity exhaust the dissolved oxygen in the aquatic ecosystem and impairs the proper functioning of the ecosystem. The process of decomposition of the algae also utilizes oxygen which reduces the bioavailability for fish and other aquatic life. The end results are diverse, and in addition to damaging the functioning of the ecosystem, include:

- A shift in habitat characteristics
- Replacement of desirable species of fish with less desirable ones
- Production of toxins by certain algae
- Loss of recreational use
- Clogging of drainage canals leading to flooding in the wet season

Nitrogen in manure may occur both in organic and inorganic forms. Depending on the form, it may be stored and immobilised within the soil, leached to ground water, or can be volatilized. Losses from excreta can take four main forms:

1. Ammonia (NH_3) - volatilization of inorganic N from housing, storage or pasture.
2. Dinitrogen (N_2) - nitrates are transformed to N_2 (harmless form).
3. Nitrous oxide (N_2O) - a harmful by-product produced under conditions of organic carbon deficiency.
4. Nitrate (NO_3) - lost to water resources in this form as it is very mobile in soil solution and can easily enter ground water. High nitrate in water resources present health issues such as poisoning in infants (methemoglobinemia), and abortion and stomach cancer in adults.

Steinfeld et al. (2006) identified five levels at which strategies to improve waste management should be targeted. These are at the:

1. ***Production level*** – the focus here is to increase feed use efficiency by the animal and reduce the quantity of excreta and hence the quantity of nutrients voided into the environment. Digestibility and therefore bioavailability of feed nutrients are two key components. Nutrition and feeding strategies strive to meet the nutrient needs of the animals without overfeeding so that there are minimal nutrients in the excreta. Animals that are overfed usually have lower levels of digestibility. Increasing feed efficiency can be accomplished by using a number of approaches including :
 - Utilisation of feed ingredients with easily digested and absorbed nutrients e.g. low phytate corn. P excretion will be reduced as it is contained in phytate in a form that is not available to the animal.
 - Not overfeeding, as this leads to excess nutrients such as minerals (macro and micro) being voided in the faeces. In addition, if protein is overfed, more N will be present in the urine.
 - Utilisation of feed additives e.g. enzymes, to aid in improving digestibility and hence bioavailability of nutrients. One classical example of the application of this technology exist where much of the P in feed ingredients used for monogastric animals (pigs and poultry) exists in the phytate form. These animals do not have the enzyme phytase which will make the phytate-P available. Adding phytase to the diets of both pigs and poultry has been shown to significantly reduce P voided in the faeces, and hence result in an increase in the bioavailability of P in these feed ingredients.
 - Pelleting feed to increase digestibility.
 - Breeding and selection of animals with better feed efficiency and growth rates.
 - Improving general environmental conditions and reducing the animal's exposure to stressors.
2. ***Collection level*** - manure is usually collected in a relatively solid form (as it is produced by the animal), or in a more liquid form where water is added to bring it to a slurry. Adding water to it increases its volume due to the dilution process (LPES, 2005). In this state, it facilitates pollution from runoff. In general it is best to minimize the amount of water coming into contact with the manure to reduce the amount of run-off.

3. ***Storage level*** - the aim of storage should be to reduce components of the manure escaping into the soil and water ways. Most of the storage systems utilized in the Caribbean involve collecting the waste and stockpiling it in an area on the farm where it is exposed to the climatic elements. In some production systems such as the slatted floor for sheep and goat production, manure is allowed to accumulate under the raised floors for extended periods (sometimes up to six months). The challenge is to keep the accumulated manure dry. This is unachievable in most instances, and the end result is a malodour associated with the breakdown of the manure and release of associated gases into the atmosphere along with runoff into drains and eventually into larger waterways. In addition to this, it often presents a suitable habitat for rodent infestation and proliferation.
4. ***Processing level*** - options available for processing manure with an aim to reduce pollution include aeration technology, anaerobic digestion to reduce chemical oxygen demand, biological oxygen demand and produce methane gas, sedimentation of biosolids, flocculation, composting, drying of manure and lagooning systems favouring natural biological activity and reduced pollution.
5. ***Utilisation level*** - when used as a fertilizer option for crop production, manure not only provides nutrients for plants but also improves soil characteristics such as soil structure, soil aeration, and water holding capacity, increases biological life in soils, improves cation exchange capacity, improves soil fertility and soil aggregate stability. Manure can also be used in the form of feed for fish and some other species to provide nutrients, although this may have some stigma attached to it. In many parts of the world manure is also used to produce energy in the form of methane gas that may be used in households on farms or in slaughter facilities.

Microbial contamination of fresh water resources

Manure may contain many pathogenic organisms and parasites which pose serious implications for human health. Many of these pathogens and parasites have a long residential time in the environment and lie dormant until conditions are favourable for their activation. Some of these pathogenic organisms associated with manure that has human health implications are: *Campylobacter* spp., *Escherichia coli*, *Salmonella* spp., *Clostridium* spp., viruses (e.g. picornavirus, parvovirus, adenovirus, Rinderpest virus), protozoa and internal parasites.

Veterinary drug residues and chemical contamination of aquatic environment

Antimicrobials are not only used in livestock production to treat diseases, but also as preventative medicine and productivity enhancers. When used in this manner, they are used at low levels over a long duration of time. In livestock production, the non-therapeutic fraction includes non-nutritive feed additives such as monensin, avilamycin, flavomycin, salinomycin, lincomycin and roxarsone.

The negative effects on the environment arise because a large portion of the drugs used are not degraded in the animal's body and ultimately end up in the environment. The consequence of these drugs ending up in the environment is the development of resistance by microorganisms.

Figure 7.5: The active drug ingredients found in broiler starter feed

BROILER STARTER	
321..R - 79A	
REG. POT TORRID	
MEDICATED	
For growth promotion, feed efficiency and improving pigmentation. An aid in the prevention of coccidiosis. Feed continuously as the sole ration to broiler chickens.	
WARNING: Do not feed to laying hens, Do not allow Horses or other equines access to formulations containing Salinomycin. Ingestion of salinomycin by equines has been fatal. Do not allow rabbits, hamsters, guinea pigs, horses or ruminants access to feeds containing lincomycin. Ingestion by these species may result in severe gastro intestinal effects.	
ACTIVE DRUG INGREDIENT	
Salinomycin	60g/metric tonne
Roxarsone.....	0.005%
Lincomycin.....	2.2g/metric tonne
GUARANTEED ANALYSIS	
Crude Protein, Min.....	21.0%
Crude Fat, Min.....	2.5%
Crude Fibre, Max.....	5.0%
INGREDIENTS	
Grain Products, Plant Protein Products, Processed Grain By-Products, Animal Fat preserved with BHA, Calcium Panthothenate,Deflourinated Phosphate, Niacin Supplement, Menadione Sodium Bisulfite, Riboflavin Supplement, D-activated Animal Sterol (Source of Vitamin D3), Ethoxyquin (a preservative), Vitamin B12 Supplement, Vitamin A Supplement, Vitamin E Supplement, Choline Chloride, Ground Limestone, Salt and Traces of Manganous Oxide, Calcium Iodate, Iron Carbonate, Iron Sulfate, Copper Sulfate and Zinc Oxide.	
945 TR	

Hormones are other biochemical compounds that are commonly used in production enterprises as ear implants or as feed additives to control growth and metabolism. Some are also used in reproduction to control the oestrous cycle by inducing or synchronizing oestrus. Some of these hormones may be natural e.g. estradiol and progesterone, while others are synthetic e.g. zeranol, melengestrol acetate and trenbolone acetate. No direct implications on human health have been scientifically proven when they are used at the correct application rates. The concern however relates to the potential effect as endocrine disrupters in humans and wild life. Some of these synthetic hormones can remain in the environment for a very long time e.g. trenbolone acetate in manure piles and therefore can find their way into fresh water resources.

Trace minerals are those required in the animal diet at levels lower than 0.01 percent in the ration, these include iron, copper, zinc, molybdenum, cobalt, iodine, manganese and selenium. Some of these are considered heavy metals and their improper use can lead to accumulation in soil and waterways in many ecosystems. In addition copper and zinc are commonly used in footbaths and as a disinfecting agent, and are routinely disposed of in the environment.

Livestock production and sediment load in fresh water resources

Livestock production contributes significantly to soil erosion, not only leading to soil and fertility loss, but also to sediment loading of streams, rivers, lakes and marine ecosystems alike. Livestock contribution to soil erosion and sedimentation is a consequence of animal feed production and the improper management of the cultivated lands, as well as the impact of livestock hooves on the land and the effects of overgrazing on pastures. Animal hooves cause significant compaction of the soil in areas where they are concentrated such as feeding, shading and resting, grazing and watering areas. The impact of the hoof is two-fold, whereby in the wet season the compaction effect is more pronounced, and in the dry season the surface of the compacted areas is loosened and the soil is carried away easily by the first heavy rains. Soil compaction in general will serve to reduce infiltration rates and consequently increase surface runoff, which is a major contributor to soil erosion. Steinfeld et al. (2006) summarised the sum total of the effects as follows:

- i. Reduced water holding capacity of the soil in the areas grazed and occupied by livestock
- ii. Increased sedimentation in water ways resulting in:
 - obstruction of the channels
 - destruction of ecosystems e.g. coral reefs where sedimentation obstructs feeding areas and nesting sites

- increased water turbidity resulting in less light penetration and therefore reduced algae and plant growth
- increased probability that rivers will flood their banks due to a reduced cross-sectional area of the channels
- more nutrients and chemicals transported to distant sites which will contaminate fresh water resources
- eutrophication

Livestock production and air pollution

Climate change and the global increase in average temperatures are often attributed to an increase in the production and release into the atmosphere of the greenhouse gases carbon dioxide, methane and nitrous oxide. Activities related to livestock production emit considerable amounts of these gases (18 percent of total anthropogenic greenhouse gas emissions), and therefore contribute to climate change. The following provides approaches essential to addressing the reduction of carbon dioxide, methane, nitrous oxide and ammonia emissions into the environment from livestock production:

1. ***Carbon dioxide emissions*** – it is essential that the environmental focus be specific in addressing issues of land degradation and land use change, which can be achieved by:
 - Establishment of improved pastures and rotational grazing management.
 - Reducing deforestation while intensifying agricultural production, i.e. the creation of incentives for forest conservation and reduced deforestation. This option will have to be supported by intensification of agricultural production to meet food security needs. This will involve the use of improved varieties (in terms of acclimatization, yield and disease resistance), better water management and increased fertilizer use, as the resulting decrease in carbon emission due to more forest conservation will outweigh the increased emissions due to more fertilizer use many times over.
 - Restoring soil organic carbon to cultivated soils via the utilisation of conservation tillage options, agricultural intensification and erosion reduction.
 - Using agroforestry options in livestock production.

2. ***Methane emissions from the ruminant animal***

These can be reduced by:

- Improving the nutrition of the animal, as methane emissions from the rumen increase with poorer quality diets. Options include improving digestibility or the digestive process. Increasing the starch content in the diet also provides an option for more readily fermentable carbohydrates which will reduce methane production.
 - Improved genetics, whereby animals with better feed conversion efficiencies and growth rate are available so that animal productivity increases.
 - More advanced options that need additional evaluation include the reduction of hydrogen production in the rumen by stimulating acetogenic bacteria, eliminating certain protozoan from the rumen (defaunation), and vaccination to reduce methanogens.
3. Methane production from the manure as anaerobically managed manure will result in methane release
- Proper balancing of feed will result in lower methane emissions as lower carbon to nitrogen ratios in feed lead to methane emissions.
 - The storage temperature of manure is important as at lower storage temperatures the methane production is highly reduced.
 - The use of biogas digesters where there is controlled anaerobic digestion of the manure in an enclosed environment, and the methane produced can be captured and utilized in the production framework or disposed of safely.
4. Nitrous emissions and ammonia volatilisation through improving the efficiency with which nitrogen is used
- Balanced feeding – giving the animal its daily protein/amino acid needs and not overfeeding protein.
 - Improved feeding practices such as grouping physiologically similar animals.
 - The use of an enclosed tank during storage to prevent volatilisation.
 - With grazing animals, avoid overgrazing and grazing animals on pastures with young lush forages that may have highly soluble nitrogen.

Food safety

One-third of all food produced in the world is lost or wasted from farm to fork, according to estimates produced by the FAO (2011). This wastage not only has an enormous negative impact on the global economy and food availability, but it also has major environmental impacts. Recent studies suggest that the world will need 70 to 100 percent more food by 2050 (Godfray et al. 2010). According to the FAO (2001), food security is defined as *‘a situation that exists when all people at all times have physical or economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life’*. Additionally, an inherent assumption of food security is that food is nutritious and safe. Food production in developing countries can be severely affected by market interventions in the developed world, such as subsidies or price supports (Godfray et al. 2010). Such is the case in the Caribbean region where preferential access to EU markets for exports such as banana and sugar has been lost. The effects of climate change, as well as the harsh competition in world markets underscore the openness and vulnerability of small, trade-dependent economies. The Caribbean is one of the most food insecure regions in the western hemisphere and has a high dependence on imported food. Food and nutrition security and safety are now important items on political agendas in the Caribbean region. The region must seek to find sustainable solutions to the challenges in the food and agriculture sector, as well as its vulnerability to global trends in food safety.

Food safety is a priority issue in agriculture, particularly in developing countries due to its linkage with food security and agricultural trade. The issue of genetically modified (GM) foods is also closely linked to food safety. Food safety is defined as *‘providing assurance that food will not cause harm to the consumer when it is prepared and/or eaten according to its intended use’* (FAO 2001), while the WHO (2004) refers to it in terms of food-borne illness, and defines it as *diseases, usually either infectious or toxic in nature, caused by agents that enter the body through the ingestion of food’*. Food safety refers to the conditions and practices that ensure foods are protected from unintentional contamination, thus rendering them safe to eat. It is a function of the nature of technology used to produce and process food. As such, it can be manipulated through genetic improvement, agronomic practices and post-production storage and processing (FAO 2001).

Food consumption all over the world is a mixture of imported agricultural products and domestic products making it difficult to find the contamination source in the case of a food scare. The globalization of the food production and the intensification of food trade enhance the risks associated with food safety (Polimeni, Iorgulescu and Bălan 2013). Food safety involves the implementation of several practices and strategies, aimed at avoiding the contamination of food, and the growth and proliferation of organisms, along the continuum

of production to consumption or ‘from farm to fork’ (Figure 7.6). Contamination can occur at several points along this food value chain such as on the farm or in the field, at the slaughter house, during processing, during transportation, in traded products, and in the home.

Management of food safety at the primary stage of production (i.e. the farm), is accomplished mainly through prevention of contamination as illustrated in Table 7.5. On-farm food safety practices help producers reduce the potential for hazard contamination of crops, livestock, personnel (farm workers and other employees) and facilities. Such contamination could lead to risks for crop or livestock produce, product spoilage (reduction in quality and subsequently quantity) and human injury or illness (choking, infections, diseases, illnesses and death). Once a hazard of any kind has been identified, it is important to assess the risk of injury or harm.

Failure to reduce food safety risks leads to an increasing strain on farm, and by extension, national economies, due to loss of productive work time, increasing cost of health care, costly surveillance programmes, loss of life, impact of vulnerable segments of the population (including children, aged persons and low income groups), impact on trade, and reduced food security.

Figure 7.6: ‘Farm to Fork’ Food Value Chain

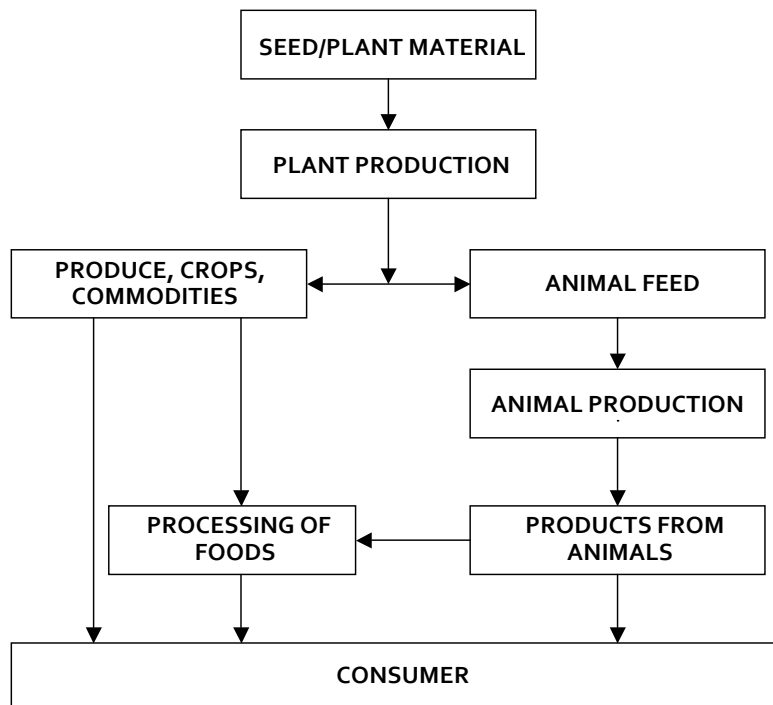


Table 7.5: Some on-farm considerations to reduce food safety hazards

On-Farm Considerations	Types of Food Safety Hazards/ Contamination	Verification	Mitigation Effects
Use of fertilizers	Chemical and microbial	Understanding whether to use organic or inorganic fertilizers Test for N, P, K nutrients.	Can be stored in plastic closed containers but not on floor, soil or with harvested products Powders, granules and liquids should be stored in covered areas to avoid contaminating water sources Lime and gypsum can be stored in the field Material Safety Data Sheets (MSDS) must be available.
Naturally occurring toxins:- Mycotoxins, such as aflatoxin and ochratoxin A, are found at measurable levels in many staple foods	Microbial	Analysis of soil pH, organic matter, heavy metal levels Analysis of water to determine that levels of heavy metals are within the acceptable range.	• Ensure soil is not acidic. • Ensure organic matter content is acceptable to stabilize heavy metals. • Avoidance of phosphate based fertilizers as they contain high contents of cadmium. • Establish records that indicated the date sampled, site sampled, tree sampled, water source sampled. All records must be signed by the relevant person at each stage throughout the sampling and testing procedures. All testing should be done at a certified laboratory.
Polycyclic aromatic hydrocarbons	Chemical	Contamination from airborne transportation of diseased particles, soil, water, emissions from forest fires and processing of foods such as drying and smoking	Chemical analysis of air, water, soil and processed foods.
Postharvest operations (handling, storage, drying, processing, packaging, transportation, marketing)	Physical, chemical and microbial	Routine Inspection and testing of produce	Use of GAPs and GMPs Implement farm certification and monitoring systems. The use of sorting, pre-cooling, chlorinated wash water, dips, refrigeration, packaging and appropriate transport and storage containers can reduce microbial load and improve quality and shelf-life.

On-Farm Considerations	Types of Food Safety Hazards/ Contamination	Verification	Mitigation Effects
Site selection: potential for contamination of crops, erosion of soil, drainage issues and wind exposure	physical, chemical and microbial	Soil testing for physical, chemical and microbial contamination	Review previous crop storage where there may be possible heavy build-up of herbicides that can harm other crops.
Heavy metals: e.g. lead, mercury, cause neurological damage in infants and children. Exposure to cadmium can also cause kidney damage, usually seen in the elderly.	Physical and chemical	Analysis of soil pH, organic matter, heavy metal levels Analysis of water to determine that levels of heavy metals are within the acceptable range.	• Ensure soil pH is not acidic. • Ensure organic matter content is acceptable to stabilize heavy metals. • Avoidance of phosphate based fertilizers as they contain high contents of cadmium. • Establish records to include date sampled, site sampled, tree sampled, water source sampled. All records must be signed by relevant persons at each stage throughout the sampling and testing procedures. All testing should be done at a certified laboratory.
Sanitary conveniences	Microbial	Testing for microbial contamination	Provision of adequate sanitary facilities, including potable water, rest areas and hand-washing facilities. On-farm living quarters must have basic amenities. Supply clean water, soap and single-use towels for hand washing.
Water including potable water, irrigation/ fertigation and waste water	Physical, chemical and microbial	Physical inspection and testing for contamination (chemical and microbial-faecal coliforms).	Physical waste identified separated and re-cycled where appropriate. Use of retention ponds and pre-treatment of water. When potable water is unavailable test water and keep records.
Chemical storage area and labelling, including workers handling and or administering veterinary medicines, chemicals and disinfectants	Chemical	verification of labelling on chemicals testing maximum residue levels (MRLs) on crops and foods	Appropriate chemical storage, adopt farm certification, training and monitoring systems. Use only approved pesticides in correct dosage and according to label instructions. Use of material safety data Sheets (MSDS) and appropriate personal protective equipment (PPEs). Practice crop rotation and implement an IPM system, including biological controls.

On-Farm Considerations	Types of Food Safety Hazards/ Contamination	Verification	Mitigation Effects
Use of manure	Pathogenic bacteria (e.g. <i>Escherichia coli</i> O157:H7, <i>Salmonella</i> and <i>Cryptosporidium</i>) Faecal Chemical	Adequate treatment of manure, use of manure compost piles to achieve high temperatures to kill pathogenic bacteria	Know source of manure Understand when to apply manure Adapt soil testing and GAPs Separate manure storage and treatment from fresh produce areas i.e. physical containment of manure to avoid contamination by other animals including birds and pests as well as fresh produce.

Contaminants, such as mycotoxins, veterinary drugs or dyes can be introduced into foods either as a result of their occurrence in the environment, natural infection by fungi, or other human activities. Other chemicals such as mercury, lead, cadmium, chloroform, benzene and polychlorinatedbiphenyls (PCBs) can get into the water supplies that are used to process foods. IPM, required by both domestic and export markets can bring about a reduction in chemical use and help in the protection of the environment. It involves the application of pesticides and herbicides only when necessary, preferring environment- friendly chemicals, and promoting the use of biological control and can be used in a variety of crops such as avocado, mango, pepper, tomato and citrus.

Poor sanitation during each stage of the transport process greatly increases microbial contamination of fresh produce consumption of which, can result in food- borne illness. Most of the reported outbreaks have been associated with bacterial contamination, particularly members of the *Enterobacteriaceae*, followed by viruses, and then parasites. The most commonly recognized foodborne infections are caused by *Campylobacter*, *Salmonella* and *Escherichia coli* O157:H7. The viruses involved in outbreaks have a human reservoir (e.g. Norwalk-like and Hepatitis A), and can be associated with products grown in contact with the soil and/or water. Outbreaks linked to protozoa (e.g. *Cryptosporidium*, *Cyclospora*, *Giardia*) have been associated more with fruits than vegetables. Protozoa and viruses are most often associated with contaminated water or food handlers (European Commission 2002).

Since no farmer or food manufacturer can guarantee neither food safety on their own, nor safety throughout the food value chain, certification standards such as Global GAP, HACCP and ISO 22000 play key roles in ensuring food safety. Global GAP focuses on the farming side of the value chain while the ISO 22000 and HACCP can be applied to every stage of the food value chain. Capacity building in the form of post-harvest extension and training programmes which include traceability and record keeping procedures are also components of these standards. Independent third parties or certification bodies can conduct audits of

farms, organizations and suppliers along the entire value chain, and issue a certificate to confirm a successful audit. However, the acceptance of food safety standards and certification may vary from market to market.

Regulatory environment

National food control systems are essential to protect the health and safety of domestic consumers, as without these, consumers can be susceptible to food borne illness outbreaks. They are also critical in enabling countries to assure the safety and quality of their foods entering international trade, and to ensure that imported foods conform to national requirements. The new global environment for food trade places considerable obligations on both importing and exporting countries to strengthen their food control systems and to implement and enforce risk-based food control strategies. In many countries, including the Caribbean islands, effective food control is undermined by the existence of fragmented legislation, multiple jurisdictions, and weaknesses in surveillance, monitoring and enforcement. Information exchange, technology transfer and capacity building are also critical strategies for food security in the Caribbean islands. In the absence of public standards (many of which have been adopted from the Codex Alimentarius Commission), farmers should be encouraged to apply voluntary standards such as Good Agricultural Practices (GAPs) while manufacturers and food processors should adhere to current Good Manufacturing Practices (GMPs). Farmers and food processors targeting export markets however, must ensure compliance with the laws of the exporting country and may be forced to adopt private standards to gain entry into the foreign markets. Governments, on the other hand must demonstrate the political will, through the provision of regulatory, financial, technical and infrastructural support mechanisms to assist farmers and food producers.

In the case of Trinidad and Tobago, the annual food import bill in 2013 was estimated at TT\$4 billion (approx. US\$620.2 million). Imports of food and beverages into Trinidad and Tobago fall under the Food and Drugs Act of 1960. Additional laws for fish and fish products were incorporated into the Food and Drugs Act, while amendments were made for alcoholic beverages and other products. The Chemistry, Food and Drugs Division (CFDD) falls within the purview of the Ministry of Health, which also enforces some components of the Pesticides and Toxic Chemicals Act. Most of the food safety laws are outdated and while revisions have been made, many are still in the drafting stage, and have not been proclaimed into law. The Ministry of Food Production administers the laws regulating Plant and Animal controls. Table 7.6 illustrates the legislation under which food safety is monitored and enforced in Trinidad and Tobago.

The regulatory climate is changing very rapidly, and regional countries need to ensure regulations are updated and enforced related to both the importation and exportation of

food. The Food Safety Modernization Act (FSMA) passed by congress in the USA on 4 January 2011, represented a significant event for the US Food and Drug Association (FDA). The FSMA allows the FDA to enforce more stringent compliance regulations and equips manufacturing and distribution companies with better response strategies to problems as they occur. Furthermore, the act extends to creating a uniform standard for imported foods to match those of domestically produced foods within the US. With limited exceptions, the rule would require domestic and foreign facilities that manufacture, process, pack, or hold human food to have written plans that identify hazards, specify the steps that will be put in place to minimize or prevent such hazards. In addition, manufacturers will be able to identify monitoring procedures, record monitoring results, and specify what actions should be taken to correct problems that arise. The FDA evaluates the plans developed, and continues to inspect the facilities to make sure the plans are being properly implemented.

Table 7.6: Current gaps in existing legislation governing food safety in Trinidad and Tobago

Legislation	Current gaps in existing legislation related to food safety
• Plant Protection Act 13 of 1975 • Registration of Plant Varieties Act (1997)	• Understanding the sanitary and phyto-sanitary requirements for the export markets and the application of non-chemical pest control practices are necessary to maintain food safety requirements. • There are no legal requirements for maximum residue levels (MRLs) of chemicals, traceability nor farm certification systems. • Limited efforts at capacity building in GAPs and farm registration are currently undertaken by the National Agricultural Marketing and Development Corporation (NAMDEVCO) in Trinidad. • Laboratory upgrade of infrastructure is required.
• Animal (Diseases and Importation) Act, Chapter 67:02, Act 19 of 1954, amended by Act 17 of 1997 • Conservation of Wildlife Act, Chapter 67:01, Act 16 of 1956, amended by Act 14 of 1963	• Update legislation on importation of animals and animal products. • Licensing and regulation of veterinarians is needed. • Training in the diagnosis of diseases related to animals, bees, etc. • Licensing requirements for the operation of bee hives, poultry depots, and livestock units. • Laboratory upgrade of infrastructure is necessary.

Legislation	Current gaps in existing legislation related to food safety
• Fisheries Act, Chapter 67:51, Act 39 of 1916, amended by Act 23 of 1975.	• This will be superseded by the Fisheries Management Bill, 2011 and provides a more controlled access to the fisheries resources of Trinidad and Tobago. • There is need to address the importation of live and processed fish and certification systems such as GMPs and HACCP. • Laboratory upgrade of infrastructure is required.
• Food and Drugs, Chapter 30:01, Act 8 of 1960 updated December 2007 • Public Health Ordinance (1917, adjusted in 1950s) • Pesticides, Toxic Chemical Act of 1979	• Regulations need to address GMPs, HACCP and FSMA for manufacturing facilities and particularly for meat and dairy products. Same with import/export of products. • Public health inspectors do not have authority to close non-compliant plants nor retail markets. • No legislation with respect to levels of chemicals and mixtures of chemicals that farmers can use on crops. • No residue (MRLs) testing, nor penalties for use of banned chemicals. • No legislation for organic farming.

Food traceability systems

Food traceability according to Alli (2012), can be defined as the identification of the origin, past or current location, condition and application of an item's known history throughout the supply chain, or the tracking of a food item forwards or backwards throughout the food supply chain from farm to table. Tracking (forward) is following the path of a traceable item through supply chain as it moves between parties. Tracing (back) is identifying the origin, attributes, or history of a traceable item located within the supply chain in order to improve food safety and reduce the potential of food recalls. Traceability systems from farm to fork should be implemented and some of the key steps in implementing such a system include: identifying key items that are traceable, determining for each item what details are required, developing a record keeping system, and developing an internal traceability programme. The benefits of such a system include:

- compliance with best practices worldwide
- risk reduction of unsafe foods to the consumer
- consumer confidence (assurance that foods are safe and wholesome)
- reduced costs, improved marketability and more competitive businesses both in local and foreign markets

- decrease in food borne illnesses
- faster recall of foods from the supply chain (production, processing, distribution, transport, retail and consumer).

Looking forward

To remain competitive in today's global business environment a thorough understanding of all parts of the agri-food value chain is important (Devanney, 2006). However as value chains become sophisticated and vital to the competitiveness of many industries, this interlinked, global nature also makes them increasingly vulnerable to a range of risks. To ensure long-term food security under constantly changing agro-ecological and environmental conditions, considerations should be given to the implementation of sustainable agricultural practices such as:

- plant genetic resources which are resilient to climate change and pests and diseases through genetic manipulation, for example, the insertion of a gene for herbicide resistance or another for resistance to pest-insect toxin.
- identifying and developing alternatives to chemical methods for the control of postharvest pathogens and pests such as the reinforcement of host resistance, biological control and applications of physical treatments.
- reducing risks associated with potential microbiological outbreaks of human pathogens that may reside on produce utilising novel methods to sanitise produce.
- exporting sensitive produce by sea under controlled conditions in order to reduce environmental problems and costs associated with air transportation must be considered.
- recycling of bio-waste for energy, feed and fertilizer can reduce the environmental impact.

In the area of biotechnology, the next decade will see the development of combinations of desirable traits and the introduction of new traits such as drought tolerance for climate change mitigation effects. The production of cloned animals with engineered, innate immunity to diseases that reduce production efficiency will have the potential to reduce substantial losses arising from mortality and subclinical infections. Biotechnology could also be used to produce plants for animal feed with modified composition that increase the efficiency of meat production and lower methane emissions. While the use of biotechnology can lead to improved food safety through reducing pesticide use and improving postharvest quality of crops, the issue of trust and public acceptance of the technology has been highlighted in debates over the acceptance of genetic modification (GM) technologies. This

technology may also pose health risks due to the possible transfer of toxins and allergens between species as GM involves germline modification of an organism and its introduction to the environment and food chain. Thus, a number of particular environmental and food safety issues will need to be assessed (for example FAO 2001; Godfray et al. 2010).

Many effective options are available for reducing the polluting and degrading effect and food safety risks associated with agricultural production practices. An increase in education and awareness among food products is only one small aspect in the fight to mitigate agricultural pollution and food safety concerns. It is essential that environmental policies and relevant legislation be put in place to combat these existing problems. The policies and legislation must be in sync with the scientific and technical options, some of which are provided in this chapter for consideration. It is to be noted that many of the available options are associated with some direct costs, however these immediate cost should be viewed as an investment that will yield long-term benefits.

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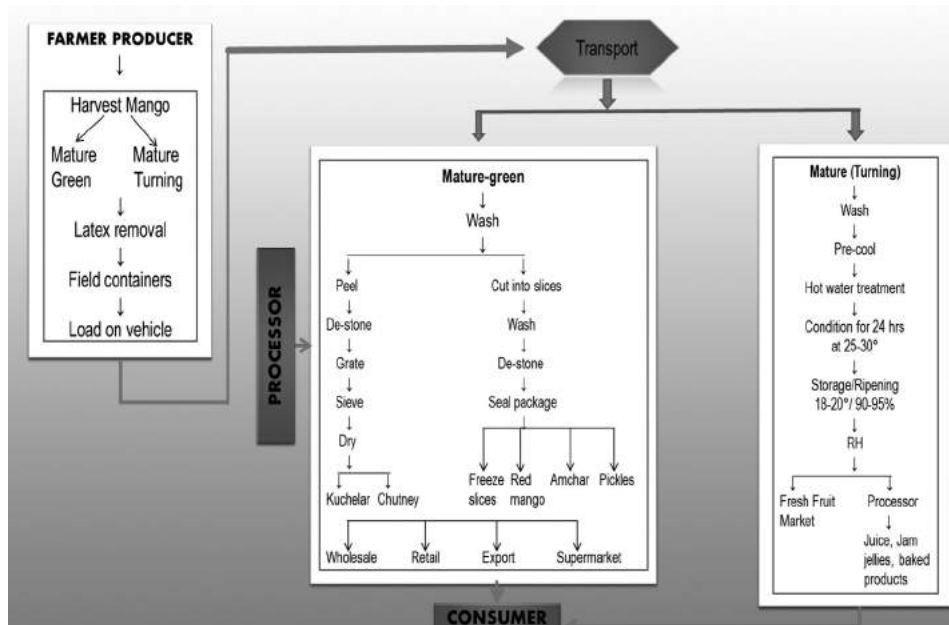
Appropriate Logistics to Reduce Losses in the Postharvest Handling System: Case of Mango

Majeed Mohammed

Fresh fruits and vegetables undergo continuous changes throughout the supply chain, from the point of harvest until consumption. As such, the postharvest handling logistics of these commodities are different from those of other food products. Because of their living and perishable nature, fresh commodities are subject to biochemical and physiological changes resulting in deterioration over time as the commodity moves along the postharvest handling system (Figure 8.1).

The quality of freshly harvested fruits and vegetables is determined by biological variations, environmental conditions, handling methods and sanitation practices. These parameters are further influenced by logistic activities such as the type of packaging, loading and unloading activities, availability of temperature controlled transport vehicles, storage facilities and the types of postharvest treatments that are implemented (Mazini and Accorsi 2013).

Figure 8.1: Postharvest handling operations and value chain for mango



While these postharvest activities cannot stop the rate of quality deterioration, they can impact the speed of quality loss by either slowing down the process via low, safe non-chilling temperature and high relative humidity, or speed it up by abusive handling whereby physical damages are incurred. Accordingly, the perception of product quality in the supply chain cannot be solely restricted to the properties of the commodity but also to the supply chain agents, processes and activities along the supply chain. Time and coordination are required to efficiently move perishable fruits and vegetables along the postharvest handling system, every delay can have negative quality consequences. In many countries, a high percentage of produce losses occur before fresh commodities reach the targeted consumers. Fonseca and Vergara (2014) estimated that postharvest losses can range from 37 percent for roots and tubers to 50 percent for fruit and vegetables. Such high losses compromise the income to producers and handlers, and eventually increase costs to consumers, thereby impacting household food security.

Pullman and Zhaohui (2012) emphasised that in order to combat losses of horticultural commodities and their subsequent impact on the well-being of societies, efficient logistics systems need to be established to deliver the right product at the appropriate time. Logistics, according to Fonseca and Vergara (2014), are fundamental for horticultural products as their high perishability requires complex planning, including short-term decisions on transportation modes, handling, packaging and storage arrangements. To ensure fresh commodities do not become damaged or compromised throughout the postharvest handling system there must be a greater reliance on maintaining the cold chain. This involves the movement of temperature sensitive commodities along a supply chain through thermal and refrigerated packaging methods, and the logistical planning to protect the integrity of these perishable commodities. The cold chain therefore can be considered:

- A science, because it requires an understanding of the chemical and biological processes linked with perishability.
- A technology, since it relies on physical means to ensure appropriate temperature conditions along the supply chain.
- A process, because of the series of tasks must be performed to prepare, store, transport and monitor commodities that are sensitive to chilling injury and heat injury.

LOGISTICS PERFORMANCE

In Latin America and the Caribbean (LAC), trade globalization has become a challenge for logistic operations in the fresh produce industry (Fonseca and Vergara 2014). Currently all LAC countries engage in importing some portion of the fresh produce they consume. While the USA is the dominant trading market for export commodities from LAC, it is also the largest hub for the re-shipping of consignments from and to other regions. For example, pineapples shipped from LAC to the Caribbean normally enter a seaport in USA, which means that LAC produce is in transit for long distances before getting to its final destination (Duran Lima and Lo Turco 2010). Unless logistics operations are optimized, long travelling distances increase the risk of low shelf life in imported produce when it arrives at the destination market (Fonseca and Vergara 2014). In LAC, the transformation of retail marketing of fresh produce has impacted on logistics as well. Development of supermarkets with distribution centres or market chains continue to grow, accounting for more share of the retail market for fresh produce in the region. Supermarkets and associated chain stores have adopted strict quality parameters which have ultimately created the need for improved logistics necessary to reduce losses during transit. At the same time, these high stringent quality standards have also influenced a higher risk of losses from rejections due to unacceptable quality (Lundqvist, De Fraiture and Molden 2008).

LOGISTIC CHALLENGES AND INTERVENTIONS

The following is a list of limitations in logistic operations in LAC for which key interventions are required in order to address the problems associated with high postharvest losses:

- a. Inadequate infrastructure for proper coordination of postharvest activities, this is primarily due to underdeveloped secondary and tertiary roads often punctuated with potholes, slippery surfaces (especially in the wet season), and unpaved surfaces which lead to extensive physical damage such as abrasions, compressions, punctures, which create avenues for secondary infections. Adequate facilities to pre-cool, sort, grade, apply post-harvest treatments, along with storage and packaging, have also been found to be wanting. Levels of physical and pathological defects of mango fruits when subjected to grading requirement and tolerance are classified in Table 8.1.
- b. Limited information and communication technologies and their application – these also represent a major constraint to the growth and competitiveness of the fresh produce industry throughout the region, particularly in rural areas.

Table 8.1: Mango fruit grading protocols

Grade designation 1	Grade requirements 2	Grade tolerances 3
Extra class	Mangoes must be of superior quality. They must be characteristic of the variety. They must be free of defects, with the exception of very slight superficial defects, provided these do not affect the general appearances of the fruit.	5 percent by number of weight of mangoes not satisfying the requirements for the grade, but meeting those of Class I or exceptional, coming within the tolerances of that grade.
Class I	Mangoes must be of good quality and characteristic of the variety. Mangoes may have the following slight defects, provided these do not affect the general appearance of the produce, the quality, the keeping quality and presentation in the package: - slight defects in shape; or - slight skin defects due to rubbing or sunburn, suberized stains due to resin exudation (elongated trails included) and healed bruises not exceeding 2,3,4,5 sq.cm. for size groups A, B, C, and D respectively	10 percent by number or weight of mangoes not satisfying the requirements for the grade, but meeting those of Class II grade or, exceptional, coming within the tolerances of that grade.
Class II	The grade includes mangoes which do not qualify for inclusion in the higher grades, but satisfy the minimum requirements. Mangoes may have the following defects, provided they retain their essential characteristics as regards the quality, keeping quality and presentation: - defects in shape; or - slight skin defects due to rubbing or sunburn, suberized stains due to resin exudation (elongated trails included) and healed bruises not exceeding 4,5,6,7 sq. cm for size groups A, B, C, D respectively.	10 percent by number or weight of mangoes not satisfying the requirements of the grade, but meeting the minimum requirements.

- c. Inadequate cold chain facilities – fresh produce demands proper temperature and relative humidity management in the entire logistic process. The development of telecommunication, information technology and information systems, especially the rise of wireless sensing technologies such as Radio Frequency Identification (RFID) and wireless sensors, provide a feasible way to improve the safety and quality of cold chain facilities. Integrating RFID systems with conditions-monitoring systems will also enhance existing track and trace applications, not only in terms of the location and movement history, but more importantly, as it relates to the condition of perishable commodities. Moreover, the availability of commodity-trace history data in combination with historical monitoring data can facilitate numerous decision-making processes.
- d. Lack of trained human capital – particularly to determine rejections arising from inappropriate harvesting and handling protocols due to overexposure of chilling sensitive commodities to extremely low temperatures, as well as the use of unsanitized water to wash and hydro-cool fruits and vegetables. Such problems can arise where there are untrained personnel working at different points in the postharvest handling system. Logistic service providers often lack sufficient knowledge in the postharvest handling of horticultural commodities. Further, many produce managers employed at supermarkets lack training in logistics concepts and procedures, which may in turn limit their ability to design appropriate solutions to store and transport commodities in an efficient manner (Rodriguez and Respetto 2013).

LOGISTICS PLANNING AND MANAGEMENT

A logistical system is composed of a number of elements which have to be managed properly in order to deliver final products in the right quantities at the right time and quality at the right place, and at a reasonable cost. This puts challenging requirements on the agro-food chain (Van der Vorst, Silva and Trienekens 2007) and there is need to make the specific logistics decision in order to meet customer expectations. For example, whilst temperature and relative humidity are critical factors affecting fruit quality (Kader, 2002), logistics decisions heavily determine these conditions by defining storage time and time of transporting perishable commodities (Luning and Marcelis 2007).

INTEGRATION OF QUALITY CONTROL AND LOGISTICS CONTROL

All logistics activities are dependent on time-dependent product information obtained through quality control activities. Time-dependent quality information of product properties could assist in ensuring that products reach intended consumers before the development

of defects. Thus, a higher level of integration of quality control and logistics control is required to predict incidences of fruit defects as well as to encourage exchange of quality information in the chain and the level of flexibility of the delivery systems to match specific consumer requirements. In underscoring the importance of quality control and logistics in the postharvest handling of fruit and vegetables, a detailed examination of these systems in mango will now follow.

QUALITY CONTROL AND LOGISTICS CONTROL IN POSTHARVEST HANDLING SYSTEM OF MANGO

Pre-harvest factors

Varietal differences, growing regions, climatic conditions and agronomic practices influence the expression of fruit maturity in all commodities including mango, with the stage maturity at the time of harvest also being crucial to the eating quality of the ripe fruit (Figure 8.2 and 8.3). Therefore, selection of the appropriate mature fruit at harvest is based on several parameters such as fruit shape, peel colour, peel texture, flesh firmness, flesh colour development, soluble solids content and latex content. As such, it is important that mango producers validate those parameters that are most effective and dependable for their own conditions (Brecht 2010).

Harvesting and maturation indices

Knowledge of the maturity indices of the particular cultivar will enable harvesters to determine the best time to harvest fruits. Logistical arrangements to speed up the harvesting process will depend on availability of harvest aids such as ladders, clippers, nets, and harvest baskets. While harvesting mangoes at the optimum stage of physiological maturity facilitates synchronised ripening, the use of the correct harvesting aids ensures minimal physical damage and lower postharvest losses.

Protection of harvested fruits from exposure to direct sunlight while awaiting transport to packinghouses, which can vary from half an hour to six hours, is critical in order to maintain fruit quality. Direct exposure to sunlight for prolonged periods of more than six hours results in higher flesh temperatures, thereby increasing the rate of respiration, transpiration and ethylene production, all of which have the potential to shorten the shelf life.

Latex exudation from mango stems at the time of harvest (Figure 8.4) can cause severe skin injury and staining, along with blister formation when fruits are subsequently ripened, resulting in unacceptable cosmetic appeal (Figure 8.4). Latex stains are aggravated when mangoes are exposed to heat and timely logistical procedures must be implemented to avoid this damage to fruits. To avoid latex damage of mango fruits in Brazil for example (Brecht 2010), mango producers train their harvesting crew to harvest mangoes with stems

over 5 cm in length and immediately transport them to packinghouses where the stems are trimmed after 12–24 hours. This procedure ensures that latex drip would no longer occur even if the stem is clipped shorter. Other suggested methods include: de-sapping in a one percent solution of calcium hydroxide; washing fruit in one percent potassium sulphate; applying a surface coating to fruit prior to de-sapping; trimming and de-sapping at the packinghouse, followed by inversion on a stationary rack or a roller-conveyor; running below water or water and detergent sprays for 20 minutes (Yahia 2011).

Transport from field to packinghouse

It is best to transport mangoes using trucks or pick-up vans that allow air circulation as the vehicle moves from the field to the packing house. To minimise physical damages (Figure 8.5), harvested fruits should be carefully placed in light coloured plastic crates that are stackable and well ventilated. Vehicle loads must be protected from sunlight by covering the top layers of mangoes with a light coloured tarpaulin. This will reduce respiration and water loss resulting in longer shelf-life. In some Caribbean islands the national marketing boards provide refrigerated transport from the field to packing houses for a small fee. Refrigerated transport would initiate pre-cooling and further reduce respiration and water loss once accompanied by a relative humidity of 90–95 percent.

Alternatively, logistical arrangements to facilitate early morning, late evening or night time harvesting, loading and unloading operations and transport from field to packing house would also favour lower fruit temperatures that can better preserve the quality and shelf life of mango fruits. Equally important, is the need to have timely, well-coordinated schedules to allow for controlled quantities of mangoes to be delivered to the reception area at the packinghouse. If mango loads exceed the capacity of the reception lines then it will take a longer period for fruits to be unloaded on the reception lines. When mangoes, which have a climacteric pattern of respiration are exposed to high ambient temperatures are subjected to delays prior to unloading on packing lines, they would incur losses in quality due to accelerated respiration, ethylene production and transpiration rates. A smooth, timely flow of mango fruits from the field and rapid unloading onto reception lines requires logistical procedures to be programmed, monitored, controlled and expedited in an efficient manner.

Pre-packing house logistics

Optimizing the use of space in the packing house as well as the efficiency of resources on the mango reception line is critical for quality maintenance. A large unloading area would cater for more transport vehicles with fruits to be unloaded in a shorter time period. Packinghouses with large, open unloading areas have less traffic congestion and also provide protection of mango fruits against sunlight, and inadequate ventilation. They also make

representative sampling and inspections for quarantine and quality control purposes more effective. Minimizing delays wherever possible is essential, as mango fruits are known to undergo rapid compositional changes in the hours following harvest (Brecht 2010).

Major changes in total soluble solids (TSS) content, flesh firmness, skin and flesh colour can be manifested in mangoes as little as 24 hours after harvest. According to Brecht (2010), a 24-hour wait period prior to heat treatment of mango resulted in a reduction of heat injury symptoms. Furthermore, a time delay prior to heat treatment can be beneficial for low maturity mangoes. Average maturity, based on internal flesh colour, can be changed by one full stage in 24 hours under typical ambient temperatures, and TSS can increase by two to three percent, while flesh firmness decreases by two to five pounds force (lb/f) according to Brecht (2010).

Packing house sanitation protocols

Regular monitoring and application of sanitation protocols of packinghouse equipment and facilities must be implemented. Containers, packing line equipment (sorters, graders, dryers), refrigeration units, transport vehicles, forklifts and floors must be sanitised using a chlorine solution of 200 ppm between 25 and 43°C, and adjusted to a pH 7 with citric or acetic acid. Pets, rodents, birds and insects must be excluded from all areas.

Packing house post-harvest treatments logistics

Temporary storage of mangoes in the shade prior to unloading on packing lines should be implemented. Fruits exposed to the sun in excess of 1 hour can be 14°C higher than fruits held in the shade, thereby resulting in heat injury. Likewise, flesh temperatures above 30°C for extended periods after harvest will result in poor ripening and flavour.

Hot water treatment

Hot water treatment (HWT) is recommended for mango fruits as an effective post-harvest treatment to minimise fruit fly damage and the fungal disease Anthracnose. There are specific requirements for successful hot water treatment of mangoes. Fruits are immersed in hot water at 46°C, with the time interval varying according to fruit shape and fruit weight. For example, mangoes with a round shape (e.g., Tommy Atkins, Haden, Keitt and Kent), weighing less than 500g will require 75 minutes, fruits between 501 and 700g need 90 minutes, while fruits between 701 and 900g will need 110 minutes. Mangoes with a flat shape such as Manila and Frances and weighing less than 375g require 65 minutes, and those weighing 376–570g need 75 minutes (USDA 2010). Accordingly, logistical protocols must be instituted to ensure that mangoes are graded by weight and size prior to hot water treatment in order to control fruit fly and at the same time to reduce fruit injury.

Furthermore, packing house managers should advise packing line operators on certain strategies that could improve the hot water treatment and overall fruit quality. Brecht (2010) has identified these as:

1. allowing only mature fruits to be given the treatment since immature mangoes are more susceptible to damage by hot water;
2. eliminating latex contact with fruit surfaces during harvest since latex damage is accelerated by hot water;
3. using potable water only, or sanitized water the first time the water is heated; and
4. improving temperature control in hot water tanks to allow treatment at the lowest allowable temperature since even 0.5°C above the required temperature could make a difference in fruit tolerance.

Post-hot water treatment cooling

Hydro-cooling mangoes after hot water treatment decreases flesh temperature more rapidly than holding in air, thereby reducing hot water injury. This pre-cooling treatment requires specific time-temperature procedures. For example, mangoes should be hydro-cooled immediately after heat treatment, by adding an additional 10 minutes to the hot water protocol. The hydro-cooled water temperature must be maintained at 21–22°C, and the duration of hydro-cooling should allow fruit flesh temperature to be between 27 and 29°C. Sanitizer levels in the hydro-cooled water should be maintained, such that effective free chlorine is 50–100ppm (Brecht 2010). Hydro-cooled mangoes must be immediately packed to minimize re-warming of fruits.

Sorting and grading

Sorting and grading must be done to remove fruits with physical injuries, incipient decay, misshapen fruits, and fruits with physiological disorders, such as heat injury or internal breakdown, lenticel damage and surface scald. Grading mangoes provides the following advantages. It:

- provides common basis for assessment by all, and is therefore beneficial to the producers, traders as well as to the consumers;
- enables producers to get a better price for their mangoes;
- assists producers and other intermediaries in preparing fresh mangoes for market with appropriate labelling;
- helps consumers to get standard, quality mangoes at fair prices;
- allows consumers to compare the prices of different qualities of mango in the market;

- assures quality of the mangoes and also reduces cost of marketing and transportation;
- enables mangoes of similar grade can be stored in bulk;
- facilitates a better understanding of market values;
- enables e-trading so that mangoes can be bought and sold without inspection;
- provides an authentic and scientific basis for promoting and managing marketing systems;
- serves as a realistic and common basis for market intelligence and reporting.

Waxing

Brecht (2010) recommended waxing of mangoes due to the resultant improvement of appearance, glossiness, and reduced water loss, but cautioned about the need for uniform wax distribution and wax formulation strength. For example, application of full-strength carnauba-based wax can induce lenticel damage on immature mangoes as well as peel damage, which could develop after a period of refrigerated storage and transport. The use of water-soluble coatings ought to be avoided since this can be dissolved during subsequent handling when condensation occurs, if and when cold fruits are subjected to warmer temperatures.

Packaging and palletisation

Mangoes should be packed in single layered, one or two-piece full telescopic, self-locking fibreboard cartons with bursting strength requirements of 250–275lb/in²). Ventilation and handle holes are recommended to provide adequate ventilation and for ease of handling. A layer of shredded paper at the base of the carton is desirable to assist in cushioning the fruits. Each alternate mango in a carton should be wrapped in tissue to reduce fruit to fruit rubbing. Small identity labels attached to alternate fruit will enhance product presentation. Palletisation is essential to minimise fruit damage due to multiple handling, and can also aid in the movement of fruit within the packinghouse, or during temporary storage (Medlicott 1990).

Storage and ripening

Attention to strict logistical procedures is necessary to optimize the ripening of mangoes. Although fruit ripening varies according to the variety and origin, a temperature of 20–22°C and 90–95 percent relative humidity is recommended. It must be noted however, that ripening at 15.5–18°C may result in the most attractive skin colour, but the flavour will remain tart and the mangoes will require a further two to three days at 21–24°C to attain a sweet flavour. Ripening at 27–30°C may result in mottled skin and strong flavour, and is retarded above 30°C. Initiation and synchronisation of ripening and a shortening of the

ripening time of mangoes can be achieved with exposure to ethylene gas. Treatment with ethylene gas is carried out in an air-tight room for 24 hours at 20–25°C and 90–95 percent relative humidity. The concentration of gas required during exposure is 10–100ppm. Air-tight rooms should have adequate air circulation to enable uniform distribution of ethylene throughout the room.

Prolonged storage of more than three to five days should not be used for fruits to be air-freighted. At storage temperatures below 12°C, unripe mangoes will develop chilling injury, which will cause a drastic reduction in fruit quality and increase spoilage. Symptoms of chilling injury include inhibition of ripening, pitting, internal discolouration, grey, scald-like discolouration of the skin, increased water loss, increased susceptibility to decay and undesirable changes to flavour. Chilling injury can be reversed if the time of holding at low temperature is prolonged. Variations exist in the degree of sensitivity of the different cultivars to chilling injury.

While most cultivars show injury below 10°C, if fruit have just reached maturity, tolerance to chilling injury increases as fruit ripen (Mohammed and Brecht, 2002). Other measures include maintenance in modified /controlled atmospheres, and conditioning at high temperatures (35–38°C) for a few hours before storage at low temperature. Chilling injury symptoms for example in cv. Keitt mangoes kept at 38°C for zero, 24 or 48 hours before storage at 5°C for 11 days decreased with increased duration at 38°C, while non-heated fruit developed severe chilling injury symptoms (McCollum, D'Aquino and McDonald 1993). Storage at 12°C and 90–95 percent relative humidity will maintain mangoes in an acceptable condition, and they will ripen in a satisfactory manner on transfer to warmer temperatures. This however will depend on variety, harvest maturity and the time of harvest in the season. Strict levels of quality control in fruit stored at low temperature is essential, as blemishes, bruises, and infections will manifest themselves to a greater degree as against when the fruit is exported by air, and marketed rapidly (Medlicott 1986). Flesh firmness is a good indicator of the stage of ripeness and can be used for managing mango ripening as shown in Table 8.2.

Table 8.2: Flesh firmness according to stage of ripeness

Ripeness stage	Flesh firmness (lb/force)	Recommendations
Mature green	>14	Treat with ethylene for 48 hours
Partially ripe	10-14	Treat with ethylene for 24 hours
Firm ripe	6-10	Best stage to send to retail stores
Soft ripe	2-6	Best stage for eating
Overripe	< 2	Good for juice

Source: Brecht (2010)

Post-harvest logistics associated with mango weevil

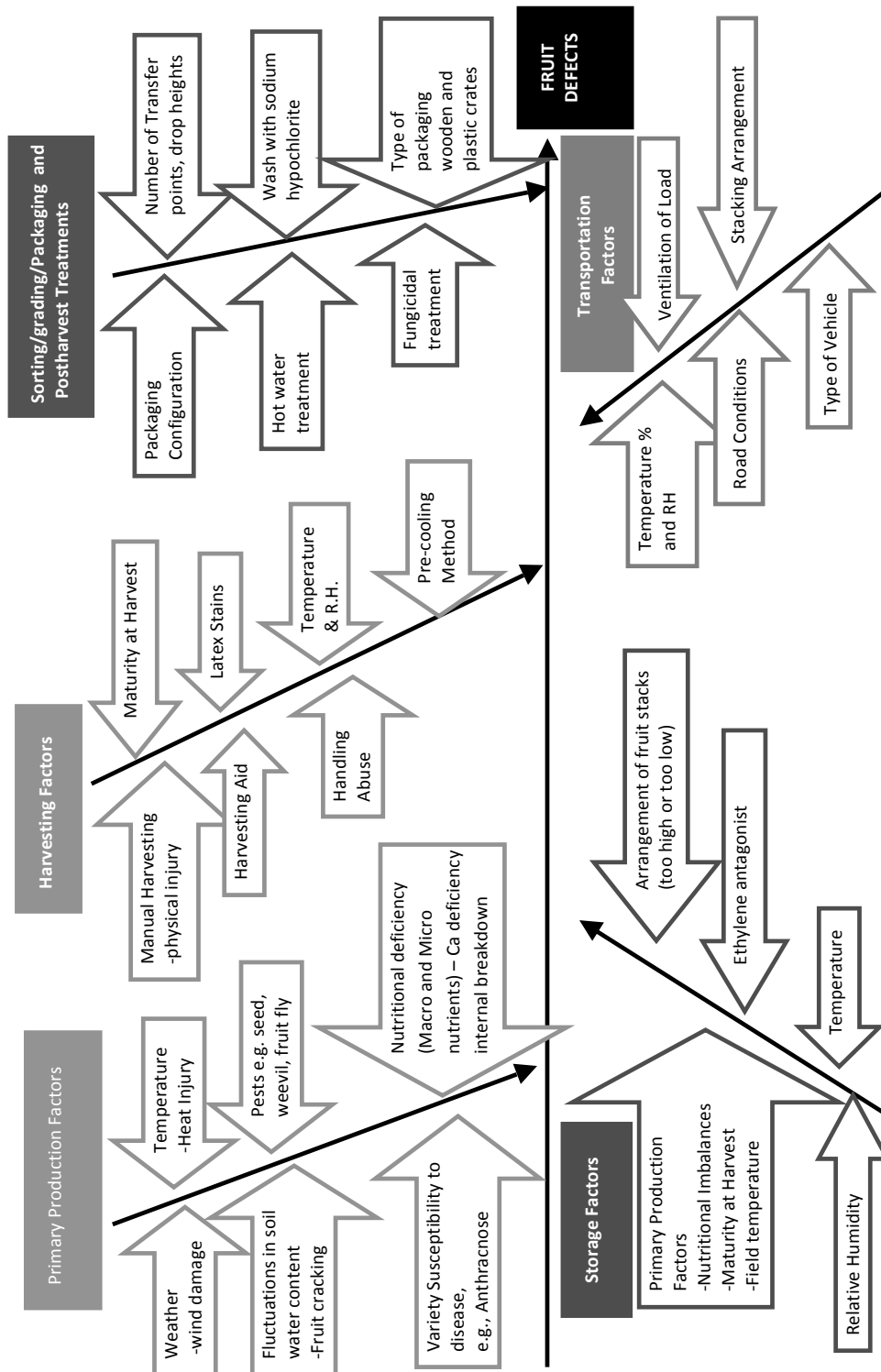
Mango is the only known host for the mango weevil (*Cryptorhynchus mangiferae*) which is found throughout most mango-growing regions and therefore it is a pest of quarantine significance. The weevil is primarily a pest of the seed, with one seed supporting up to five larvae, although occasionally it may be found in the flesh of the fruit. Eggs are laid on the outside of the developing fruit and the larvae penetrate the young seed, where the weevil completes its development (Yahia 2011). Mango oviposition occurs when the fruit is marble size, and may occur in less than eight days or up to 90 days (Shukla and Tandom 1985). As the fruit matures and the seed covering becomes hard, the first instars will not be able to penetrate the endocarp. Fruits, which fall to the ground, can become sufficiently damaged to allow the weevils to move out of the seed and seek hiding places where they can survive (Yahia 2011).

Mango seed weevil is an important limiting factor for the international trade of mango and prevents the export of fresh fruit to areas not infested with this pest (Figure 8.6). The flesh of ripe fruit is damaged when adults emerge from the seeds, and the weevil-damaged seeds may limit plant propagation in nurseries and orchards (Yahia 2011).

TRANSPORTATION LOGISTICS FOR LOCAL, REGIONAL AND FOREIGN MARKETS

Many of the losses that occur during transportation of mango fruits are due to inappropriate packaging and box arrangement inside transport vehicles. Common types of mechanical damage during transportation or distribution are impact damage through dropping, compression damage due to high stacking, punctures from container protrusions, and vibration damage (Figure 8.7). Vibration damage of mango fruits results in abrasion marks and cuts ranging from light scars to skin removal and possibly some flesh. Compression injury of mango fruits is associated with bruises, cracks, splits and deformation. Proper packaging and configuration of mango fruits help to immobilize the fruits within the container and reduce abrasion injury due to fruit-to-fruit contact during transportation. It is also important to stack fruits during transportation and distribution to enable proper air circulation to facilitate the removal of heat from the fruits as well as to dissipate incoming heat from the atmosphere.

Figure 8.7: Cause and effect diagram of mango defects



TRANSPORTATION LOGISTICS FOR LOCAL, REGIONAL AND FOREIGN MARKETS

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Mango fruits destined for shipping overseas should always be pre-cooled. Pre-cooling is essential to remove field heat, and slow the rate of the various biochemical and physiological processes within the fruit, as well as to decrease the refrigeration demand during cold storage or refrigerated transport. The selection and use of boxes for marine container shipment of mango fruits should include the following logistical procedures:

- corrugated boxes should be strong enough to withstand the effects of high humidity during storage and transport;
- boxes must never be stacked beyond edges of pallets;
- pallet loads should be unitized and secured;
- boxes and inner packaging should allow vertical airflow, especially if fruits are warmer than the refrigeration set point temperature when stowed;
- box vents should be aligned between layers of boxes;
- pallets should be used where deck board spacing aligns with box vents;

Thompson et al. (2000) have devised a container loading checklist, applicable to mango fruits for export to regional and extra-regional markets. Steps should be taken to ensure that the:

- interior of container is clean and odour-free;
- container is not damaged and door seals are in good repair, and floor drains are open;
- refrigeration unit is operational and the container is cooled to desired loading temperature;

- mango loads are at the specified pulp temperature and properly stowed;
- portable temperature recorder charts are marked with load identification, start time and date;
- thermostat is set to the correct temperature and fresh air exchange is set properly;
- security seal is properly attached to rear door of container.

LOGISTICS DURING PROCESSING AND DEVELOPMENT OF MANGO VALUE-ADDED PRODUCTS

Fresh-cut technology

The fresh-cut mango industry is developing rapidly throughout the Caribbean. The quality of the whole fruit of the fresh mango fruit is an important requirement for maintaining the wholesomeness and overall acceptability of fresh-cut mango slices or cubes. Other factors include the cultivar, pre-harvest cultural practices and climatic conditions, maturity at harvest, method of harvesting, postharvest harvest handling practices cited above, time between harvest and preparation of the fresh-cut fruit (Figure 8.8). The method of preparation, such as, sharpness of cutting blade or device, size and surface area of the cut pieces, washing, use of sanitizers and removal of surface moisture, and subsequent handling conditions (packaging, speed of cooling, maintaining optimum temperature and relative humidity, expedited marketing), must also be integrated into the overall quality logistics management to attain a high quality product.

In Trinidad and Tobago for example, the cultivars most suitable for fresh-cut purposes are cv. Long, cv. Rose, cv. Tommy Atkins, while in Guyana, it is mainly cv. Buxton spice. Regardless of the cultivar used for fresh-cut mango, fruits must be harvested mature-green to mature with light yellow flesh colour to ensure better flavour quality. The post-cutting life of fresh-cut mango at 5°C is eight to ten days, but depending on the cultivar this could be limited by flesh browning and softening (Yahia 2011). Peeling fruits to a depth of at least 2 mm and trimming flesh near the stem could however minimize fruit discolouration (Limbanyen, Brecht, Sargent and Bartz 1998). In other studies, Allong, Wickham and Mohammed (2000) indicated that fresh-cut slices from half-ripe (12.5 to 14 percent TSS) and firm-ripe (14.5 to 17 percent TSS) cv. Julie and cv. Graham mangoes had a shelf life of eight days or four days at 10°C. Half-ripe (13 to 16 percent Soluble Solids Content) mangoes were found to be ideal for fresh-cut in terms of maintenance of acceptable appearance, texture, and taste during post-cutting life at 5°C.

A major quality logistics requirement for fresh-cut mangoes is the use of very sharp tools to peel fruits and cut flesh into slices or cubes in order to reduce cellular damage and leakage

of cellular contents and enzymatic browning. Selection of packaging containers is another important logistical option. The use of rigid containers reduces water loss and mechanical damage during distribution. Shelf life of fresh-cut mango cubes or chunks (Figure 8.9 – page 210) is limited by browning and softening, but cubes treated with one percent calcium chloride and stored in sealed modified atmospheric packages had a shelf-life of 12 days compared to nine days for those dipped in one percent calcium chloride and stored in air. Sanitation of the whole fruit and the processing equipment, tools and facilities as well as the maintenance of a low temperature environment during all fresh-cut process are all important to reduce potential microbial problems.

Value-added products

Mangoes are processed into several products such as, juices, nectars, jelly powders, fruit bars, flakes, dried products, jams, puree, dehydrated products and canned slices. However, only about 0.22 percent of mangoes produced in the world are processed (Yahia 2011). Green mangoes are processed into pickles, brine stock and chutney (Figure 8.10 – page 210). There are two classifications of pickles; salt pickles and oil pickles, processed from whole and sliced fruit with and without stones. Diverse types of pickles vary mainly in the proportions and kinds of spices used in their preparations. The ingredients are mixed together and filled into wide-mouthed bottles, and extra oil added to form a 1-2cm layer over the pickles (Yahia 2011). Chutney is prepared from peeled, sliced or grated mature or semi-ripe mango by cooking the shredded fruit with salt over medium heat for five to seven minutes. Sugar, spices and vinegar are added, and cooking is done over moderate heat until the product resembles a thick puree. The remaining ingredients are added and simmered for another five minutes, cooled and preserved in sterilized jars. Spices usually include cumin seeds, ground cloves, cinnamon, chilli powder, ginger and nutmeg (Yahia 2011).

Drying procedures such as sun-drying, tunnel drying, vacuum drying, or osmotic dehydration can also be applied to sliced mango with or without the peel. However sun drying is more popular in most countries because it is inexpensive. The product is however, susceptible to contamination by dirt, insects, rodents and microorganisms. At the same time, it must be noted that the process requires several days based on sunlight availability and temperature control. More hygienic and equally cost effective systems such as solar dryers are available. These have been adopted by medium to large-scale processors. Spray-dried mango powders are used for flavouring confectionery and pharmaceutical preparations as well as in the manufacture of baby foods and tropical fruit drinks which are fortified with nutrients to replace those portions lost during processing (Raymundo, Ombico and de Villa 2009).

The puree of the green mango can also be converted to a powder similar to the puree of ripe mangoes by spray drying. The spray dried powders can then be mixed with other condiments and used as a souring agent for some dishes, or as raw material in the manufacture of instant green mango shake (University of the Philippines Los Banos 2005). Edible pulp makes up to 33–85 percent of the fresh fruit, while peel and kernel amount to four to seven percent and 9–40 percent respectively (Wu, Chen and Fang 1993). By-products of mango may amount to 35–60 percent of the total fruit weight. Other parts of the mango fruit are also utilized, such as the mango kernels, which are a source of fat, natural antioxidants, starch, flour and feed. Studies have been conducted on the peel for possible use in the production of biogas, dietary fibre with high antioxidant activity and as a source of pectin (Berardini, Knodler and Schieber Carle 2005).

LOGISTICAL FACTORS ASSOCIATED WITH CAUSES AND SYMPTOMS OF DEFECTS

Mangoes grown throughout the LAC region are highly susceptible to Anthracnose which is caused by a fungus *Colletotrichum gloeosporioides* (Figure 8.11). Infection occurs during flowering and fruit set and its severity increases with high humidity and rainfall. Disease symptoms include small, dark spots that become enlarged to irregular, dark brown areas as the fruit ripens. Accordingly, the fungus often remains dormant on green fruits and develops as the fruit ripens and loses its natural resistance. The timing of pre-harvest fungicidal treatments is therefore critical in reducing the incidence of this disease (Table 8.3). If this is done then consumer satisfaction for disease free fruits will increase and eventually the reputation of high quality fruits will impact positively on demand and prices.

Some cultivars of mango such as cv. Julie and cv. Tommy Atkins are highly susceptible to internal physiological disorders in which there is disintegration of the flesh around the seed into a jellylike mass. Soft nose also occurs where there is partial ripening of the flesh at the distal end of the fruit, with stem-end cavity resulting in necrosis of the flesh around the cavity. According to Brecht (2010), some of these disorders can be reduced by increasing the calcium content via proper pre-harvest calcium applications (Table 8.3).

Table 8.3: Factors influencing pre-harvest and postharvest defects in mango fruits

Factors influencing pre-harvest and postharvest fruit defects	
Mango defects of pre-harvest origin	Mango defects of harvesting and postharvest handling origin
• Anthracnose • Insect damage (Figure 8.12) • Jelly seed • Lenticel damage (spots) • Misshapen • Scab • Scars (russetting) • Skin breaks and cracks • Soft nose • Stem-end cavity • Sunburn and sunscald • Bird damage (Figure 8.13)	• Bruising • Decay • Elevated carbon dioxide injury • External (skin) discoloration (due to heat injury or chilling injury) • Immature (poor quality when ripe) • Internal (flesh) discoloration (due to heat injury or chilling injury) • Not well trimmed (stem is longer than 12.7mm [0.5 inch]) • Overripe (too soft) • Sapburn • Shrivelling (water loss) • Sunken discoloured areas (due to chilling injury) • Sunken shoulder areas (due to heat damage to the flesh below) • Uneven (blotchy) ripening (due to heat injury or chilling injury) • Void spaces in the flesh (due to heat injury or irradiation damage)

Logistical demands for mangoes are influenced by their importance as a local and export product. Mango fruits harvested at the immature stage can be utilized as a range of value-added products such as pickles, chutney, amchar, frozen slices and cubes, kuchelar, dried products, juices, nectars, canned slices and leathers. Mango fruits that are ripe can be eaten as a fresh fruit or in fresh-cut salads, and may also be processed into jams, jellies, squash, puree, dehydrated and canned slices. However, these fruits are easily bruised, affecting their taste and appearance, thus reducing the selling price. Being perishable, mango fruits, which have an average shelf life of two weeks require certain handling and storage conditions. The need for logistics management of mango fruits has come to the fore following the recent global energy crisis followed by the global financial crisis. Logistics management is therefore an important tool to enhance competitiveness, while ensuring a focus on serviceability. Accordingly, considering the perishable nature of mangoes and

how prices correlate to freshness, improvements in the postharvest handling system and value-chain must focus on time to market.

Key factors for the supply of high quality mango include: harvesting fruit at the optimum maturity stage for the intended market; careful handling to minimize physical injury; treatments for decay control; storing and shipping at the optimum temperature and atmosphere to maintain high quality (Yahia 2011). Strategies used to extend the postharvest life of mango are based on the proper management of ripening, ethylene production and diseases. Research to investigate improved procedures for storage and ripening that would allow preconditioned, ripening-initiated, ready-to-eat mangoes for consumers is required. Genetic transformation of mango to manipulate the progression and uniformity of ripening and softening is also considered a desirable strategy (Yahia 2011).

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Ecological Modernization of Caribbean Agrosystems: From Concept to Design

Audrey Fanchone, Jean-Louis Diman, Gisèle Alexandre, Serge Valet and Harry Ozier-Lafontaine

INTRODUCTION

Agriculture is now facing a new challenge, as it is not only expected to maximize production while reducing adverse impacts on the environment, but also ensure various ecosystem services (ES) and to diminish disservices (harmful effects). The Millennium Ecosystem Assessment (MEA), which pointed out the importance of proper ecosystem functioning for human well-being, was a turning point in the consideration of the services provided by agriculture. As a result, a transformation of agricultural systems from conventional agricultural systems is therefore expected. Since agrosystems are ecosystems controlled by humans, farming practices lie at the core of this transition of agriculture. Integrated systems are the main forms of farming systems observed all over the world, and in Latin America and the Caribbean (LAC), they represent a vast legacy of experiences in the history, tradition and culture of such countries.

Ecosystem services (ES): The multiple ways by which people benefit from ecosystems e.g.:

- (i) Food: Ecosystems provide the conditions for growing food. Food comes principally from managed agro-ecosystems but marine and freshwater systems or forests also provide food for human consumption.
- (ii) Raw materials: Ecosystems provide a great diversity of materials for construction and fuel including wood, biofuels and plant oils that are directly derived from wild and cultivated plant species.
- (iii) Fresh water: Ecosystems play a vital role in the global hydrological cycle, as they regulate the flow and purification of water. Vegetation and forests influence the quantity of water available locally.
- (iv) Medicinal resources: Ecosystems and biodiversity provide many plants used as traditional medicines as well as providing the raw materials for the pharmaceutical industry. All ecosystems are a potential source of medicinal resources.

More generally, in the Caribbean, multispecies systems whether mixed cropping systems, livestock farming systems or integrated ones, provide several ES. Using these systems as examples, this chapter examines the major driving forces that condition changes in farming practices. Agro-ecological engineering which relies on the ecological paradigm, is regarded as a suitable concept and approach to support this transformation. The chapter also proposes methods that might support the design of innovative agricultural systems, namely the step by step method and the *de novo* method. These methods are supported by concrete examples coming from several Caribbean or other tropical environments.

FROM THE 'GREEN REVOLUTION' TO THE DOUBLE GREEN REVOLUTION

After the Second World War, the shift from the concept of subsistence farming to the 'Green Revolution' represented a change in the prevailing agricultural paradigm, whereby the main objective assigned to agriculture was that of ensuring food security by securing an adequate market supply, a reasonable standard of living, and increasing farmers' incomes. During the 1980s, this production objective was largely achieved, and surpassed the requirements in Europe and many industrialized countries. This new standard involved the use of seeds of high-yielding varieties, primarily of wheat and rice, and the adoption of a modern package of agricultural tools and practices involving chemical fertilizers, tractors, pesticides, irrigation, mechanical threshers, electric and diesel pumps, among other things (Parayil 2003). This system, however, led to a decrease in farm numbers (rural exodus, loss of rural jobs), specialization and marginalization of territories, standardization of landscape, and deterioration of natural resources. The 'Green Revolution' also caused enormous environmental impacts, including soil degradation, water pollution and loss of biodiversity.

Agriculture is not only expected to produce food and fibre either for direct consumption or for industrial use, but also has to provide some other functions while at the same time minimizing adverse effects on the environment (Zhang et al. 2007). The new challenges faced by agriculture are to ensure various ES, to resolve apparent conflicts between them, and to diminish its disservices (Doré et al. 2011). The Millennium Ecosystem Assessment provided a new conceptual framework for analysing these multiple ES (MEA 2005). In new agrosystems, ES are not externalities, but are intentionally produced by stakeholders, who create such services by implementing practices (minimum tillage, crop association, organic fertilisation, integrated control of pests) which modify the production sequence. A new issue for researchers is therefore the evaluation of the cost of the production of such ES. In the International Assessment of Agricultural Science and Technology for

Development report (IAASTD 2008) it has been argued that the challenge to achieving this multi-objective agriculture not only requires continuing the development of disciplinary knowledge, but also more systemic approaches, and has recently officially called for a reorientation of agricultural science and technology towards more holistic approaches. New concepts such as ‘agroecology’ and ‘ecological intensification’ have been developed to support this transformation.

Vanloqueren and Baret (2009) have defined agroecological engineering as ‘an umbrella concept for different agricultural practices and innovations such as biological control, cultivar mixtures, agroforestry systems, habitat management techniques (e.g. strip management or beetle banks around wheat fields), or natural systems agriculture, aiming at perennial food-grain-producing systems. Crop rotations, soil fertility improvement practices, mixed crop and livestock management and intercropping are also included. Some applications involve cutting edge technologies while others are old practices (e.g. traditional systems that provide significant insights to agroecology). For these authors, ‘the scientific paradigm on which agroecological engineering relies is ecology (and holism)’. As such, the objective is the design of productive agricultural systems that require as few agrochemicals and energy inputs as possible, and instead rely on ecological interactions and synergisms between biological components to produce the mechanisms that will enable the systems to boost their own soil fertility, productivity and crop protection (Altieri 1995).

Some aspects of agroecological engineering may be related to biomimicry (Benyus 1997), as illustrated in Figure 9.1. Doré et al., (2011) noted that in natural ecosystems, as a result of the various animal and plant species, the final ecosystem is provided with a number of services, for instance pollination. In standard cropping systems, these interactions may lead to pest damage on crops, and so must be managed utilizing various control methods to limit yield loss. An increase in plant species diversity in systems mimicking natural ecosystems could allow natural enemies to control pests and generate ES (Doré et al. 2011). The concept of agroecological engineering, which sets out to improve the structure of the agricultural system and ‘to make every part of the structure work well’ (Liang 1998), differs from genetic engineering for example, which has as its primary objective the improvement of only a single element of the agroecosystem, for example (modifying existing plants or designing new plants).

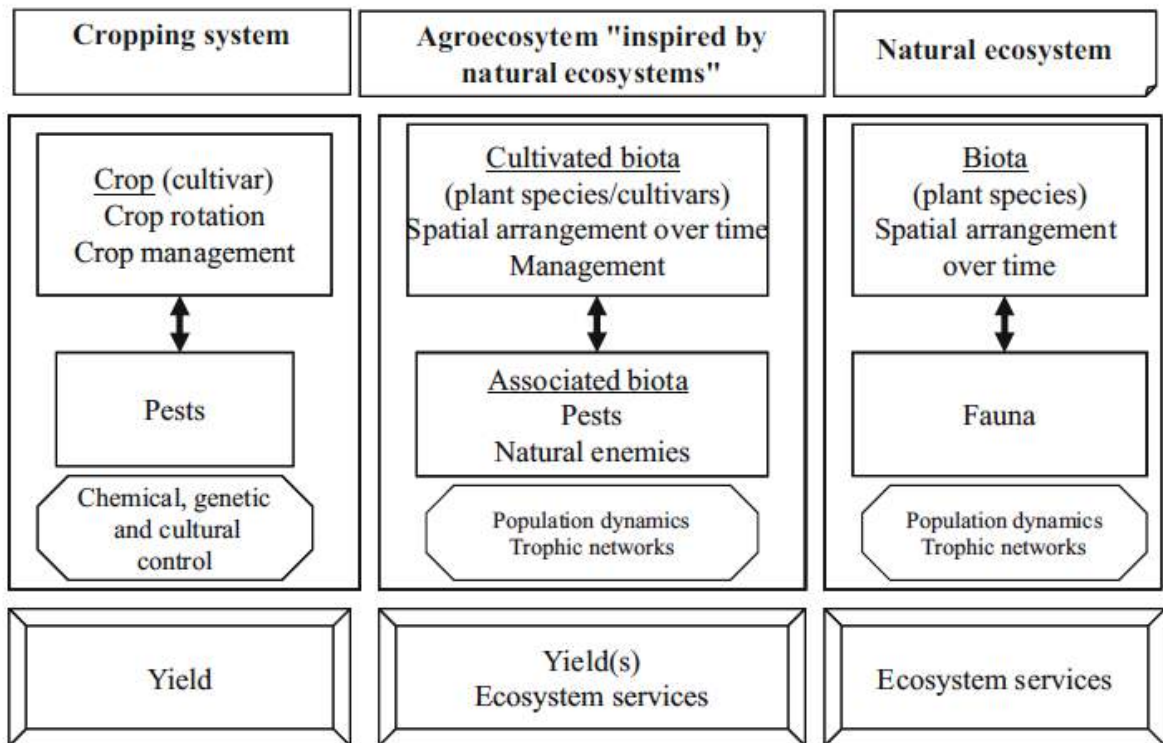
Because agrosystems are ecosystems controlled by humans, farming practices are at the core of this transition of agriculture. According to Meynard et al. (2006) four major driving forces promote the transformation of farming practices. These are:

- i. the recognition of the responsibility of agriculture in the deterioration of the environment;

- ii. the evolution of the demand for food and non-food products;
- iii. the consideration of work and incomes of the farmers; and
- iv. the evolution of the place of agriculture in the territories.

However, this transformation of agricultural practices presents some challenges. The first challenge is between the economy and the environment, because of the necessity to decrease inputs (e.g. fertilizers, phytosanitary products) and the absence of compensation for production losses or additional workload, with the second being between the individual logic of the farmers and that of the collective governance. This latter challenge is related to supply chains in the same territory, which compete directly or indirectly for the same raw materials such as fertile soils, flat lands, irrigated water and local breeds (Le Bail 2000).

Figure 9.1: A comparison of natural ecosystems, conventional cropping systems and agroecosystems inspired from natural ecosystems, with emphasis on crop protection.



Source: Doré et al. (2011)

ENHANCING AND INTEGRATING ES IN CARIBBEAN AGRICULTURAL SYSTEMS

In some parts of the world, integrated systems (IS) are the predominant forms of farming systems (Herrero et al. 2010). Nowadays, IS produce close to 50 percent of the world's cereals and most of the staples consumed by poor people: 41 percent of maize, 86 percent of rice, 66 percent of sorghum, and 74 percent of millet production (Herrero et al. 2009). They also generate the bulk of livestock products in the developing world: 75 percent of the milk and 60 percent of the meat, and employ many millions of people on farms, in formal and informal markets, in processing plants, and other parts of the value chain. Although there is a lack of available information in LAC, IS have an informal background of rich experiences in the history and tradition of these countries (González-García et al. 2012). In these countries, IS have persisted over time because as natural ecosystems, they appear to be well adapted to local constraints, after a long process of natural selection (Dawson and Fry 1998; Ewel 1999). This is even more the case for most of the small and large islands of the Caribbean where there are added constraints such as: the shortage of arable land and the high competition between agriculture and other uses such as urbanization and tourism. In these countries, the urgent need to increase outputs of each piece of agricultural land by producing food, feed, and other ES, tests the boundaries of conventional agriculture. The challenge in the Caribbean zone therefore becomes to promote IS which enable the provision of ES.

ECOSYSTEM SERVICES PROVIDED BY CARIBBEAN SYSTEMS

MULTI-FUNCTIONALITY AND ECOSYSTEM SERVICES

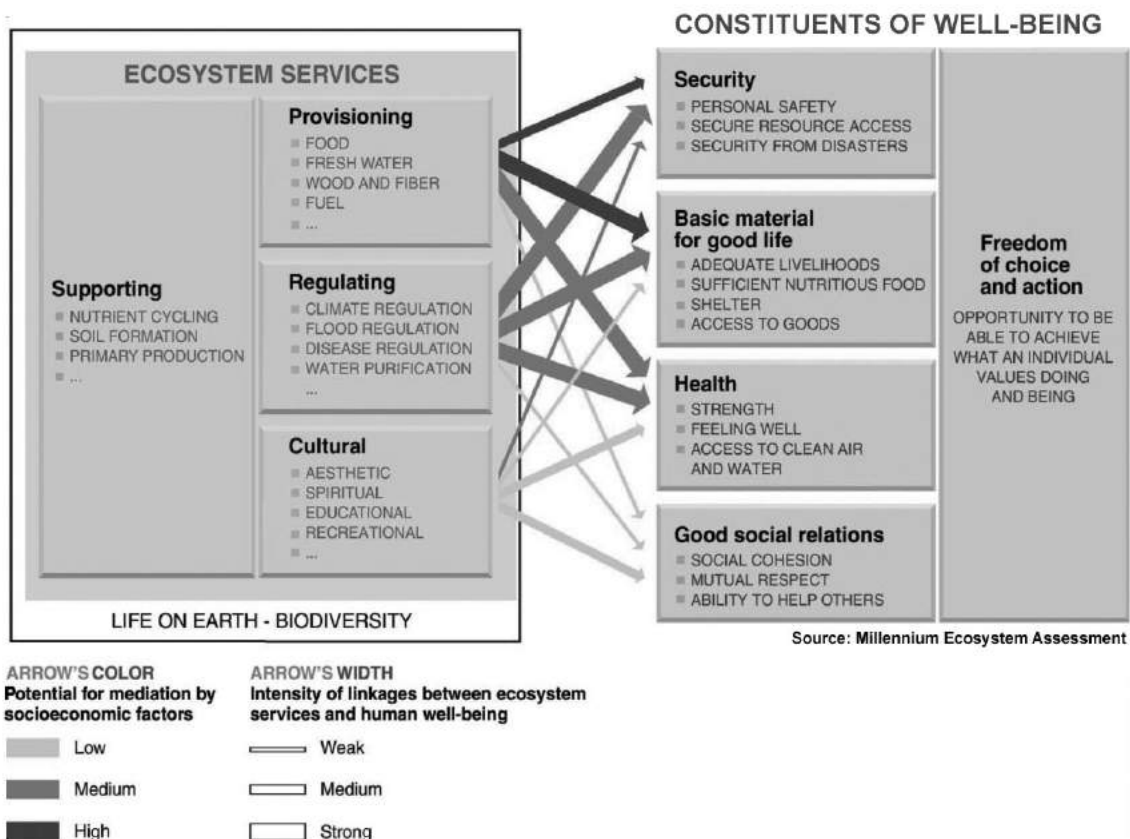
Agriculture fulfils three main functions, namely:

1. production (including economics aspects) – of food and non-food goods, and the provision of raw material for industry;
2. socio-cultural – to maintain the social fabric of rural areas, planning in territories and transmitting of a cultural heritage; and
3. environmental – biodiversity preservation, regulation of the environment, conservation and regulation of water quality, and to decrease energy consumption.

Despite an awareness of the multifunctional character of agriculture, this concept has not been embraced within the public policy context. According to MEA (2005), the acknowledgement of the importance of ecosystem functioning for human well-being, provided a turning point in the consideration of the services provided by agriculture.

The concept of ES not only encompasses the same functions as those expressed by multi-functionality, but also embodies the maintenance of the good functioning of the ecosystem. ES emphasize the human usage of natural processes through the supply of material goods, determine ecological regulation modes, and the role of the ecosystem to support both productive and non-productive activities.

Figure 9.2: The multi-scale framework of the Millennium Ecosystem Assessment



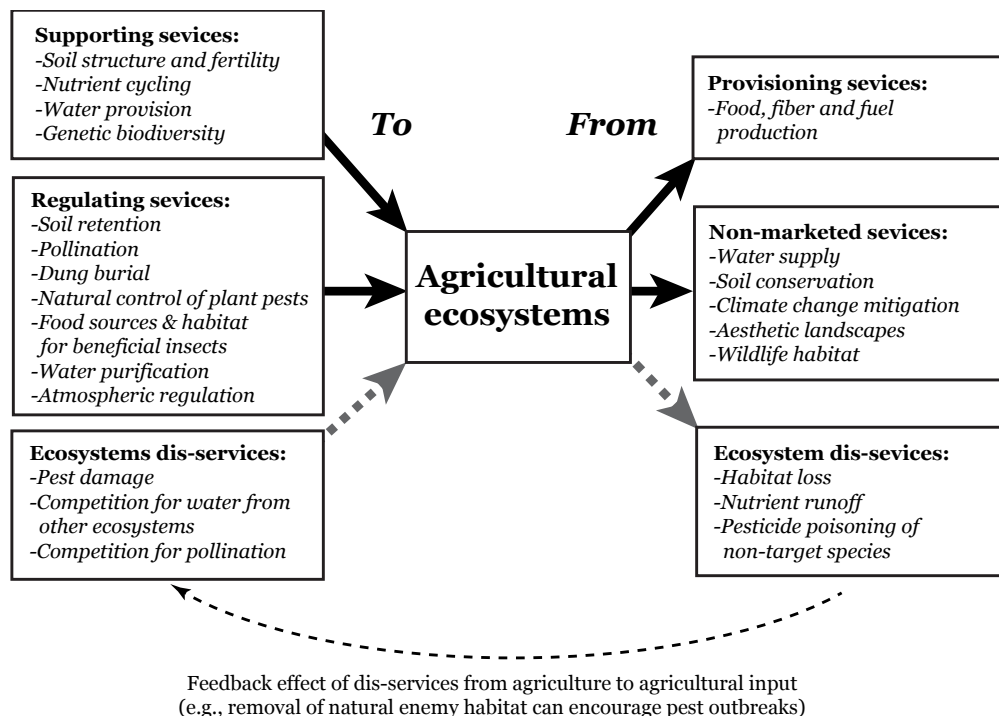
Source: MEA (2005)

THE MEA (2005): A CONCEPTUAL FRAMEWORK TO STUDY ES

The MEA defined four categories of ES; supporting, provisioning, regulating and cultural (Figure 9.2). The supporting services relate to services that are necessary for the production of all other ES. They differ from provisioning, regulating, and cultural services in that their impacts on people are often indirect or occur over a very long time, whereas changes in the other categories have relatively direct and short-term impacts on people. While the provisioning services relate to the products obtained from the ecosystem, the regulating services are the benefits obtained from the regulation of ecosystem processes. Finally, the cultural services relate to the non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences.

As the figure shows, many of the services listed within the MEA framework are highly interlinked and involve different aspects of the same biological processes. Moreover, MEA services only relate to the positive impacts of ecosystems on human well-being. The basic concept adopted by the MEA, is based on a multi-scale and multi-disciplinary approach that provides an integrated perspective by emphasizing the interdependence between socio-economic and environmental issues.

Figure 9.3: Classification of ecosystem services from the Millennium Ecosystem Assessment



Source: Zhang et al. (2007)

ES IN AGROSYSTEMS

The sustainability of agrosystems presupposes the preservation of their economic and ecological viability, i.e. the preservation of their productive capacity, as it relates to the maintenance of the good ecological functioning of the soils and the economical production of this system (market and societal value). Zhang et al. (2007) presented a conceptual framework for agrosystems and introduced the concept of disservices (Figure 9.3).

ES PROVIDED BY MULTISPECIES SYSTEMS

The following sections provide an overview of some of the ES provided by multispecies systems in tropical areas.

Mixed crop systems

In considering the provisioning of services, productivity per unit area can be increased when crops are combined, compared to single crops systems (Willey 1979; Jolliffe 1997), provided that the combination is suitable. Yield advantage occurs because growth resources such as light, water, and nutrients are more completely absorbed and converted to crop biomass by the intercrop over time and space. This is as a result of differences in the competitive ability for growth resources between the component crops, in characteristics such as rates of canopy development, final canopy size (width and height), photosynthetic adaptation of canopies to irradiance conditions, and rooting depth (Midmore 1993; Morris and Garrity 1993; Tsubo, Walker and Mukhala 2001). Biotic factors such as the presence of mycorrhizae, bacteria, fungi, termites and insects also play equally important roles (Derelle 2012). When tubers are used in combination with legumes/maize, the land equivalent ratios (LER) of the sweet potato and bean combination, ranges from 1.69 to 1.79, depending on density of beans. For a yam and maize/peanut combination, the LER ranges from 0.98 to 1.60, and was found to result in favourable yields/unit area, as well as yam tuber size (Cornet, 2005; Lyonga 1980; Odurukwe 1986). A tomato and cowpea combination produces a LER of 1.08 to 1.31 depending on their respective densities (Obedoni et al. 2005).

Soil protection/conservation services are also part of the regulating services. Cropping combinations and the hedges or trees associated with them, due to the high crop density, play a significant role in reducing soil and water erosion, thus contributing to the conservation or resilience of soils. An example of this can be found in West-Cameroon, where, as compared with mixed cropping systems, intensive monoculture was found to offer less soil protection against the ‘splash’ effect of raindrops that have high kinetic energy (Valet 1999). For andosols cultivated with maize monocrops on a 25 percent slope, such erosion can reach 122 T/ha/year (1996).

Pest and disease control represents yet another regulating service provided by multispecies systems. Five hypotheses are generally advanced to explain the ability of crop combinations to regulate plant pests:

1. The disruption hypothesis (push): one of the associated species disrupts the ability of the pathogen to attack the host plant by confusing it through the emission of volatile substances, visual effects, and a barrier effect (Khan et al. 1998).
2. The hypothesis of the trap plant (pull): one of the associated species attracts pathogens, keeping them out of reach of the more vulnerable crop and also attracts predators to the pests.
3. The natural enemies' hypothesis: based on the ability of mixed systems to favour greater diversity of predators and parasites.
4. The hypothesis of micro-environment modification: mixed cropping systems can either create more favourable conditions for the plant under attack, or less favourable conditions for the development of the parasite, or more favourable conditions for the development of its natural enemies.
5. Vertical and horizontal barrier effect – enabling plants to be concealed from insects, diluting the vector, modifying temperatures and the exposure that favours insects climbing up a stem.

One of the major roles of crop combinations is their ability to resist attack by multiple pests and diseases. An analysis performed by Risch (1983) on an assessment of pests and natural enemies in polyculture as against monoculture, showed that in 53 percent of cases, in the former, less serious attacks occurred than in the latter. More importantly, the percentage of natural enemies of mixed crops is greater than in monocultures (59 percent vs. 9 percent), yet in only 32 percent of the studies it was shown that there was no difference between monocultures and mixed cropping systems. The beneficial effect of mixed cropping in controlling disease and parasites was confirmed by other researchers (see for example Rämert, Lennartsson and Davies 2002; Root 1973; Szumigalski and Rene, 2005; Vandermeer 1989). The beneficial effect is however not easy to demonstrate, as it is complex and unpredictable (Trenbath 1999). A cropping system with plant species used for different purposes can therefore assist in effectively addressing the issue of insect pests.

Livestock farming systems

Particularly under tropical conditions, a major challenge associated with livestock farming systems (LFS) has been a lack of recognition of the importance and benefits to be derived from the non-productive functions of animals, as well as the husbandry activities for the

farmer/household and society (Lhoste et al. 1993). The LFS is not only concerned with the production of high-quality commodities, to meet the objective of food security, but also with the provision of multiple ecoservices as prescribed by MEA (2005). Animals and LFS are considered as highly multifunctional in tropical agroecosystems (Dedieu et al. 2011). With respect to the framework provided by Zhang et al. (2007), in the Caribbean, the first ES of LFS remains the provision of services (i.e. production of food, fibre, fuel). LFS also fulfil other categories of ES including: supporting services (soil structure and fertility, nutrient cycling, and genetic biodiversity), regulating services (soil retention, dung burial, atmospheric regulation), and non-marketable services (soil conservation, climate change mitigation, and wildlife habitat).

In most farming systems in the world, LFS are practiced in association with crops (Herrero et al. 2010). In such integrated systems, crop and livestock activities compete for the same scarce resources which include land, labour, capital and skills. Consequently, in general, the productivity of livestock in mixed systems (e.g. milk production/animal/day, growth and reproduction rates), is lower than in specialised systems, so that the provisioning ES can be considered somewhat reduced, leading to the conclusion that IS are less productive. However, while there may be lower productivity per unit land or animal in one enterprise, higher overall productivity is common. This has been demonstrated for example in the case of integrated dairy systems in Cuba that have been assessed to be as productive as intensive single systems and totally more sustainable (Funes-Monzote and Monzote 2001). From the IS perspective, livestock plays many vital roles in the households and economies of the developing world, including producing food and power, generating income, storing capital reserves, and enhancing social status (Alexandre et al. 2014). In addition, livestock can be used for weed control, production of manure for fertilizer (Boval, Bellon and Alexandre 2014) and also for fuel (Preston and Rodriguez 2014).

Crop–livestock integration is generally driven by increased population pressure, the main feature characterizing the Caribbean islands, which is often the main reason for farmers to intensify their farming systems. Livestock can affect the cycling of nutrients, opening alternative pathways, such as importation of nutrients from common land, and affect the speed and efficiency with which nutrients can be converted to plant-useable forms (Delve et al. 2001). Inclusion of livestock in mixed farming systems can provide an alternative use for crop residues. For example, if farmers need to plant a crop soon after harvesting a previous one, stubble incorporation may not be feasible, so that farmers may resort to burning it, resulting in increased carbon dioxide emissions. In contrast, livestock in IS can be used to remove and process stubble, potentially reducing the losses of carbon and nutrients. Blending crops and livestock has the potential to maintain ecosystem function and health and help prevent agricultural systems from becoming too ‘brittle’, by promoting

greater biodiversity and an increased capacity to absorb shocks to the natural resource base, something which Holling (2001) defined as resilience.

From an ecological viewpoint, grasslands are ecosystems which exhibit a strong link between herbivores and floral diversity (Gliessman 2009) and when well-managed, can be a tool for ecological and regulating services, notably to maintain and restore biodiversity of the open landscape (Ma and Swinton 2011). Moreover, grasslands can potentially offset a significant proportion of global greenhouse gas (GHG) emissions. Appropriate management strategies, in the areas of stocking rate, grazing pressure and application of nitrogen fertilization would however be key (Boval et al. 2014). Animals contribute to improving the quality of the ground cover, important for soil erosion prevention and the watershed processes of infiltration and water retention (Gliessman et al. 2009). Thus, pastoral nomadism, a complex set of practices and knowledge, ensures the long-term maintenance of a sophisticated ‘triangle of sustainability’, which includes plants, animals and people.

Beyond the ecological services, natural resources and landscapes may provide numerous social, cultural, recreational, and aesthetic services which satisfy human need and well-being (Ma and Swinton 2011; Boval and Dixon 2012). As such, most traditional agroecosystems have remarkable characteristics which are regulated by strong cultural values and collective forms of social organization, including customary institutions for agro-ecological management, normative arrangements for resource access and benefit sharing, value systems and rituals (Altieri and Toledo 2011). Livestock production systems based on grasslands therefore have great potential for social equity, poverty alleviation, risk reduction and gender equality (Gliessman 2009). These services must be seriously considered as they are well supported by agro-ecological concepts. The development of local food chains, in addition to renewing the meaning of farm work and the social links between city and country, also has an impact on energy consumption (Mundler and Rumpus 2012). These are important in the context of the exploitation of grassland eco-economic factors and are properly taken into account in the agro-ecological concepts.

Examples of integrated systems in the Caribbean

From Creole garden to simplified multispecies systems

Multispecies cropping systems cover many modes of spatial distribution: on the surface, above and below the ground level, and time distribution, in relay with perennial or annual species (Valet and Ozier-Lafontaine 2014). The archetype of multispecies cropping systems in the Caribbean is the Creole garden that combines very different plants (e.g. grasses, shrubs and trees) in varying combinations, and in contrasting environments (i.e. lowlands and highlands). These systems are very close to agroforestry systems which incorporate trees and shrubs (Figure 9.4).

The principles of the Creole garden are very similar to those of agroforestry systems, as they involve the growing of annual or biennial agricultural crops along with forest species. The long-term effects of this system on soil fertility will however depend on the management practices adopted at establishment, as well as at subsequent re-establishment. Complementary, supplementary and competitive interactions exist between trees and crops, and higher crop yields have been obtained when some agricultural crops are inter-planted near leguminous trees such as *Faidherbia albida* (Acacia) (FAO 1994). Allelopathic interactions between trees and agricultural crops have also been investigated and such interactions have been reported (Susesht and Vinaya 1987). Many variations of this system are found in small family farms, involving between two and three species in the plots (Figure 9.5), which are not only chosen for human or animal consumption, but also for ES, namely in the form of the supply of nitrogen by legumes, and quick ground cover of creeping species for weed control.

According to Valet and Ozier-Lafontaine (2014), while the idea that ‘intercropping was only for peasant farming and has no place in modern agriculture’, has persisted for a long time among researchers and developers, it appears that in many areas of the world, traditional farmers developed or inherited complex farming systems in the form of polycultures that were well adapted to the local conditions. It has been further suggested (Valet and Ozier-Lafontaine 2014) that this has helped farmers to sustainably manage harsh environments and to meet their subsistence needs, without depending on mechanization, chemical fertilizers, pesticides or other technologies of modern agricultural science. These practices, which are generally more efficient than the high-intensity agricultural systems, highlight the ‘agroecological engineering’ developed over centuries by many peasants in tropical zones.

The Tosoly farm of Colombia

Preston (2009) has noted that farming systems should aim at maximizing plant biomass production from locally available diversified resources, processing of the biomass on the farm to provide food, feed and energy, and recycling of all waste materials. In addition, the generation of electricity can be a by-product of food/feed production instead of developing biofuels, which threaten food security (Suárez and Martín 2012). Biomass is fractioned into inedible cell wall materials that can be converted, through gasification into a source of fuel for the internal combustion engines driving electrical generators. The cell contents and related structures are used as human food or animal feed. It also offers opportunities for sequestration of carbon in the form of biochar, the solid residue remaining after gasification of the biomass, which in turn is used to enhance soil fertility and crop productivity.

On the Tosoly farm, located in a humid, tropical region of Colombia, the integrated food-feed-fuel model has been implemented by Preston and Rodriguez (2013). The farm is a medium-sized unit (7 ha), and in order to promote biodiversity, the crops (sugar cane, fruit and forage trees, and some forage plants) on the farm, are replicated in different areas. The livestock and fuel components are chosen for their capacity to utilize the crops and by-products produced on the farm. All crops must be at least dual-purpose, have good biomass productivity, as it relates to the efficient capture of solar energy (new energy revolution), and adequate chemical composition (in mixed diets).

The inclusion of livestock in the farming system is seen as a means of optimising the use of highly productive perennial crops such as sugar cane and multi-purpose trees. Sugar cane is easily separated into energy-rich juice, which can replace cereal grains in the feeding of pigs, as is done in Trinidad and Tobago, and Guadeloupe (Archimède et al. 2013), and residual bagasse, which can be used as one of the feedstocks for the gasifier. Forage trees are the natural feed resources for goats, which selectively consume the leaves, leaving the fibrous stems as another feedstock for gasification. Other farmyard animals are combined to maximize the use of feedstuffs, providing manure or draught power, and livestock products such as eggs, rabbit meat and honey. Any surplus commodities which remain after the family needs have been satisfied, are sold in the village market. Waste water from coffee pulping, family washing, and also all high moisture wastes from pigs and other animals are recycled through polyethylene biodigesters. Effluent from all biodigesters is combined and recycled to fertilise crops.

Fruit tree-crop-chicken farm of Martinique

Due to the wet climatic conditions found in Martinique throughout the year, fast weed growth is fast, resulting in the need for the implementation of permanent control measures in fruit tree crop systems, as this has a strong negative impact on yields. Weed control however generates high maintenance costs to fruit producers. Chemical weed control is the most common method used, but this is not a sustainable method due to issues related to water pollution and soil erosion (Hipps and Samuelson 1991; Duran-Zuazo and Rodriguez-Pleguezuelo 2008). Grazing animals which do not harm the cash crops therefore constitute a viable alternative. In Martinique for example, poultry (chickens and geese) were used in an orchard of guava trees and the feasibility and effectiveness of weed control were evaluated (Lavigne, Dumbardon-Martial and Lavigne 2012). It was found that although geese can be used to effectively control the herbaceous biomass, weed selection by the birds leads to a significant modification of the flora. The use of grass and perennial legumes in the orchard can also serve to enhance this cultivation system. The long-term effect of such

an association however, remains to be assessed. Management of the stocking rate also plays a crucial role in such systems. In high stocking rate systems, over grazing can lead to deforestation and loss of associated biodiversity. This example shows how management practices can encompass both the provision of ecological services (weed management) and ecological disservices (loss of biodiversity).

The neo-tropical animal wildlife programme in Trinidad and Tobago

Added to the previous ES of production and regulation functions, this section underlines some other environmental and socio-economic services provided by livestock via the utilisation of an original case study. Tropical LFS have exhibited rich and high diversity not only for domesticated animals, but also for wildlife (species best adapted to their natural habitat). One is presented through the neo-tropical animal wildlife program implemented in the Caribbean (Garcia 2005). Around 30 important neo-tropical animal wildlife species are found in LAC. Twelve of these species are native to Trinidad and Tobago, where they are sold at higher prices than domestic animals. The neo-tropical animal wildlife programme fosters the high biodiversity of wildlife, building a whole concept to sustain a viable economic activity on the basis of AE principles developed at the food system level. According to Garcia (2005), the value of neo-tropical animal wildlife is varied, and can be broken down into an ecological role, economic importance, a nutritional function and socio-cultural significance. All of these features have a real impact on farmers' or hunters' income, gastronomy and agro-tourism in the country, something that is very difficult to assess.

The agroecological transition process in a family farm, San Juan, Cuba

The San Juan farm is one of the more than 100,000 farms distributed by the Cuban government in the recent years. It is located in Junco village in the Cienfuegos valley and is currently owned by the Rey-Novoa family, which has extensive experience in traditional agriculture. Funes-Monzote (2009) studied the agroecological transition process of this agroecosystem over a period of eight years (2004–2011), taking into account criteria of social equity, economic rationality and ecological sustainability. It is a traditional peasant farm, in which agroecological transition started in 2004, from land which was managed in a conventional agriculture mode and then abandoned for nearly a decade. A detailed characterization was performed which considered the attributes of sustainable agroecosystems in an annual cyclical process of assessment, design, management and evaluation, according to the methodologies proposed by Masera et al. (1999); Funes-Monzote (2009). The family was involved in the identification, selection and implementation of the indicators of sustainability.

The key lessons derived from the Rey-Novoa family experience with an innovative process of agroecological transition were (Rey-Novoa and Funes-Monzote 2013):

1. greater food self-sufficiency and traditional production;
2. promotion of local, drought-tolerant pasture in rotation or silvopastoral systems;
3. increased nutrient recycling, water, soil and forest conservation, and the biodiversity associated with native crops and animals;
4. account of natural conditions (male effect) in bovine reproduction;
5. genetic and species diversification on the farm via the integration of trees with crops and animals;
6. minimal dependence on external inputs for the basic infrastructure of housing, transportation, production, supply sources and reservoirs, irrigation of low power energy and water consumption.

The experience of the Rey-Novoa family farm shows that efforts to promote agriculture and knowledge processes in harmony with nature and society, must consist not only of actions to preserve and strengthen the productive logic of peasant families, but also a broad process of empowerment, capacity building and agricultural innovation at the local level, based on the participation of families with help from researchers, local institutions and rural organizations to redesign the agricultural land (Funes-Monzote 2013).

An agroecological transition model adopted in the context of the family farm is something that can be replicated within the framework of other agricultural systems found within the Caribbean in the quest for sustainability. As has shown, the process of agroecological transition helps to mitigate the degradation that exists in several agroecosystems. It is therefore critical that such studies should be continued. This will allow for the development of an agricultural model that is less dependent on oil, has a low environmental impact, is better suited to climate change, and can be characterised as a local and multifunctional agriculture.

AVAILABLE TOOLS AND PRACTICAL RECOMMENDATIONS

In light of the foregoing, a number of tools are available for use, in addition to which, a number of practical recommendations can be made, which can be adopted to help in the management of these ecosystems.

Selection of cover crops for ES

At the National Institute for Agricultural Research (INRA) in Guadeloupe, an expert system, SIMSERV was developed to assist with the selection of cover crops (Ozier-Lafontaine

et al. 2011).¹ This tool was created to optimise the selection of potential species to one or more services, while shortening the time of selection. This approach offers the advantage of capturing expert knowledge in an easily accessible and reusable database. For each cover crop, SIMSERV calculates the potential for it to provide a service in a given context, which is defined by the user who provides required information related to the: i) required service, ii) description of agroecological and socio-economic characteristics, iii) mode of establishment - in rotation or association, and iv) a cash crop.

The system matches the data defined for the particular context, with information from the database, which is then used to calculate the capacity for each cover crop to provide the service or not. The method of calculating is based on the aggregation of decisions in a “decision tree”. Three profiles are given in the application: i) the administrator builds the decision tree; ii) the expert assigns values to the indicators to describe the cash crops and the cover crops; and iii) the user uses this information to describe his/her scenario, then chooses a context. Based on the analysis for each cover crop, the results, which are presented in tabular form, provide the user with an indication of the name and the qualitative assessment obtained for the selected service. Cover crops – ‘very good’, based on their capacity to provide the service, in response to the selected context.

Soil organic matter conservation

The soil organic matter (OM) is one of the essential components of agrosystems. Among its agro-environmental functions, OM helps maintain the structure and porosity of the soil (effect on water storage, its ventilation and the risk of erosion), stimulate biological activity, preserve biodiversity of the soil, provide nutrients to the crops (nitrogen, phosphorus, sulphur) and also helps to retain some micro pollutants (i.e. an effect on water quality). Changes in the OM content due to improper land use and farming practices, greatly affect all soil functions; the physical, chemical and biological quality. To address this, the MorGwanik[®] tool was developed.² It is based on the results obtained at the INRA French Antilles and Guiana Research Centre, with respect to the functioning of tropical soils, the fate of crop residues and the organic inputs (compost and agricultural reusable waste). It also takes into account the effect of the great diversity of soils and microclimates present in Guadeloupe on the OM content. MorGwanik[®] was designed to estimate the evolution of the OM content in agricultural soils of Guadeloupe according to some user-defined choices,

1. For further details on SIMSERV see: <http://toolsforagroecology.antilles.inra.fr/simserv>.

2. Further details on this tool can be found at: <http://toolsforagroecology.antilles.inra.fr/morgwanik/index.php/morgwanik/>.

such as location of the farm, useful crop rotation, type and rate of organic fertilizers used. It is intended for agricultural stakeholders such as farmers, technical advisors, policy makers, researchers, agronomists, and environmental professionals, and can also be easily adapted to systems found in the other Caribbean islands.

Animal feeding strategies

Both the quantity and quality of feeds are deciding factors not only for animal survival but more importantly to meet their nutrient needs for maintenance and production. Feeding and nutrition-related factors also impact upon, and often determine individual vulnerability to climatic constraints or potential diseases. Feeding practices should ideally match the available local resources as previously stated (Preston 2009). Many authors have recommended exploiting available feed and by-products instead of building a feeding system according to animal requirements (refer to the examples of sugar cane and cocoyam outlined in the section on the Tosoly farm). It is not a question of maximising the biological function of production, but rather optimising the feed resource partitioning at both the farm and territory levels, in the absence of competition between users.

The following section provides some recommendations in the area of feeding animals based on data gathered from Caribbean and Latin American experiences in the area of domestic animal (Table 9.1) and wildlife production (Table 9.2) suited for the region. Brown-Uddenberg et al. (2004) for example, reported that the agouti (*Dasyprocta leporina*) can eat any kind of vegetable matter, and in Trinidad, these animals, both in the wild and captivity, were reported to eat a wide variety of fruits from trees and shrubs (40 species), herbs and grasses (four species), garden crops (17 species) and livestock feeds. The peccary (*Tayassu tajacu*), a pig-like mammal, is known to be herbivorous and frugivorous in Brazil and Trinidad (Young et al. 2012) and is regarded as a pseudo-ruminant, thus indicating a potential for non-conventional farming.

Table 9.1: Foliage and non-conventional feeds offered to goats and pigs as examples of the high biodiversity of Latin America

Feed	Goat/sheep	Pig	Reference
Sweet potato (<i>Ipomoea batatas</i>)			
• foliage	x	X	2] and 4]
• tuber		X	2] and 4]
Cassava (<i>Manihot esculenta</i>)			
• foliage	x	X	2] and 4]
• tuber**		x	4]
Water spinach (<i>Ipomoea aquatica</i>)			
• foliage		X	2]
Mulberry (<i>Morus alba</i>)			
• foliage	x	X	1], 2] and 3]
Cocoyam (<i>Xanthosoma saggitifolium</i>)			
• foliage		X	2] and 4]
Gliricidia (<i>Gliricidia sepium</i>)			
• foliage	x		1], 3] and 4]
Erythrina (<i>Erythrina glauca</i>)			
• foliage	x	X	3]
Banana (<i>Musa paradisiaca</i>)			
• foliage	x		3]
• stem	x		3] and 4]
• fruit***	x	x	4]
Sugar cane (<i>Sacharum officinalis</i>)			
• foliage	x		4]
• stick	x	X	4]
• juice		X	4]
• bagasse	x		3]

after detoxification; *goat - green; pig - green and ripe; x – study undertaken

Source: Iglesias et al. (2006)¹; Rodriguez (2010)²; Alexandre et al. (2012)³ and Archimède et al. (2014)⁴

Table 9.2: Resources consumed by wild mammals in Trinidad and Tobago

Feed	Agouti	Peccary	Reference*
Sweet potato (<i>Ipomoea batatas</i>)			
• foliage	x	X	1] and 2]
• tuber		X	2]
Cassava (<i>Manihot esculenta</i>)			
• foliage	x	X	1] and 4]
• tuber**		x	2] and 4]
Pumpkin			
• fruit	x	X	1], 2] and 4]
Water grass (<i>Commelina elegans</i>)			
• foliage	x		3]
<i>Trichantera gigantea</i>			
• foliage		X	4]
<i>Leucaena leucocephala</i>			
• foliage	x	X	3]
Banana (<i>Musa paradisiaca</i>)			
• fruit**	x	X	4]
Sugar cane (<i>Sacharum officinalis</i>)			
• foliage	x		1]

** Agouti – ripe fruit; Peccary – green

Source: Garcia et al., (2006)¹; Nogueira-Fihlo (2010)²; Garcia et al. (2012)³ and Young et al. (2012)⁴

THE CHALLENGE OF REDESIGNING FARMING SYSTEMS

Meynard et al. (2006) listed four major driving forces behind changes in farming practices. These are: the deterioration of the environment and the recognized responsibility of agriculture; the evolution of the demand of food and non-food products; the consideration of work and incomes of farmers in a globalized world; and the evolution of the place of agriculture in the territories. Because of these forces, some radical changes to cropping and livestock farming systems are emerging. The improvement of agricultural systems clearly calls for innovative measures to facilitate an improvement of the ES, the adaptation to climate change, the integration of territorial dynamics, and the design of agri-food systems.

The classic challenge remains between economic and environmental requirements. The other challenges are between the individual farmer's decisions and territorial dynamic, and between sectors of a same territory, associated with competition among different productions for territorial resources.

Resolving these challenges and reconciling contradictory demands require either the working out of new compromises, or the proposal of new solutions to resolve them, as against focussing on the somewhat unattainable desirable innovations or ideal farming systems. A systematic approach to innovation is required, which involves: identifying a range of solutions; leaving the decision-making to farmers and other stakeholders; helping them to build their own systems adapted to their specific realities; and in the process, compromising where necessary.

The pathways to innovative design

These encompass a consideration of the objectives and constraints of each actor in the innovative process, both at the farm level and at the country level. At farm level, in order to support farmers in the design of systems adapted to their situation, two major approaches can be distinguished: the 'de novo' design and the step-by-step design (Meynard et al. 2012). The 'de novo' design aims to design cropping or farming systems that break away from existing systems (very often model-based design), whereas, the step-by-step design incorporates the transition towards innovative systems by improving the existing systems step by step, in a progressive manner. This latter system is primarily based on a spiral of continuous improvement including diagnosis/development of possible systems/implementation/and new diagnosis.

At the country level, interactions of stakeholders around resource management need to be supported. Innovations relating to the co-ordination of farming systems at the country level can assist by taking into account the different interests of the various stakeholders which can be contradictory and often irreconcilable. Identification of action items for public authorities is at the core of the designing process since these constitute the means to facilitate the transition process. Public actions have to be taken carefully because: i) they sometimes strongly limit the capacity of farmers to adapt to the diversity of soils, climates and situations; ii) they are codified at the elementary agricultural technique level whereas environmental impacts often depend on interactions between several techniques; and iii) they are often felt to be constraints. Within this context, institutional innovation is required that will favour agronomic or agro-ecological innovation.

Scientists are then faced with a paradoxes since innovative design cannot be programmed (by definition) and yet it is essential if it is to fully feature in the programmes of

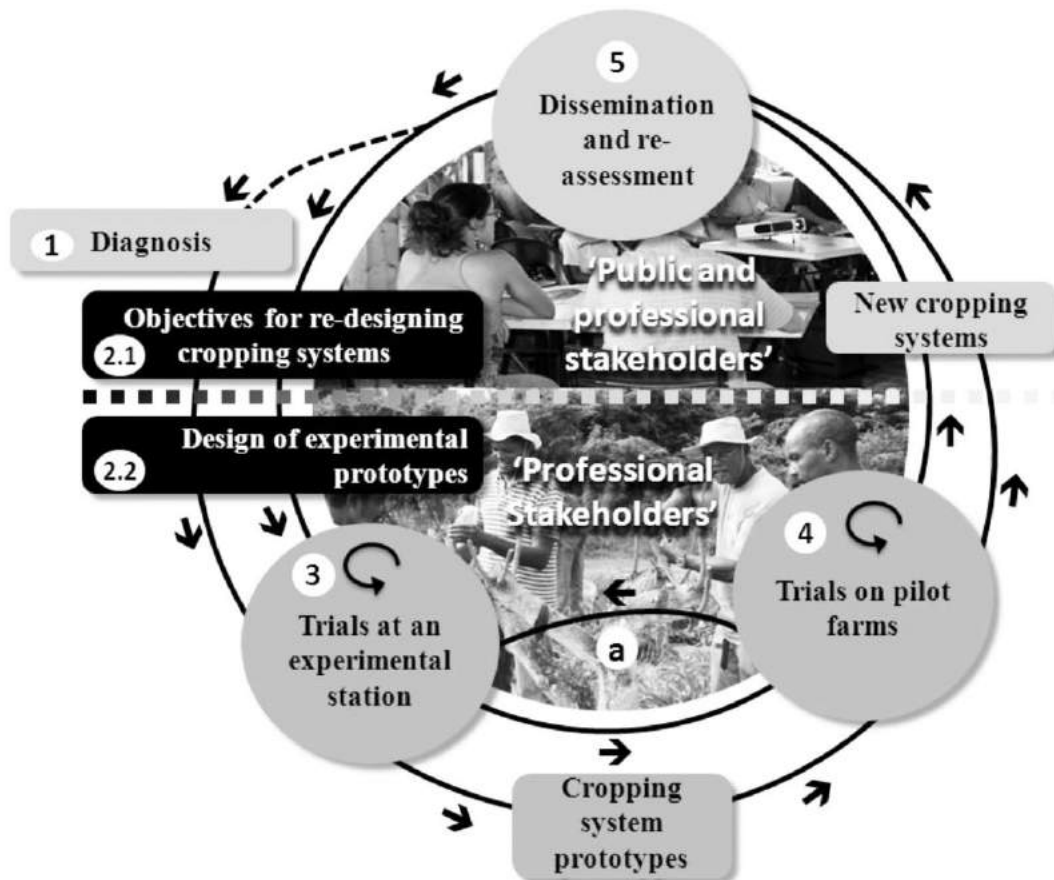
research institutions/organisations and contribute to the shaping of scientific priorities, interdisciplinarity and partnership. The following section elaborates how this pathway was used to design systems adapted to the Caribbean region. Two examples are provided: the step-by-step design of citrus systems (Le Bellec et al. 2012) and the de novo design of banana farming systems (Blazy et al. 2010 and Archimède et al. 2012).

EXAMPLES OF TWO DESIGN SYSTEMS IN THE CARIBBEAN

Step-by-step design of citrus systems

This design methodology has been used for citrus farmers in Guadeloupe as a mechanism to reduce herbicide load. Where changes were made in the field, the expectation was that there would be impacts felt within the whole farming system (local), in the agricultural sector (regional), and the pesticide industry (global). These represent some of the ‘cascading effects’ that are mostly unpredictable, but would nevertheless influence the general sustainability of the modified regional socio-economic and agricultural landscape (Kinzig et al. 2006). This demands a need for dynamic, non-linear, multi-stakeholder, and transdisciplinary approaches (Veldkamp et al. 2009) to sustainable development, in order to preserve the structure, identity, and functions of a ‘socio-ecological system’ (Walker et al. 2004).

With a view to redesigning an alternative citrus production systems adapted to the Guadeloupe particular context, Le Bellec et al. (2011) developed the DISC method (DISC: an acronym for re-Design and assessment of Innovative Sustainable Cropping Systems), which involves, a multi-scale, multi-stakeholder, participatory approach, and represents an improvement on the classical prototyping methods developed at field level. The DISC method involves four categories of stakeholders distributed into two distinct groups; professional stakeholders (farmers, researchers, and agricultural advisors), and public stakeholders (representatives of the State, regional institutions, civil organizations), and has been used to address citrus production in Guadeloupe (Figure 9.6), where local demand for citrus is covered mostly by imports. To satisfy this demand, producers had to increase production while reducing the use of pesticides, in accordance with French government objectives (Ecophyto 2008). This ruling was introduced at a time when citrus producers were still facing unresolved technical difficulties and were struggling to improve the quality of their products on the local market. The main concern in re-designing citrus cropping systems therefore was to develop lower-input cropping systems with improved economic and quality performances, in a move toward sustainable citrus production in Guadeloupe (Le Bellec et al. 2012).

Figure 9.6: DISC method application on the Guadeloupian citrus production

Note: 1) public stakeholders convey global orientations for local agricultural development through an agronomical diagnosis, and a participatory analysis;; 2.1 and 2.2) specific goals are set for citrus cropping systems redesigning (low-herbicide use); 3) at experimental station scale, five prototypes are tested and assessed with a specific grid; 4) two low-herbicide prototypes with satisfying global results are selected and transferred to citrus growers; the latter use decision-support indicators to monitor their practices while they integrate new techniques to their cropping systems. the set of ten indicators characterizes a degree of sustainability of the cropping system; once innovative cropping systems are running, their number on the local area leads to the validations of global goals; at local area scale, three indicators will assess the realization of the goals; 5) through multi stakeholder consultation and, if need be, through a new agronomical diagnosis, new goals are set for the pursuance of the innovative process

Source: Le Bellec et al. (2012)

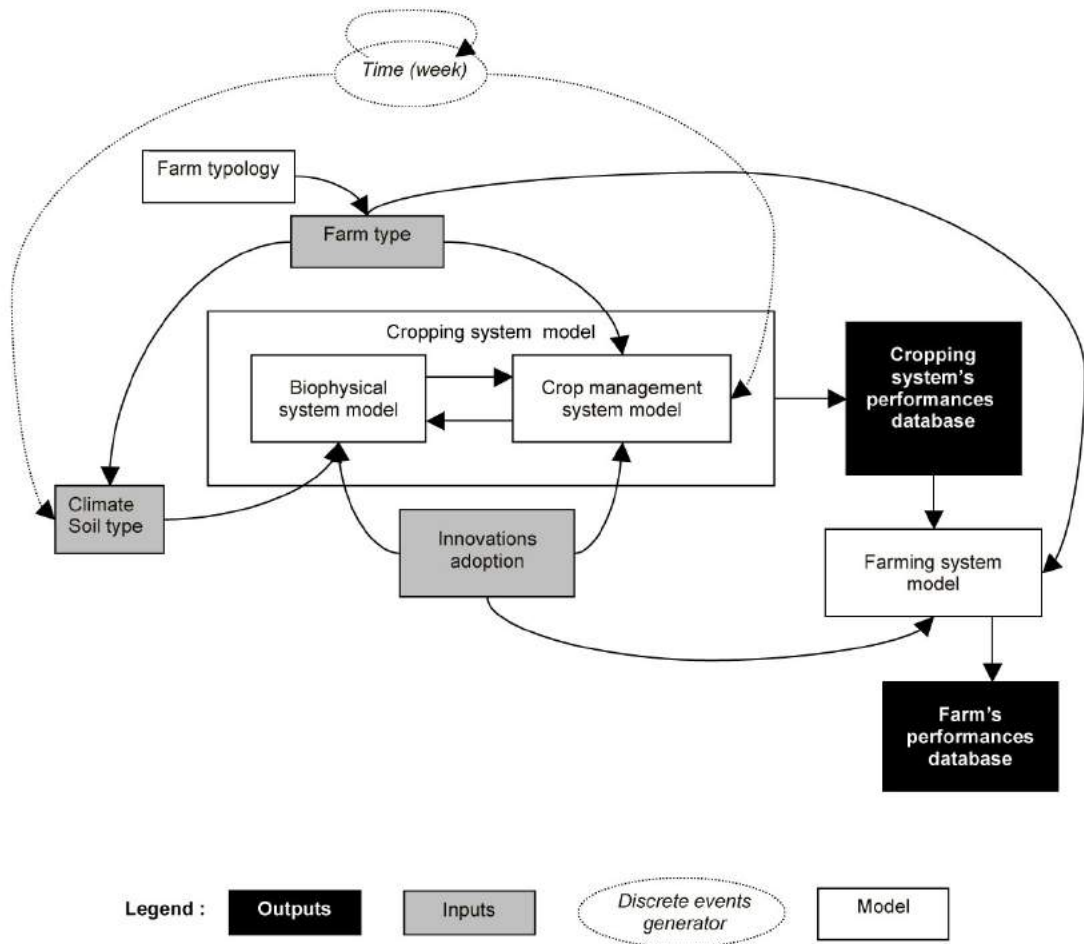
Two workshops were held for the main actors involved in the citrus industry, and included farmers implementing citrus production and specialist researchers in the area of citrus production. A study was undertaken by the researchers with the objective of identifying the types of farming strategies implemented by producers and the constraints they face (Le Bellec et al. 2011). While the goal of the workshop with the stakeholders was aimed at focusing on the design of cropping systems prototypes, the other one for public stakeholders was aimed at establishing objectives for the new cropping system based on an integrated regional perspective. Experiments were performed at the local experimental station to test and adjust the prototypes to performance objectives, and an assessment tool was constructed to evaluate prototypes. It was found that the two main technical constraints that needed to be overcome to improve Guadeloupian citrus cropping systems were: i) the inability to mechanise many fields due to steep slopes and stony soils; and ii) the lack of producer-specific skills regarding the use of chemicals in the management of orchards.

Based on these results, it was collectively agreed that the focus of the redesign process should be on the development of an alternative low-chemical weed control management strategy that would be compatible with the absence of mechanisation on the farms (Le Bellec et al. 2011). Five weed control prototypes were jointly designed as well as two multicriteria assessment tools. Results indicated that farmers involved in the study independently transferred the new technique to their own farms, and as such automatically became pilot farmers. The DISC method created an ongoing dynamic relationship between agricultural and public stakeholders that enabled them find solutions that can be continuously adjusted to stakeholder's, expectations (Le Bellec et al. 2012).

De novo design of banana cropping systems

Blazy et al. (2010) and Archimede et al., (2012) performed an *ex ante* assessment of agroecological innovations in banana production in Guadeloupe using modelling. In the case of Blazy et al., (2010), BANAD was used. This is a computer bioeconomic model that jointly simulates bioeconomic and 'technico-economic processes' of resource management at the farm level for assessing several innovative prototypes of environmentally-friendly management systems. The outputs of the BANAD model are dynamic, and based on a weekly time-step. They also include information on the banana production, cash flows, workload and environmental impacts (Figure 9.7). The inputs of the model are the: (i) farm's economic, technical and environmental characteristics; (ii) innovative crop management system parameters; and (iii) policy and market conditions (Blazy et al. 2010).

Figure 9.7: The general structure of BANAD, a bio-economic farm model for the assessment of the impact of innovation adoption



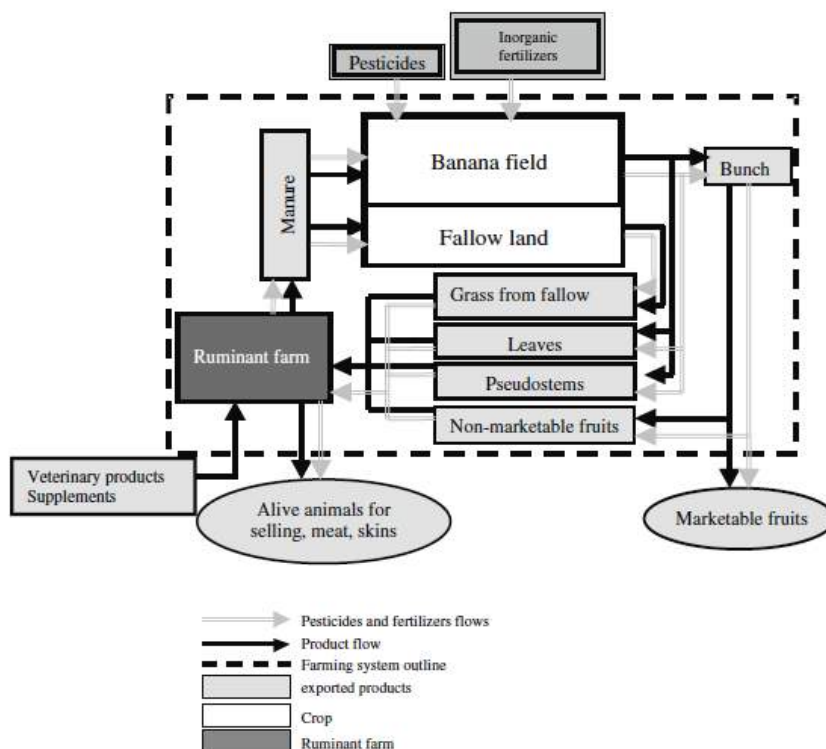
Source: Blazy et al. (2010)

On the other hand, the model employed by Archimede et al. (2012) was a mechanistic model, which was conducted at the farm level. The outputs of this model are also dynamic, but are however based on a yearly time-step and relative to the crop production (total level of biomass of the land fallow and of each compartment of the banana plant including marketable and non-marketable fruits) and animal production (desired stocking rate of animals for the required meat production). The main input data were the total area

dedicated to banana production, the percentage of surface to be left in fallow, the specific characteristics of each ruminant species and the average yield and quality of the banana field and its by-products (Figure 9.8).

These two models facilitated the assessment of several agroecological innovations which enabled the reduction or the total avoidance of the use of pesticides in fields. The main innovations tested by Blazy et al. (2010) were the introduction of cultivated rotations to interrupt the cycle of *Radopholus similis* (a nematode), intercropping banana with, firstly *Canavalia ensiformis* (jack bean), a legume cover crop which can limit weed development and provide nitrogen to the soil without increasing the pest population (McIntyre et al. 2001), and secondly, a new hybrid cultivar of banana that has partial resistance to the fungi *Mycosphaerella musicola* and *M. fijiensis*, and which is sufficiently tolerant to the nematode *R. similis* so that fungicide and nematicide application can be avoided (Tixier et al. 2008).

Figure 9.8: Diagrammatic representation of a ICLS based on the integration of banana crops, and small or large ruminants production



Source: Archimede et al., (2012)

An innovative organic banana system consisting of an improved fallow with *Crotalaria juncea*, intercropped with *C. ensiformis*, new hybrid cultivar, and organic fertilisation, with no chemical inputs, was assessed on three different farm types (characterised according to their biophysical and economic parameters). These parameters included the physical state of the land, and the parasite load, climate and soil types, crop rotation, management decision rules and manpower characteristics (cost and efficiency). Using a similar methodology, Archimede et al. (2012) studied the opportunity to transform monoculture banana farms into mixed farming systems with ruminants feeding on banana by-products (leaves, pseudostems and non-marketable fruits), and forage from land left fallow to break the cycle of the nematode *R. similis*.

Five theoretical farm types were established based on the following: presence or absence of the fallow, and the type of ruminants used (i.e. cattle, sheep, or goats). Blazy et al. (2010) found that the impacts of agroecological innovations vary considerably according to: i) the farm type in which the innovation is integrated; ii) the nature of the agroecological innovations; and iii) the criteria considered and the time span of the assessment. The study conducted by Archimede et al. (2012) also revealed that increasing farming system sustainability through alternatives such as using fallow land (rotation) and the integration of ruminant production is feasible from a biotechnical point of view. The methodology employed by these two groups facilitated a rapid assessment of the relevance of innovations under ‘real’ farm conditions. Such assessment studies would be almost impossible to be made through on-farm trials, and so are more easily accommodated via the utilisation of computer models. This approach would enable the development of policy initiatives to promote the adoption of environmentally-friendly innovations, which for the sake of completeness would still require on-farm validation by stakeholders.

CONCLUSION

Agriculture in the region is extremely diverse and mainly driven by mixed farming systems which include crops and livestock and is practised mainly by rural households. This type of agriculture has nevertheless been excluded for a long time from the political, scientific and technical spheres, giving way to the promotion of export crops. Today, in light of the MEA, the complex diversity and multifunctionality of such agricultural systems is being promoted as an innovative approach to renew productive practices for a sustainable development. Researchers in the region are now able to offer different methodologies to design innovative systems corresponding to the current societal expectations, which can either be gradual (step by step), or sudden (de novo). These have been tested in Guadeloupe in response to certain phytosanitary restrictions faced by the banana and citrus farmers. Other countries

in the region can also benefit from these methodologies, which can be adapted to their individual realities. The adoption of these alternative technologies by farmers in our region should therefore be considered a priority.

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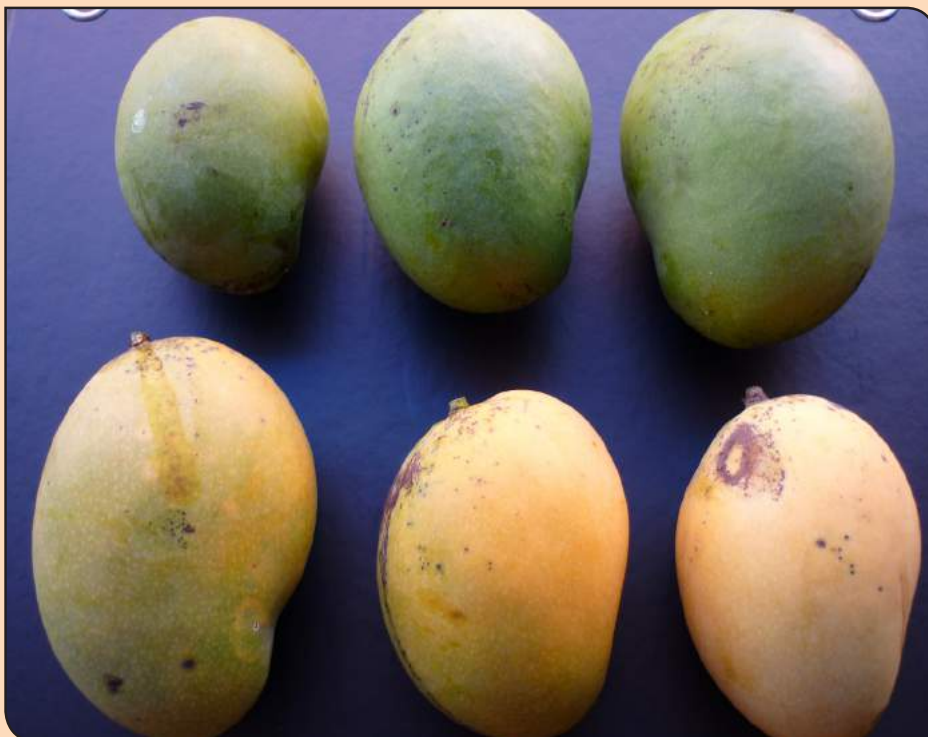
Figure 7.3: Algal growth (green) associated with animal manure



Figure 7.4: Solid and liquid waste from feedlot



Figure 8.2: Skin colour at different stages of maturity and ripening cv. Long



Source: Mohammed and Craig (2014)

Figure 8.3: Flesh colour at different stages of ripening cv. Long



Source: Mohammed and Craig (2014)

Figure 8.4: Latex stains on harvested fruits



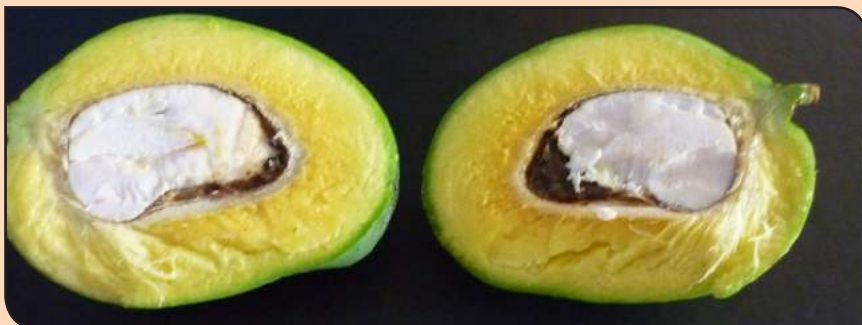
Source: Mohammed and Craig (2014)

Figure 8.5: Various types of physical damages



Source: Mohammed and Craig (2014)

Figure 8.6: Mango seed weevil



Source: Mohammed and Craig (2014)

Figure 8.8: Fresh-cut mango slices in retail market



Source: Mohammed and Craig (2014)

Figure 8.9: Frozen mango chunks



Source: Mohammed and Craig (2014)

Figure 8.10: Mango value-added products



Source: Mohammed and Craig (2014)

Figure 8.11: Anthracnose infections on cv. Julie mango fruit



Source: Mohammed and Craig (2014)

Figure 8.12: Scale insect damage



Source: Mohammed and Craig (2014)

Figure 8.13: Bird damage



Source: Mohammed and Craig (2014)

Figure 9.4: An example of a Creole garden which involves the growing of annual and biennial agricultural crops along with forest species.



Photo by Magalie Lesieur-Jannoyer

Figure 9.5: An example of multispecies system in a Guadeloupe farm



Photo by H. Ozier-Lafontaine

Agricultural Diversification and Non-Traditional Systems for Sustainable Food Production

Leighton Naraine, Stuart LaPlace, Clare Bowen-O'Connor, Amenold Pierre and Kevin Meehan

INTRODUCTION

This chapter considers the challenge of creating a sustainable supply of food for local consumption in the Caribbean with some potential for export. While it is important to note recent trends in large-scale production, including a long decline in plantation systems geared for the export of single crops, and more recent attempts to boost commercial farming for delivery to niche export markets, the focus here is not primarily on commercial or export agriculture. Rather, the chapter looks at recent and emerging efforts to implement non-traditional systems geared for small-scale farming. These systems are aimed at strengthening local food security and adapting traditional farming methods in the face of rapidly changing climates. In the context of this chapter, traditional agriculture is considered as the cultivation of crops in the ground, depending mainly on rainfall and with minimal use of irrigation. It is a system practiced widely for the past several decades and even centuries in the Caribbean.

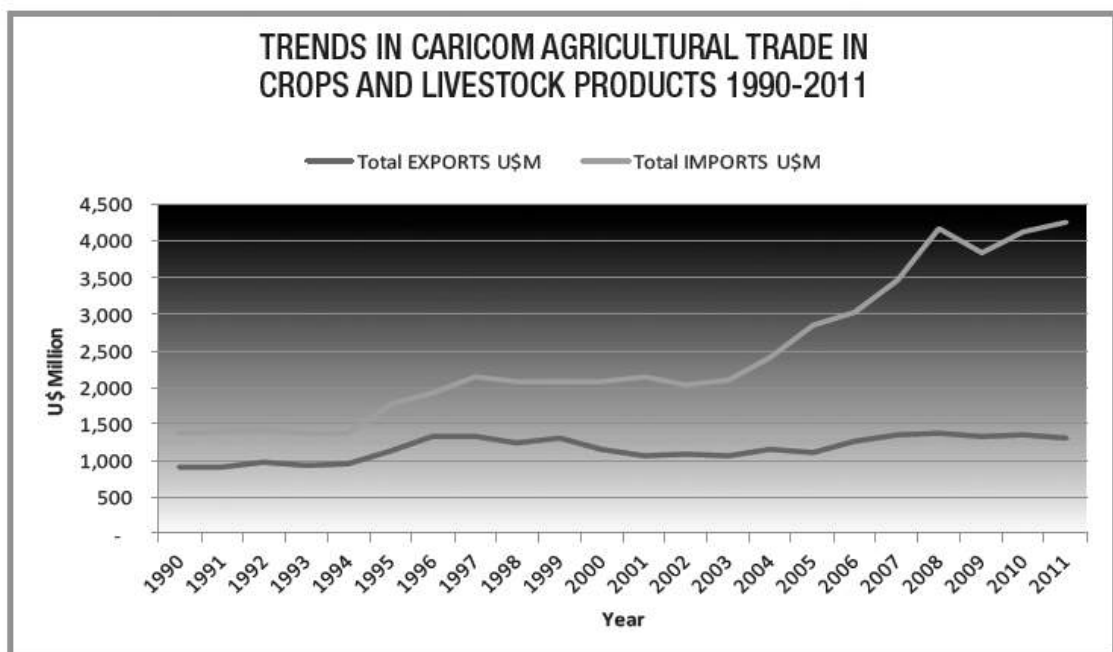
The following pages focus mainly on the production of food crops, with some mention of livestock. Drawing mostly on examples from the Eastern Caribbean and Haiti, the authors describe a range of non-traditional techniques currently being developed in the region. A more detailed look at one non-traditional approach spearheaded by researchers in St Kitts and Nevis is then provided. This system, founded at Clarence Fitzroy Bryant College (CFBC) in St Kitts is now poised for implementation in Nevis, Barbados, Trinidad and Tobago, Guyana and Haiti. It blends protected

agriculture shade house technology with a combination of hydroponics, organoponics, and hybridponics growing systems. The prospect summed up in the conclusion is to confront barriers of regional fragmentation and vulnerability with regional collaborations that transfer knowledge, adapt it to community-based needs, and improve food security and social resilience at the local level throughout the Caribbean.

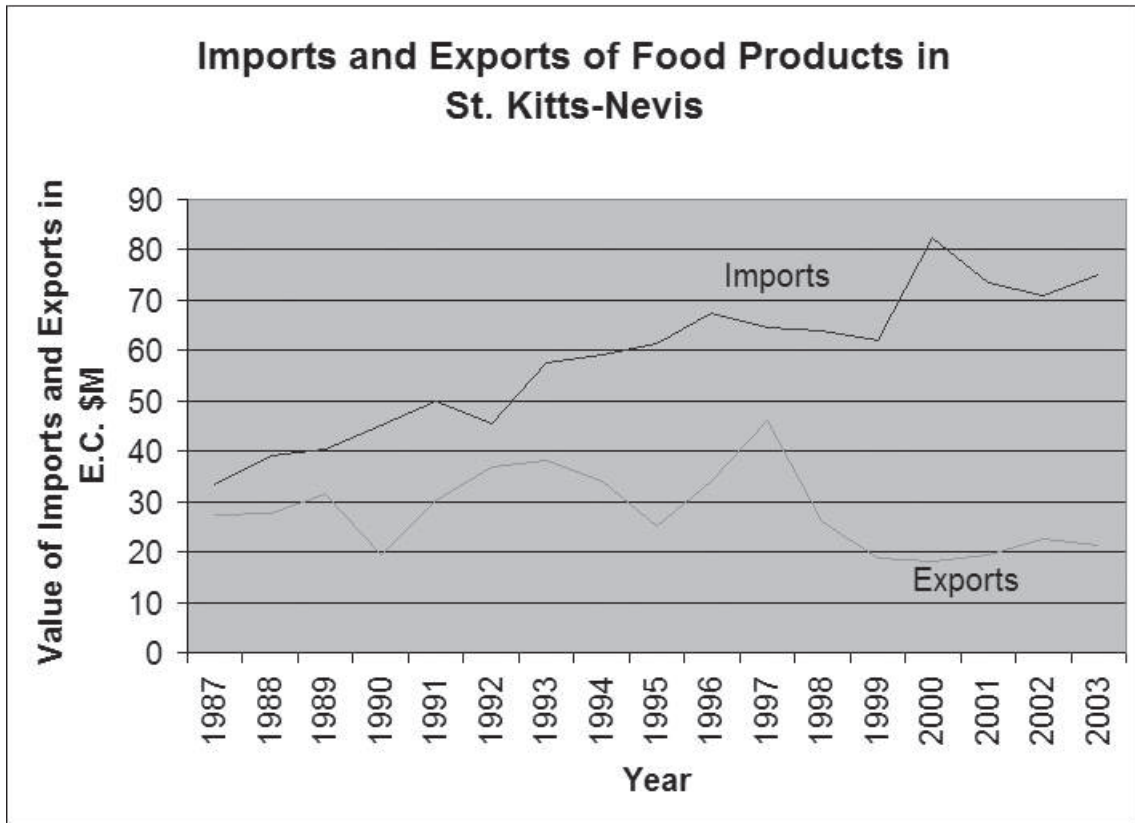
DIVERSIFICATION: FROM EXPORT AGRICULTURE TO LOCAL FOOD PRODUCTION

In most Caribbean countries, particularly in the smaller island nations, food imports have been increasing while exports of agricultural products have been decreasing, as seen in Figure 10.1.

Figure 10.1: Trends in CARICOM agricultural trade



Source: FAOSTAT (2013)

Figure 10.2: Food imports and exports in St Kitts-Nevis

Source: St Kitts Planning Unit, Department of Statistics (2005)

The situation in St Kitts and Nevis as illustrated in Figure 10.2 is typical of the trend among its Caribbean counterparts. Agricultural production for local consumption has also been decreasing and, in the case of St Kitts and Nevis, the contribution of agriculture to Gross Domestic Product (GDP) accounted for only 4.5 percent in 2000, with sugar cane accounting for close to half of that amount.

Many Caribbean economists, historians, and other writers on the political economy of agriculture in the region (Marie 1979; Codrington 1984; Marshall 1991; Barrow 1992; Beckford 1994) have pointed out that plantation systems for commercial crops such as sugar and bananas tended to de-emphasize food production for local consumption thereby creating a dependence on imports. Indeed, the plantation economies have shaped Caribbean agriculture practices for centuries with an export-oriented focus on cash crops, while local food production remained minimal. Given the legacy of the plantation system, Caribbean people often find themselves without the necessary mindsets or practical models

to develop and implement new approaches to growing food, making the problem of local food production an even more severe challenge. The plantation system, while it casts a long historical shadow, was in decline more than a century before the recent final closure of sugar mills in Barbados, Trinidad and Tobago, and St Kitts and massive down-sizing in other countries. As many as five decades ago, some Caribbean countries began making attempts to manage the shift away from plantation economies and simultaneously address the problem of local food production. Initially, these efforts took place within a framework of agricultural diversification, and more recently have been motivated by additional concerns about food security and rapidly intensifying climate change.

According to Wilson and Bekele (1999), agricultural diversification refers to increasing the range of agricultural output at farm, sectoral or regional levels either through expanding the number of crop or livestock species produced, or by vertical integration of one or more species into a diversified product mix, through processing. With such processing, diversification could also be achieved by internationally sourcing raw material, e.g. fresh fruit to achieve all year manufacture of products for an export market or continuous supply of local demand.

Beginning in the mid-1960s and carrying through to the late-1990s, studies undertaken at the Caribbean Community Secretariat, the Faculty of Agriculture of the University of the West Indies (UWI), and the Caribbean Food and Nutrition Institute (CFNI) indicate both the technical and economic feasibility of substantially increased production of food in the countries of the region. Under the rubric of ‘agricultural diversification’, Demas (1987) and Wilson and Bekele (1999) elaborated planning strategies to manage a shift away from the plantation model of Caribbean agriculture. Three main elements in a successful approach to diversified farming were proposed by Demas (1987). First is the intensification of traditional crop production by increasing productivity through technologically advanced farming practices and irrigation, and by adding value through further processing, thereby generating alternative products from the raw material of traditional crops. Second, is the increased production of non-traditional crops for national and regional consumption, and third, is the increased production of non-traditional crops for export to extra-regional markets. Wilson and Bekele (1999) recognized the existence of operational models for expanding the export of niche products such as hot peppers, aloes, and Sea Island cotton, and for increasing the productivity of crops and livestock for local food markets throughout the region. Arguing that claims about agricultural diversification remain arbitrary and subjective without the use of quantitative models to determine whether or not diversification has taken place, Wilson and Bekele (1999) also contributed more quantitative assessment tools to measure productivity, sustainability, competitiveness, and flexibility.

Trejos and de las Casas (1997) argued for hemispheric integration to boost food production, as well as for a comprehensive model of sustainable development resting on three pillars: participation by producers and organizations; reconversion of production structures, to make them more efficient when overhauled, and enable products to secure a better market position, while conserving resources and increasing equity; and institutional transformation for the improvement of their ability to respond to the demands and needs of agricultural producers and to serve as facilitators to streamline relations among institutions in the framework of sustainable development.

Against the backdrop of these preceding decades of scholarship on efforts to shift Caribbean agriculture by introducing the need for sustainable food production practices, Naraine (2005) surveyed the state of domestic agricultural production in St Kitts. Historically dominated by the oldest sugar plantation system in the region, monocrop cultivation occupied the major portion of arable land and the most productive soils, leaving food crop and livestock production to peasant farmers on the fringes with small, scattered land holdings. Over the decades, farmers toiled against the vagaries of weather, mostly on hillsides, and depended on rain-fed systems to a large extent. Traditional producers also faced declining soil fertility on already marginal land, poor infrastructure, outmoded technology, lack of service support and expertise, and lack of sufficient institutional support from either governmental entities, non-governmental organizations (NGOs), or community based organizations (CBOs). In addition, lack of access to credit, low prices for their produce with seasonal oversupply which was quickly followed by scarcity in off-season periods, lack of marketing systems, nuisances of dog attacks on livestock, monkeys and stray-roaming livestock feeding on food crops, and, not infrequently, environmental disasters attributed to severe storms and hurricanes, have all compounded to negatively impact agricultural development. More recently, the issue of competition with lower-priced imported produce at the market highlighted some of the disadvantages associated with globalization. Opening up national boundaries and lowering tariffs to increase trade constitute a cost to local companies that are, in most cases, ill-equipped to compete at the global level and are therefore marginalized (Barker 2012).

EVALUATING AGRICULTURAL DIVERSIFICATION

Naraine (2005) evaluated the extent of agricultural diversification in St. Kitts using an adapted version of the Shannon Index of Entropy (SIE), represented by the formula (Masisi, et al. 2008):

$$(I_i) = \sum n - p_{it} [\ln(p_{it})]$$

where, (I_i) is a measure of diversification in agricultural systems, using as the basic factor, the proportion of total revenue, p_{it} from the i^{th} ($i = 1, 2, \dots, n$, where $n \geq 1$) agricultural commodity in year (t). Thus, a perfectly diversified agricultural system would have an entropy index of $\log(n)$ and a perfectly specialized system with one commodity an index of zero (0), with the parameters for evaluating diversification to include: productivity, sustainability, competitiveness, and flexibility. This model may be adapted to calculate diversification (SIE) for individual countries or the Caribbean, collectively. However, diversification at the regional or national level alone is not sufficient to measure the success of agricultural diversification in the Caribbean. Naraine (2005) further argued that the success of the sector depends on the individual success of farmers or enterprises, and that national or regional success hinges upon the cumulative effect of individual productivity, sustainability, competitiveness, and flexibility.

Applying the SIE, Naraine (2005) found a low level of diversification of approximately two crop types at the enterprise level in St Kitts in 2005, affecting food production. The optimum determined by the SIE is five crop types (leafy greens, beans, ground provisions, tomato, herbs and peppers) that would correlate with optimum productivity, particularly when there is a total of approximately five crop and livestock types combined. Such integrated farms benefit from sustainability with multiple revenue streams, ecological considerations with effective recycling, and flexibility when faced with varying market changes.

In the intervening decade, discussions have shifted away from viewing Caribbean agricultural diversification as a way of replacing foreign exchange losses due to failing export crops. Instead, there has been greater emphasis on boosting local production through developing non-traditional farming techniques. Because of this, SIE results may now vary, and current data, if gathered for the same variables as in 2005, may reveal that diversification has improved with a corresponding improvement in food production with the introduction of the non-traditional systems identified later in this chapter.

ADAPTATION TO CLIMATE CHANGE

Trotz (2007) asserts that over the last 15–20 years, climate change has emerged as a major concern for small-island and low-lying coastal developing states of the Caribbean region. Impacts ranging from loss of life and food security to saltwater intrusion into aquifers and breakdown of law and order may be extended to Small Island Developing States (SIDS) throughout the world.

The intensification of these trends is confirmed in recent reports from the National Academy of Sciences (2013) and the Royal Society (2014). Barker (2012) directly links climate changes to a crisis in Caribbean agriculture, as increasingly irregular rain patterns

and more extreme tropical weather events compound the stresses and shocks imposed by globalization. With the view that climate change is negatively impacting the physical environment and, in turn, human lives, livelihoods, and biodiversity, it is prudent for all societies to act to minimize the impacts upon the environment and communities.

Minimizing impacts is typically achieved with mitigation, but there is a growing trend with the adaptation approach to climate change. Mitigation tends to be more of a reactive approach, while adaptation, by making decisions with foresight based on potential risks, is essentially proactive and can be more feasible and effective towards long-term solutions. Simoes et al. (2010) identified the characteristics and benefits of adaptation to climate change, using examples from northeast Brazil. The main lesson to be learned from that case is the need for building adaptive capacity at all educational and skill levels, both formal and non-formal. Adaptive capacity is essential for people in communities to adapt to changing climatic conditions and related environmental degradation.

The immediacy of climate change and the need to adapt adds another layer of urgency to the question of agricultural diversification, and it was with that in mind that faculty and students at the CFBC, St. Kitts-Nevis, have experimented since 2006 with non-traditional plant growing systems as an adaptation strategy to climate change. They have developed growing systems (hydroponics, organoponics, and hybridponics) that demonstrate documented high productivity, despite the challenges encountered by Caribbean farmers due to climate change impacts, land scarcity and competition with other sectors for land, and a host of other environmental and human impacts that negatively affect production of garden vegetables.

From 2010 forward, the CFBC collaborated with researchers and students from the University of Central Florida to move beyond experimentation by demonstrating 'proof of concept' on a production-scale design of growing systems. In addition to building shade house growing systems for hydroponics (44.6 m²) and organoponics (37.2 m²), and using them in tandem to create a novel hybridponics growing method, faculty-student teams have conducted marketing research in the field to generate a model for commercializing crop outputs and estimating livelihood potential. The data presented in student research submitted for the Caribbean Advanced Proficiency Exam (CAPE®) assessments and at the 2013 United Nations Educational, Scientific and Cultural Organization (UNESCO) Sub-regional Conference on Environmental Policy and Planning for the Caribbean indicated that output from this system is profitable enough to generate a competitive income of more than EC\$2,000 (US\$740) per month. This system is profiled in greater detail in the following discussion, but first we present a survey of recent efforts to develop non-traditional techniques throughout the region.

NON-TRADITIONAL AGRICULTURAL SYSTEMS IN PRACTICE

In addition to the techniques of hydroponics, organoponics and hybridoponics proposed in this chapter, there are several relevant examples of non-traditional agricultural practices throughout the region, which offer the opportunity to use new varieties and move away from the traditional plantation-style monoculture systems. Additionally, these practices are less tedious and therefore more attractive to youth who are less inclined to venture into the traditional drudgery of plantation-style or open-field farming. Several new and improved techniques have been introduced to the region within the last 20 years. In the case of crops for example, varietal trials, tissue culture, protected agriculture systems and low-cost alternatives, coordinated urban and peri-urban systems in the form of backyard and school gardens, and hydroponics have been implemented to increase food production. For livestock, artificial insemination is being used in St Kitts and Nevis to reduce the importation of live animals.

VARIETAL TRIALS FOR HEAT TOLERANT TOMATOES

Varietal trials are useful for the introduction of new cultivars (commonly referred to by producers as varieties) to the agricultural sector, which are chosen for optimum performance in the field, high yields and market acceptance. Varietal trials require controlled conditions and consistent data collection, and in the case of St Kitts and Nevis, with a hot, dry climate, the selection of heat tolerant cultivars is important. Farmers have reported that the annual drought is longer and the annual rains during the rainy season have become progressively more intense within the last 10 years, something which is evidenced by the frequency of forest fires during the dry periods and the increasing intensity of flooding throughout the region. The Department of Agriculture (DoA), St Kitts and Nevis, embarked on a series of varietal trials to select the most suitable varieties for production of various crops.

Varietal selection

There are many heat tolerant varieties on the market internationally with new ones being released frequently; therefore, it is important to research the varieties before selection. Varieties may be determinate (the plant dies after a single fruiting), or indeterminate (plants continue to grow and fruit until killed or removed by grower). As these require different management techniques, growers must determine which type is most suitable for their application. Determinate varieties require minimal staking or support and minimal pruning. Indeterminate varieties require extensive support and pruning, and although removal of suckers is highly recommended, it is not mandatory. It is important to choose high quality seed from reputable seed companies to attain best seed germination and crop productivity.

Field preparation and layout

For uniformity, areas should be selected that are free from shade and level where possible, otherwise, the field should be divided into blocks with uniform characteristics before planting. The soil should be tilled and banked in rows with 0.91 m spacing between ridges to allow for adequate drainage. Rows should run in the direction of the contours whenever possible to reduced erosion. Drip irrigation tubing of 1.3 cm diameter should be used with 45.7 cm spacing between emitters. Rows should be covered with plastic mulch to reduce weeds and water loss due to surface evaporation. The size of the trial plot would be determined by the number of varieties to be tested.

Seed germination and planting

General seed germination practices should be followed to ensure seedling uniformity. Firstly, calculate the number of seeds to sow for each variety depending on number of replications. More replications are required if the field is not uniform as the field will need to be divided into blocks. Sterilise seedling trays, mix growing media (e.g. ProMix®), with slow release fertiliser and apply evenly to seedling trays, and place one seed per cell. Finally, cover the seeds with a light covering of growing media and water gently to prevent seeds from being dislodged from the cells. Ensure only one cultivar is sown per tray and that trays are properly labelled with the cultivar name. Trays may be placed in a germination chamber or shade house dedicated to seedling germination. The seedlings should be frequently checked to ensure the media is sufficiently moist. Once plants have achieved three to four true leaves and attain a height of 10–15 cm they may be transplanted to the field.

For a uniform field, varieties should be randomly assigned to rows using random number tables. For a field with blocks, varieties should be assigned randomly to rows within blocks. A field map should be prepared to record the layout of the varieties, and standard fertilisation practices should be employed. Seven to ten days after transplanting, a complete fertiliser should be applied. About six weeks after transplanting, at the onset of flowering, a potassium-rich fertiliser should be applied to encourage flowering and fruit set. Data collection for each cultivar should include pest resistance, crop yield, and presence of wilting and nutrient deficiency. In keeping with good agricultural practices, records should be kept on inputs for calculation of the cost of production. Market acceptability and organoleptic (taste) assessments are required to determine the suitability of the best performing varieties for introduction to the market.

In 2013, the DoA, St. Kitts and Nevis, successfully tested four Israeli tomato cultivars to replace the commonly used Heatmaster and Heatwave. The cultivar HA3080 had the lowest yields, while HA3019, HA3057, and HA3091 had similar yields to Heatmaster (Table 10.1).

Table 10.1: Results from tomato varietal trial comparing four Israeli cultivars

Variety	Yield (kg/ha)
HA 3019	9,000
HA 3057	9,000
HA 3091	10,000
Heatmaster	9,500
HA 3080	6,000

Source: Jackson (2014)

The cultivars were selected based on similar visual fruit characteristics, heat tolerance and availability. In St Kitts, visual characteristics are a major determinant of public acceptance. Thus, with the exception of HA3080, the tested Israeli cultivars are suitable replacements for the two common varieties. Time constraints represented a major shortcoming to such varietal trials as they limit the length of the trials. As such, it is commonplace for organoleptic testing and market viability studies to be eliminated before introduction, and conducted while the crop is on the market. This has led to several cultivars being withdrawn from the market as a result of the taste not meeting the expectations of the consumer.

TISSUE CULTURE

Plant tissue culture, as a non-traditional method for generating propagules, has been successfully adopted in several Caribbean territories (Table 10.2). Since 1994, significant increases in propagation were realised in root crops, banana and orchids throughout the region. The Caribbean Agricultural Research and Development Institute (CARDI) and International Co-operative Development Fund (ICDF), Taiwan, have contributed significantly to this development.

General process

Plant tissue culture, *in vitro* propagation or micro-propagation is the process of propagating plant material (cell, tissues or organs) in an aseptic (i.e. free of pathogenic organisms) controlled environment using nutrient media.

Table 10.2: Tissue culture laboratories in various Caribbean countries and major crops produced

Country	Agency	Crop
St Lucia	Ministry of Agriculture	Yam, Orchid, Banana
St Vincent and the Grenadines	Ministry of Agriculture	Banana, root crops (30 varieties cassava; 24 Varieties sweet potato)
Belize	University of Belize	Papaya, Sugar cane, Pumpkin, Citrus, Banana, Plantain, Orchid
Grenada	Ministry of Agriculture	Nutmeg, Banana, Spices, Plantain, Orchids, Cassava
Barbados	Ministry of Agriculture	Cassava
Barbados	West Indies Board of Breeding	Germplasm research on sugar cane
Trinidad and Tobago	Ministry of Agriculture	Cassava
Trinidad and Tobago	The University of the West Indies	Cassava, Anthuriums, Orchids, Banana, Sweet Potato
Trinidad and Tobago	Tobago House of Assembly	Cassava, Yam, Sweet potato

Source: Adapted from Gonzalez (2010)

Plant material preparation

Plant material may be collected from field plots or from their native habitat. Before it is transferred to the laboratory, where possible, sterilise the material and propagate using traditional methods in a greenhouse to reduce the amount of surface contaminants introduced to the lab. The samples collected from the greenhouse-propagated material should also be freed of loose contaminants and debris with running water for a few minutes. Cut the material into suitable lengths and surface sterilise with low to medium percentage bleach-wash containing one or two drops of dishwashing liquid. The sterilisation process needs to be optimised for each crop as the time to decontamination varies. Keep in mind that 100 percent decontamination is not always achieved so cultures should be monitored frequently.

Media selection and preparation

Many media preparations are a modification of Murashige-Skoog standard for media preparation (Murashige-Skoog 1962) and vary by the type and amounts of macro- and micronutrients, vitamins, carbohydrate source, and plant growth regulators or plant

hormones, the latter two of which are used to regulate the growth and development of the cultured plants. The media are available pre-packaged, from a number of international suppliers.¹ Alternatively, media recipes can be found in several publications, for example, Saad and Elshahed (2012). Great care must be taken when preparing media. The order of addition of components must be strictly followed to prevent undesirable side reactions and precipitation of salts. Once prepared, media must be sterilised either by filtration, ultraviolet light, or autoclaved (steam steriliser or pressure cooker), and then decanted into the desired culture container (e.g. test tubes, petri-dishes, baby food jars, magenta boxes).

Culture initiation and sub-culture

All steps from the sterilisation of plant material to root initiation need to be performed in an enclosed lab environment using a specialised piece of equipment, the laminar flow hood, in which air flow is in one direction toward the user. The sterilised plant material is cut into smaller pieces (explants) and placed on culture media and observed daily for signs of growth and contamination. If contamination occurs, remove the contaminated container, autoclave and discard the material. Culture containers may be re-used if they are made of glass or specialised plastic. Growing cultures may be sub-divided and placed on fresh media every three to four weeks depending on the rate of growth, a process called sub-culturing. Because nutrients in the medium are used by the explant, therefore frequent sub-culturing is necessary.

Rooting and acclimation

After several rounds of sub-culturing, shoots are transferred to a rooting medium, which may or may not contain the plant growth regulators, auxin or cytokinin, or a combination of both. This is dependent on the plant in culture, and has to be optimised for each plant type. Rooting cultures are then hardened or acclimated through a series of steps. The total number of steps in the process is again determined by the plant type.

Box 10.1 outlines the key benefits and limitations associated with the adoption of tissue culture.

1. Examples of international suppliers include: Phytotechnology Laboratories (<http://www.phytotechlab.com/>); Carolina Biological Supply Company (www.carolina.com); Sigma Chemicals (<http://www.sigma-aldrich.com/>); Life Technologies/Invitrogen (www.invitrogen.com); Kitchen Culture Kits (www.kitchenculturekit.com).

Box 10.1: Benefits and Limitations to the Adoption of Tissue Culture

Benefits: • Increased production of planting material to meet local and regional demand • Saves foreign exchange • Reduction in disease introduction through importation • Source of additional income • Increased potential for discovery and introduction of new varieties • Genetic improvement through genetic modification technologies, mutation, somatic hybridisation, identification of somatic hybrids (beneficial), heat resistant varieties • Efficient production of disease-free plants • Conservation through germplasm maintenance • Builds local knowledge • Potential for increased revenue from reduced inputs	Limitations: • Steep initial investment and limited access to easy financing for farmers • Small budget allocation • Limited technical support • Local and regional disease diagnostics and quarantine: diagnostic services including virus indexing and genetically modified organism detection (limited services provided in Barbados and Trinidad) • Inter-regional transportation and movement of living material policies • Long decision-making process in some territories • Establishment of germplasm banks • Training for handling tissue culture material in territories without facilities • Local or regional equipment maintenance • Lack of buy-in from different stakeholders
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Tissue culture in the CARICOM region

In St Lucia, within the Tissue Culture Unit, Department of Agriculture, Propagation Division, the tissue culture facilities were upgraded. The lab now produces high quality disease-free material for propagation and germplasm conservation. Over 200,000 tissue-cultured plants are produced annually; however, the facility has the capacity to produce 500,000. The main commodities are banana, yam and orchid. In 2013, orchid production was self-sustaining in that the revenue generated from the sale of orchids was sufficient for equipment and lab maintenance and employee salaries. In St Vincent and the Grenadines, tissue culture facilities were upgraded in 2012. The tissue culture lab actively micro-propagates and distributes roots and tubers, and planting material both locally and

regionally. Cassava, yam, sweet potato and dasheen plantlets (micro-propagated plants) have been distributed regionally to members of the Organisation of Eastern Caribbean States (OECS), Jamaica and Barbados (CARDI Bi-Weekly 2014).

The major challenge faced was in the distribution and acclimation of material, resulting in distributed plantlets dying in several of the receiving territories. The limited number of adequately trained personnel to manage the acclimation of the plantlets is one area that therefore needs to be addressed.

PROTECTED AGRICULTURE: GREENHOUSE MODELS

Protected agriculture has been reintroduced into the Caribbean region with the construction and commissioning of several tropical greenhouses to increase year-round local production and reduce imports (Table 10.3). In 2012, the largest fully temperature-controlled greenhouse in the region was constructed in St Kitts with ICDF, Taiwan.

Selected greenhouse results

In 2010, the Agricultural Resource Management (ARM) Project, funded by the Sugar Industry Diversification Foundation (SIDF), embarked on a project to fund the re-introduction of greenhouse farming to St Kitts and Nevis. The initial project included the construction of ten dams and four demonstration greenhouses with drip irrigation and water storage systems. By 2014, eight greenhouses in St Kitts and two in Nevis were completed. Farmers were provided with the infrastructure, supplies and training to operationalize the systems. The objective was that farmers will adopt the technology and take full responsibility for the greenhouses at the end of the project. Greenhouse cultivars (hybrid seeds) of tomato, sweet pepper, lettuce and cucumber were imported for planting in the greenhouses. The structures were outfitted with fertigation systems (irrigation and fertiliser mixer) and timers. In the initial phase, because in-soil planting was used, rows were prepared and covered with plastic mulch and drip lines (micro-irrigation) for precision watering.

Table 10.3: Protected agriculture structures in CARICOM territories

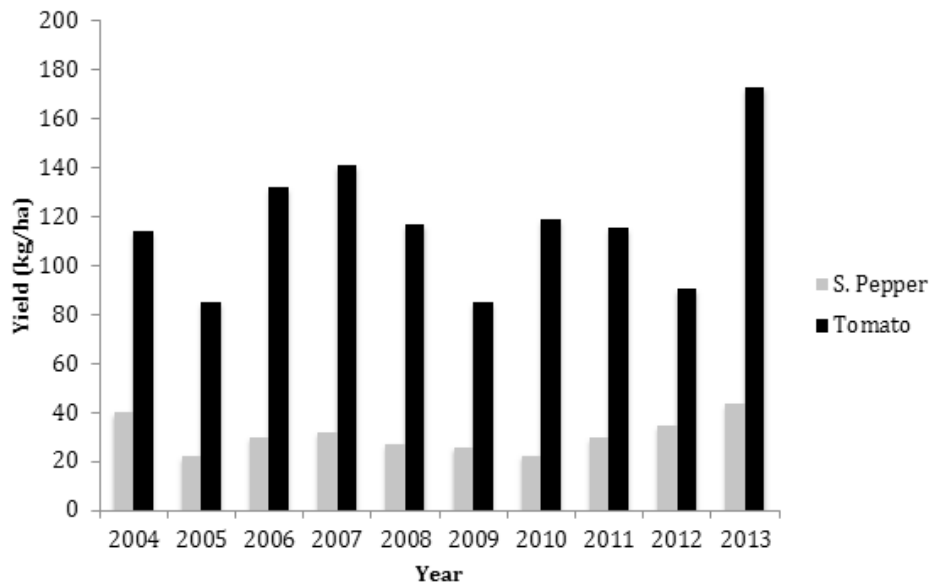
Country	No. of structures (year)
Dominica	190 (2012)
Jamaica	261 (2013)
St Lucia	246 (2010)
Trinidad and Tobago	50 (2012)
St Kitts and Nevis	10 (2013)
Grenada	18 (2010)
St Vincent and the Grenadines	130 (2010)

Source: Adapted from CARDI (2010 and 2012)

In Haiti, as part of the WINNER program, a five-year project sponsored by the United States Agency for International Development (USAID), and implemented by the development contractor Chemonics, as many as 1,000 greenhouses were constructed during 2012–13 period. The programme is not without controversies related to the distribution of Monsanto seeds treated with potentially toxic pesticides and herbicides (Innocent 2011; ‘Monsanto in Haiti’ 2011), inconsistent delivery of promised storage supplies (Lentfer 2013), alleged by-passing of the Haitian Ministry of Agriculture (Center for Economic Policy and Research 2011) and an overall approach that threatens to displace long-standing peasant association networks with US-style agribusiness (Yaffe, 2011). WINNER does, however, represent an attempt to boost higher-scale commercial production, partly through greenhouse protected agriculture, and deliver that produce to local consumers through outlets such as the new weekly Mache Peyizan market in Tabarre (‘WINNER’s Farmers’ Market Delivers on Expectations’ 2012).

In St. Kitts, sweet pepper and tomato production fluctuated greatly from 2004 to 2012 (Figure 10.3), however, in 2013, a 25 percent increase in sweet pepper and a similar 20 percent increase in tomato production were realised (Jackson 2014). Since the increase in cash crop production corresponded to the commissioning of the greenhouses, it can be concluded that the greenhouse crop cultivation contributed to the increase in production of these crops.

Figure 10.3: Total sweet pepper and tomato production from 2004 to 2013



PROTECTED AGRICULTURE: SHADE HOUSE MODELS

Haiti and St. Kitts and Nevis have also seen the implementation of another kind of small-scale protected agriculture based on shade houses that retain the protective roofing and walls of the greenhouse model but forego energy-intensive climate control systems and instead allow air to pass through walls. The University of Nouvelle Grand'Anse (UNOGA) is a small private university that shares a 8.5 ha campus with the Fondation Nouvelle Grand'Anse (FNGA), headquartered in Dekade, along the Grand'Anse river, 9 km southeast of Jeremie, the provincial capital. In order to develop new income generating activities, and to present farmers with a new and more profitable method of farming, faculty and students at UNOGA partnered with technicians from FNGA to install a shade house and test the results of protected vegetable production. During this process, tomatoes, carrots, chard, cabbage, and hot pepper have been tested under the shade house. The most recent harvest data for February–March 2014 indicate that 109 kg of hot pepper (Habanero) were collected from 46 plants.

Inside a previously constructed shade house of 200 m², a drip irrigation system was installed, and distribution pipes were connected to water tank of 2,272l capacity. The water tank used gravity to provide water to the test crops, though some electric power was needed to pump water from the river to a main concrete water tower connected to the campus pigsty. Six in-ground beds were prepared with two drip irrigation lines each. Each bed was seeded with one different vegetable — carrot, chard, cabbage, and hot pepper — and tomatoes were seeded to two beds, and the test crops irrigated for 4 hours twice a week.

The testbed system from Dekade (Figure 10.4) was replicated at a more remote site near Pic Makaya (Figure 10.5) in southern Grand'Anse with participation of another peasant community and support provided by UNOGA faculty and FNGA technicians.

General benefits and limitations

As part of the experiment, researchers collected qualitative data on how local farmers perceived the non-traditional system. Most farmers can be described as small-scale and vulnerable with farms between 0.5 and 1.5 ha in size, and typically situated on eroded land. Farmers noted several general benefits and limitations of shade house protected farming when compared with traditional open-air, rain-fed agriculture (Box 10.2).

Participants were also asked to analyse how this system specifically could be adapted to the conditions and environment of peasant farmers in rural Haiti. They produced the following list of additional benefits and limitations (Box 10.3).

Box 10.2: Benefits and Limitations of Shade House, Protected Farming Compared to Traditional Open-Air, Rain-Fed Agriculture

Benefits: • Optimal plant productivity • Faster maturity (especially cabbage) • Easy control of weeds and insects • Higher yield per unit area • Economic profitability • Reduction of direct exposure to sun • Reduction of evaporation • Better working conditions for the farm worker, less physical effort • Reduction in the area of planting (less land, more results) • Environmental protection, particularly as in the case of crops that require staking (pre-staking was installed). There was no need to use wood to support the tomatoes, for example. • Possibility of continuous production • Protection against animal intrusion	Limitations: • Higher frequency of maintenance • Reduced pollination (especially with tomatoes) • Need for additional pollination support in certain types of crop • Non-adaptation of certain crops (e.g. tomato). It was found that tomatoes in general may not be adapted to the system, the specific variety may not be adapted to the system (indeterminate growth), and the system may need more frequent crop maintenance • Need for an automatic irrigation system, with additional costs for set-up, maintenance and cleaning • Rapid spread of disease and insects in case of attack • High cost of installing the system
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Box 10.3: Specific Benefits and Limitations for Rural Haiti

Benefits: • Easy to maintain • The farmer has more time for other activities, such as livestock • Better economic returns and opportunity to grow more profitable crops than beans and corn	Limitations: • High installation cost means the farmers will not undertake such an activity without additional support • The issue of identifying appropriate cultivars • New agricultural practices and training would be required for peasants
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HYDROPONICS COMMUNITY FARMS

In addition to the CFBC hydroponics system, two alternate hydroponic farms were established in St Kitts and Nevis. The Skills Training and Entrepreneurial Program (STEP), a joint venture between the Ministry of Agriculture and the Department of Education, was launched in 2012 with young males as the major beneficiaries. The program provides training in crop production using a vertical hydroponics system as a platform for enterprise development. Crops are grown in vertically stacked pots filled with coconut mesh housed in open-sided shade houses with a reflective porous roof. Vertical drip lines are installed in the stacked pots, and fertigation is fully automated (Figures 10.6A and 10.6B). The program has been hailed a success as there is a steady supply of produce sold to local restaurants and supermarkets. The major crops produced include tomatoes, lettuce, squash and beets, and there is an occasional demand for micro-greens (juvenile plantlets often eaten raw in salads).

NON-TRADITIONAL PRODUCTS THROUGH AGRO-PROCESSING

Agro-processing of non-traditional products like flour from breadfruit, cassava, and sweet potato has become an important component for revenue generation in the Caribbean region. Establishments such as the Trinidad and Tobago Agribusiness Association (TTABA), the National Agricultural Marketing and Development Corporation (NAMDEVCO) of Trinidad and Tobago, and the Agro-processors' Cooperatives of St. Kitts and Nevis, produce such commodities as alternatives to already existing products. In addition, these products have a higher nutritive value than the more refined products gracing the supermarket shelves. Successful agro-processing requires adequate facilities for processing and storage. However, a consistent theme throughout the region is the limited access to funding and support for acquisition and training for personnel. This problem was somewhat alleviated in 2014 in St Kitts and Nevis, when the storage facilities for value-addition to some crops were upgraded.

Researchers and students at the University of Nouvelle Grand' Anse (UNOGA), Jeremie, Haiti, have been successful in producing breadfruit flour and marketing it as a food tourism souvenir product. It has also been introduced on a limited basis in the United States as an artisanal grain substitute popular with those who prefer gluten free diets or the so-called Paleo-diet. UNOGA researchers have also had experimental success developing a dried fruit roll and energy bar by combining fruits and vegetables in a boiling pot then drying out the paste and shaping it as needed.

CLARENCE FITZROY BRYANT COLLEGE (CFBC) MODEL: HYDROPONICS, ORGANOPONICS, AND HYBRIDPONICS

Within the broader context of non-traditional agriculture adaptations reviewed above, researchers, students, government agencies, NGOs, businesses and community-based stakeholders have partnered to develop a new system that combines several techniques. This approach blends shade house protected agriculture with a combination of hydroponics, organoponics, and hybridponics growing systems. The sections that follow provide more detail on the different systems with emphasis on key aspects of hydroponic growing (effective plant combination, choice of growing medium, and managing nutrient solutions), data on plant productivity, and a commercialization model.

HYDROPONICS DEFINITION, SYSTEM DESIGN AND BENEFITS

What is Hydroponics?

Hydroponics can be defined as a technique used to grow plants without soil, in a system containing the following elements: the root zone, the aerial organs of the plant, an irrigation system to supply nutrient solution to the root zone, and a drainage system for dealing with runoff (Schröder and Leith 2002). In the CFBC adaptation model in St Kitts, these components were adapted to include the use of an electric pump to continuously circulate nutrient solution over the root system of plants located in a growth medium and protected by a shade house enclosure.

CFBC model system design

Researchers and students began by creating three small systems on the main campus—one traditional, one organoponics, and one hydroponics—to compare various aspects of plant growth across systems. A series of six field observations of these on-campus growing systems were conducted to collect and compare a wide spectrum of data related to plant productivity. While the full results are available in a longer paper (Thomas 2010), the actual field reports (in their unedited form) from visits numbered 1, 5 and 6, are presented on the following pages.

Figure 10.7A: Organoponics lettuce

Figure 10.7B: Hydroponics lettuce germination

	Organoponics plants	Hydroponics plants
Lettuce		

Figure 10.7C: Organoponics basil

Figure 10. 7D: Hydroponics basil germination

	Organoponics plants	Hydroponics plants
Basil		

Figure 10.7E: Parsley

Parsley	
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Figure 10.8A: Lettuce organoponics

Figure 10.8B: Lettuce hydroponics

	Organoponics	Hydroponics
Lettuce		

Figure 10.8C: Basil organoponics

Figure 10.8D: Basil hydroponics

	Organoponics	Hydroponics
Basil		

Figure 10.9A: Lettuce organoponics

	Organoponics
Lettuce	

Figure 10.9b: Basil organoponics

	Organoponics
Basil	

Visit/Entry Number: 1**Date (Organoponics):** 4th February, 2010**Date (Hydroponics):** 29th March, 2010

Objectives	Activities	Observations				Interpretative Comments
		Organoponics		Hydroponics		
		Lettuce	Basil	Lettuce	Basil	
Physical						
To measure the height of plant	The height of the plants was measured.	4.3 cm	4.8 cm	0.4 cm	1.5 cm	At this visit, the plants within the organoponics system were transplanted at three weeks old. These were grown <i>in vitro</i> before they were transplanted. Figures 10.7A and 10.7B show the size of the plants at the point of transplantation. The first measurements were recorded a week afterwards when they were four weeks old. By means of comparison to week three, there was vigorous growth of the plants in all aspects of the plants shown in this system. The colours of the stems and the leaves of the two plants were ideal based on the proposed/standard look of the ideal as indicated previously. The measurements for the hydroponics plants however were recorded from the first week of growth. There was growth. The colours of the two plants matched those which were proposed in the same section as above.
To measure the width of plant	The width of the plants was measured	9.0 cm	7.2 cm	2.5 cm	2.0 cm	
To measure the length of the longest leaf	The length of the longest leaf was measured	5.4 cm	3.4 cm	2.4 cm	0.9 cm	
To measure the width of the broadest leaf	The width of the broadest leaf was measured.	2.5 cm	2.2 cm	1.3 cm	0.7 cm	
To observe the colour of the stem	The colour of the stem was observed.	Green	Purple-reddish	Green	Purple-Reddish	
To observe the colour of the leaves	The colour of the leaves was observed.	Green	Dark Green	Green	Dark Green	

Objectives		Activities	Observations			Interpretative Comments
			Organoponics Lettuce Basil	Hydroponics Lettuce Basil		
Biological						
Pests:						
To examine the types of pests present	The plants were examined for the presence of pests.	No pests were found on the plants.	No pests were found on the plants.			There were no pests found in neither system. When plants begin to germinate, they have large stores of sucrose in their roots for proper root growth. Without efficient growth of the roots, plants' development will be restricted, growth will be stunted and photosynthesis will be prohibited. There are no large food stores in the stems of these plants at these stages. Hence, pests will not gain adequate food and thus they avoid these crops and seek others. Moreover, some diseases such as mosaic are caused by other organisms. There were no adverse effects of pests or diseases on the plants.
To determine the extent to which the pests impact the plants	The impacts that pests had on the plants were recorded.	There were no impacts caused by pests.	There were no impacts induced by pests.			
Diseases:						
To examine the types of diseases present	The plants were examined for the presence of diseases.	There were no diseases that were examined on the plants.	There were no diseases that were examined on the plants.			
To determine the extent to which these diseases impact the plants	The impacts that diseases had on the plants were recorded.	There were no implications since no diseases were recognized.	There were no implications since no diseases were found.			

Objectives	Activities	Observations			Interpretative Comments
		Organoponics Lettuce Basil	Hydroponics Lettuce Basil		
Environmental					
To record any pest control mechanisms	Any biological control mechanism that was imposed was documented.	Parsleys and thymes were the pest control mechanisms in this system.	Parsleys and thymes were the pest control mechanisms in this system.		Parsley and thymes were cultivated in the same medium near the plants that were observed. This was essential because as these 'two pests detractors' grew, they produced high levels of alkaloid and toxins within their leaves.
To record the type of Irrigation System used	The type of irrigation system used and the water quantity used was recorded.	The drip irrigation system was used. Five gallons were used for this visit.	The reservoir of the hydroponics system contained water that was continuously recycled. Only 25 gallons of water was used in the reservoir even though its maximum capacity is 40 gallons.		Figure 10.7E shows how parsley leaves appear. They are so green because they are uninfested by pests and are disease resistant due to their large stores of alkaloid and toxins. In the event that any pest consume or taste-even this plant, they will be repulsed as it will taste bitter. This was strategically done because the taste is not enticing for pests and so, thymes and parsleys are undesirable for them. Since pests are the main sources of diseases, the plants are said to be disease-resistant also as they have dual effects in warding off pests and diseases simultaneously. Furthermore, five gallons of water was used for the organoponics system initially as plants did not require as much like in the latter stages at these early points of growth and development. Although the hydroponics system's reservoir maximum capacity was 40 gallons (as mentioned before) only 25 gallons was used as the number of baskets/cups used was reduced considerably by 30.

Objectives	Activities	Observations			Interpretative Comments
		Organoponics Lettuce Basil	Hydroponics Lettuce Basil		
Nutrients					
Fertilizers: To assess the addition of any Nitrogen (N) to the plants medium	Any addition of Nitrate to the plants' root medium was noted.	No Nitrate was added to the soil.	No Nitrates were added in solution.	There was no urgency to add any nutrients to the systems at this first visit. However, prior to these visits, manure and bagasse ash were added to the soil in the Organoponics system. They contained NPK. There was no addition of the three nutrient solutions. Furthermore, the pH value of the Organoponics system was 7.5. According to the Ferry Morse Seed company Premium Soil Test Kit Lab Book, this range is not the most suitable for neither plant's growth at optimal levels (pH requirements noted before). Nevertheless, after four weeks, the plants still showed signs of growth and development. On the other hand, the solution for the Hydroponics at the first field visit appeared to be favourable for the lettuces being 7, but inappropriate for the basil plants. Although the pH value seemed to be inadequate, the basil crops still grew in the conditions that were presented to them.	
To assess the application of Phosphorus (P) to the plants medium	Any application of Phosphorus to the plants' root medium was recorded.	No Phosphorus was applied to this medium.	No Phosphorus was applied to this medium.		
To assess the supplement of Potassium (K) to the plants' medium	Any supplement of Potash to the plants' root medium was documented.	There was no supplementation of Potash to the soil.	There was no supplementation of Potash to the solution.		
To measure the Potenz Hydrogen (pH) of the plants medium	The pH value of the plants' medium was noted.	7.5	7		

Visit/Entry Number: 5

Date (Organoponics): 4th March, 2010Date (Hydroponics): 23rd April, 2010

Objectives	Activities	Observations				Interpretative Comments
		Organoponics		Hydroponics		
Physical		Lettuce	Basil	Lettuce	Basil	
To measure the height of the plant	The height of the plants was measured.	11.8 cm	29.3 cm	15.7 cm	40.3 cm	By this visit, the plants continued to show great improvements in terms of growth and development. The organoponics lettuces grew by 16 percent while the basil grew by 25 percent for this visit. Meanwhile in the hydroponics system, the lettuces grew by 8 percent whereas the basil grew by 33 percent. As the hydroponics system continued to express dominance, growth is smaller than the weeks before as plants began to reach their maximal point as they continue to exploit the various nutrients. The colours of all the plants were ideal.
To measure the width of the plant	The width of the plants was measured.	37.0 cm	28.0 cm	27.8 cm	30.6 cm	
To measure the length of the longest leaf	The length of the longest leaf was measured.	19.0 cm	9.1 cm	19.4 cm	9.2 cm	
To measure the width of the broadest leaf	The width of the broadest leaf was measured.	16.8 cm	5.5 cm	21.0 cm	4.6 cm	
To observe the colour of the stem	The colour of the stem was observed	Dark Green	Purplish-Reddish	Dark Green	Purplish-Reddish	
To observe the colour of the leaves	The colour of the leaves was observed.	Dark Green	Green	Dark Green	Dark Green	

Objectives	Activities	Observations				Interpretative Comments
		Organoponics		Hydroponics		
		Lettuce	Basil	Lettuce	Basil	
Biological						
Pests	The plants were examined for the presence of pests.	There were no pests found.	Leaf miners and caterpillars found.	No pests were found in this system at this visit.	The only plants that seemed to be affected by pests and diseases were the organoponics basil. Caterpillars and leaf miners still affected these plants as there was an abundance of food sources present. Aphids are known to feed on plants once their food sources are sufficient. These were expected to be seen, but were not. It is possible that the time of visit was a factor and the inspection of the plants was insufficient.	
To determine the extent to which the pests impact the plants	The impacts that the pests had on the plants were recorded.	There were no impacts induced by pests.	There were whitish-yellowish caused trails in the leaves caused by leaf miners.	There were no impacts induced by pests.		
Diseases						
To examine the types of diseases present	The plants were examined for the presence of diseases.	There were no diseases seen.	There were no diseases seen.	There were no diseases seen.		
To determine the extent to which these diseases impact the plants	The impacts that the diseases had on the plants were recorded.	No implications since no diseases were found.	There were no implications since no diseases were found.	There were no implications since no diseases were found.		

Objectives	Activities	Observations				Interpretative Comments
		Organoponics		Hydroponics		
		Lettuce	Basil	Lettuce	Basil	
Environmental						
To record any pest control mechanisms	Any biological control mechanism that was imposed was documented.	Parsley and thyme were used to deter pests.		Parsleys and thymes were used to deter pests.		The same biological pests control mechanisms were employed as in visit one. This was so because the reasons for the usages of these pest-resistant plants remained constant as they manufactured more and more alkaloids and toxins as they grew. In this way, the leaves kept detracting pests while they grow. Since pests are the vectors that transmit diseases, then the repelling of these pests prevented diseases also.
To record the type of irrigation system used	The type of irrigation system used was noted and the water quantity used was recorded.	The drip irrigation system was used. Eighteen gallons were used for this visit.		The reservoir of the hydroponics system contained water that was continuously recycled. The same 25 gallons of water was used in this reservoir even though its maximum capacity is 40 gallons.		

Objectives		Activities	Observations				Interpretative Comments
			Organoponics		Hydroponics		
			Lettuce	Basil	Lettuce	Basil	
Nutrients/Fertilizers							
To assess the addition of any Nitrogen (N) to the plants medium	Any addition of Nitrate to the plants' root medium was noted.	No Nitrate was added to the system.			No Nitrate was added to the system.		There was no addition of nutrients in the organoponics system despite the pH values and nutrient concentrations that existed therein. Nutrient solutions that contained NPK were added to the reservoir in the hydroponics system the previous week. This was expected to sustain the system for the time being. Hence, none of the solutions were used here.
To assess the application of Phosphorus (P) to the plants medium	Any application of Phosphorus to the plants' root medium was recorded.	No Phosphorus was added to the system.			No Phosphorus was added to the system.		
To assess the supplement of Potassium (K) to the plants' medium	Any supplement of Potash to the plants' root medium was documented.	No Potassium was added to the system.			No Potassium was added to the system.		
To measure the Potenz Hydrogen (pH) of the plants medium	The pH value of the plants' root medium was tested and noted.	7.5			7		

Visit/Entry Number: 6

Objectives	Activities	Observations			Interpretative Comments
		Organoponics			
		Lettuce	Basil		
Physical					
To measure the height of plant	The height of the plants was measured.	15.3 cm	30.5 cm		There was a ten percent growth of the lettuce and a four percent growth of the basil. Plants started to slow in growth as the 'plateau' effect was taking place in which growth was minimal. This may be due to the deficiencies in nutrients as plants would have already utilized large quantities to get to these stages. It was also possible that they neared the point of maximal growth. The leaves and stem colours were ideal.
To measure the width of plant	The width of the plants was measured.	41.2 cm	40.7 cm		
To measure the length of longest leaf	The length of the longest leaf was measured.	19.6 cm	9.3 cm		
To measure the width of broadest leaf	The width of the broadest leaf was measured.	19.5 cm	5.7 cm		
To observe the colour of the stem	The colour of the stem was observed	Green	Reddish		
To observe the colour of the leaves	The colour of the leaves was observed.	Green	Green		

Objectives	Activities	Observations			Interpretative Comments
		Lettuce	Organoponics	Basil	
Biological					
Pests: To examine the types of pests present	The plants were examined for the presence of pests.	No pests were found in this system at this visit.	Leaf miners	The lettuce at this stage seemed to be unaffected. However, the aphids are likely to be in effect still because there are large stores of sucrose in the plants stems at this time. It is also possible that other organisms still invaded the system, but were not spotted upon the visit as this could have been a factor that influenced the results. Nonetheless, the diminishing of symptoms of diseases showed the plants recuperated. It can be that these deficiencies only occurred at the point in time because they were inaccessible to the plants at those specific times. The leaves, like in week four and five would have been bombarded by flies and thus causing leaf miners.	
To determine the extent to which the pests impact the plants	The impacts that the pests had on the plants were recorded.	There were no effects induced by pests since they were absent.	There were whitish-yellowish caused trails in the leaves caused by leaf miners.		
Diseases: To examine the types of diseases present	The plants were examined for the presence of diseases.	There were no diseases that were examined	There were no diseases that were examined.		
To determine the extent to which these diseases impact the plants	The impacts that the diseases had on the plants were recorded.	There were no implications since no diseases were found.	There were no implications since no diseases were found.		

Objectives	Activities	Observations			Interpretative Comments
		Lettuce	Organoponics	Basil	
Environmental	To record any pest control mechanisms	Any biological control mechanism that was imposed was documented.	Parsleys and thymes were used to resist pests.	Parsleys and thymes were used to resist pests.	The same biological pests control mechanisms were employed as in visit one. This was so because the reasons for the usages of these pest-resistant plants remained constant as they manufactured more and more alkaloids and toxins as they grew. In this way, the leaves kept dettracting pests while they grow. Since pests are the vectors that transmit diseases, then the repelling of these pests prevented diseases also.
	To record the type of irrigation system used	The type of irrigation system used was noted and the water quantity used was recorded.	The drip irrigation system was used. Twenty gallons were used for this visit.	The reservoir of the hydroponics system contained water that was continuously recycled. The same 25 gallons of water was used in this reservoir even though its maximum capacity is 40 gallons.	

Objectives		Observations			Interpretative Comments
		Activities	Organoponics		
			Lettuce	Basil	
Nutrients Fertilizers To assess the addition of any Nitrogen (N) to the plants medium	Any addition of Nitrate to the plants' root medium was noted.	No Nitrate was added to the system.	No Nitrate was added to the system.	There was no addition of nutrients in the organoponics system despite the pH values and nutrient concentrations that existed therein. Nutrient solutions that contained NPK were added to the reservoir in the hydroponics system two previous weeks. This was expected to sustain the system for the time being. Hence, none of the solutions were used here.	
	To assess the application of Phosphorus (P) to the plants medium	Any application of Phosphorus to the plants' root medium was recorded.	No Phosphorus was added to the system.		No Phosphorus was added to the system.
To assess the supplement of Potassium (K) to the plants' medium To measure the Potenz Hydrogen (pH) of the plants medium	Any supplement of Potash to the plants' root medium was documented.	No Potassium was added to the system.	No Potassium was added to the system.		
	The pH value of the plants' root medium was tested and noted.	7.5	7		

Additional data from the initial phase of experiments are presented in the section on plant productivity later on, and indicate significantly enhanced productivity moving from traditional to organoponics to hydroponics. Having achieved the desired results, the research team re-designed the hydroponic system on a much larger scale. A semi-commercial hydroponic system was designed and built at the CFBC. It has an individual plant capacity of 300 plants but can accommodate as many as 1,200 plants, depending on the crop choice. Instead of adopting the typical system designs that already existed, the technology was adapted and simplified to reach the intended target population; low resource persons. In one adaptation, the CFBC system utilized water straight from the municipal source, meaning no reverse osmosis system was needed to purify the water before nutrients are added and mixed.

Researchers also managed to reduce the electrical components to just one commercial pump that can deliver 4,921 l in circulation every hour at 167 watts. The question of algae growth as well as suitable O₂ levels for root development was satisfied with a high pressure piping system that was accomplished by simply reducing the pipe size 3.8 cm from the reservoir to the growth chambers at 0.95 cm. Chambers were designed to accommodate large rooting systems and withstand high water pressures by using 12.7 cm² x 12.7 cm² schedule 40 PVC. All seeds were sown directly into the hydroponics system in a growth media called clay pellets that are placed in a netted plastic cup 7.6 cm deep x 7.6 cm wide. These pellets have been used for the past six years and still can be used for some more years. The hydroponics system was also designed to be operated by one individual (male or female) who would be able to dismantle and relocate in 30 minutes or less when hurricanes threaten. During six years of operation, the research team successfully grew 16 crops as an adaptive feature, which included cultivars of the following:

Basil	Corn	Lettuce	Soya bean
Bell peppers	Cucumber	Okra	Strawberries
Broccoli	Eggplant	Sage	String bean
Cabbage	Jalapeno peppers	Season peppers	Tomato

GENERAL BENEFITS

CFCB College researchers noted the following benefits of using hydroponic techniques to grow plants

- Production can be year round (i.e. not seasonal)
- No leaching of nutrients to the environment
- No use of pesticides
- No weeds
- High nutritional values
- Maximum production in confined areas
- Efficient use of water
- Less labour intensive
- Can be carried out in any local location
- Sustainable
- Promotes gender equity

EXPERIMENT 1: WATER USAGE COMPARISON AT THE CFBC PLANT RESEARCH FACILITY

In order to compare the efficiency of the three CFBC model plant growing systems (hydroponics, organoponics, and traditional), several experiments were conducted, two of which are presented below. The 1st experiment compares water usage among the three systems, and the 2nd experiment examines shade effects on plant growth and development in the hydroponics system.

This experiment sought to determine the quantity of water needed to bring lettuce to full maturity under the various systems, namely hydroponics, organoponics and traditional systems. The hypothesis was also tested that plants in hydroponics systems will utilize less water than other soil based systems from planting to harvest. The methodology employed was as follows:

- All lettuce seeds were germinated in rockwool media to ensure appropriate requirements and eliminate bias across seedling test group.
- Soil samples for organoponics and traditional techniques were tested and upgraded to ensure that they are within nutrient range of the hydroponics nutrient formulae.
- The emitter delivery on both organoponics and traditional system were recorded (50ml/minute).

- All three planting systems were located within the same shade house and exposed to the same atmospheric conditions.
- The hydroponics system used was a completely water-based circulatory system in which water was taken straight from the municipal source and to which a specific formulae were added.
- Traditional and organoponics system were fed twice daily (morning and afternoon) for 10 minutes.
- Plants were allowed to mature fully without any interference.

Table 10.4 presents the results of the experiment.

Table 10.4: Water use across three (3) growing systems using lettuce (*Lactuca sativa*)

Parameters	Hydroponics	Organoponics	Traditional
Maturity from seed	25 days	45 days	58 days
Water used	10,730 ml	59,530 ml	78,570 ml
Shade conditions	30%	30%	30%
Delivery method	Circulation	50ml/min for 10 minutes, twice daily	50ml/min for 10 minutes, twice daily
Water source	Municipal	Municipal	Municipal

EXPERIMENT 2: SHADE EFFECTS ON PLANT GROWTH AND DEVELOPMENT AT CFBC PLANT RESEARCH FACILITY

This experiment sought to determine the effects of excessive shading on plant development, as well as test the hypothesis that shade intensity reduces the quality of nutrient uptake and quality of the product. The methodology was as follows:

- Seedlings were sown directly into the same hydroponics system type designed by S. LaPlace - nutrient flow, ebb and flow, and aeroponics combination
- one system was shaded using 50 percent saran mesh
- one system was shaded with 30 percent saran mesh
- water source was municipal

The nutrient formulae used included:

- **Primary formula:**
(1.32 ml/L - 2.5 percent ammonium phosphate, 1.0 percent potassium phosphate 2:1:6 (NPK) – 6.0 percent potassium nitrate, 0.5 percent magnesium nitrate

- **Secondary formula:**

(0.88 ml/L - 5.0 percent phosphoric acid, 4.0 percent potassium phosphate 0:5:4 (NPK) - 1.5 percent magnesium phosphate, 1.0 percent potassium sulphate 5.0 percent calcium nitrate
0.1 percent potassium borate, 0.0005 percent cobalt nitrate, 0.01 percent copper

- **Trace formula:**

(0.99 ml/L - EDTA, 0.1 percent iron EDTA, 0.05 percent manganese EDTA, 5:0:4 (NPK) - 0.0008 percent ammonium molybdate, 0.015 percent zinc EDTA
The results of this experiment are presented in Table 10.5.

Table 10.5: Results for lettuce (*Lactuca sativa*) with 30 percent shade vs. 50 percent shade

Parameters	30% shade	50% shade
Water used	13.4 l	8.26 l
Taste	palatable	bitter
Leaf quality	durable	brittle
Comparative weight	heavier	lighter
Leaf colour	lighter	darker

CHOOSING PLANT COMBINATIONS AND GROWING MEDIA FOR HYDROPONIC CULTIVATION

PLANTING SCENARIO

When planting more than one crop in a hydroponics system, the dynamics concerning water and nutrient use can become very challenging. For example, if peppers and tomatoes are planted together in the same system, researchers found that peppers must be planted first. The rationale behind this is that tomatoes are considered vines and their growth rate compared to a pepper plant is much faster. The root system on a vine is better adapted for rapid growth and therefore the nutrient uptake is proportionally rapid. In a system where both plants are competing for the same nutrients, the more adapted and sensitized root system will be more efficient in accessing these available nutrients. Therefore a tomato would outgrow a pepper, causing the pepper to show signs of deficiency while the tomato is thriving.

In terms of a strategy, the peppers should be planted before the tomatoes, allowed to establish themselves in the system for about two weeks, and then the tomatoes can be planted. This would ensure that the pepper plant will be able to access the nutrients as

well as the tomato during growth and development. If the number of crop types grown simultaneously is to be increased, then a clear understanding of the nutrient requirements for each plant must be understood and carefully worked out, probably through experimentation. The first step should involve examining each crop individually, and having an appreciation of their growing patterns before combining them with other crops. Crops that are in the same family often have similar growth patterns and nutrient requirements, so that for example, if tomatoes are being cultivated, then it would also be possible to grow eggplant, cucumber and melons. In like manner, lettuce can be combined with cabbage, broccoli and cauliflower.

Pollination requirements are also factors that should be kept in mind when considering growing plants hydroponically, particularly when a secure location is used that restricts the entry of organisms beyond a certain size. If wind is allowed to penetrate the growing facility then wind pollination can occur. With crops like strawberries it is often necessary to release a bee inside the shade house to assist; one bee can pollinate over 600 flowers in a day. Where pollinators do not have access, and flowers are bisexual, it is also possible to hand pollinate the flowers by using a 'spin toothbrush' to massage the flowers and increase the likelihood of successful pollination.

GROWING MEDIUM

Plants in a hydroponic system are typically placed in an inert medium to stabilize them as circulating nutrient solution passes through the root network. Choosing a growing medium is dictated by the type of crops to be cultivated, and the growth period. Key determining factors include the potential environmental impact of a particular medium, as well as, productivity and time to harvest for a particular crop. Short-term crops like strings beans, lettuce and cucumbers have root systems that establish quickly. Lettuce for instance is better suited for rockwool as a medium because it only takes about 23–25 days to grow and harvest, and will need to be quickly and easily removed and replaced to keep the rotation from harvest to replant consistent. Other crops like cucumbers and beans have a three to four month growing cycle that requires a stronger anchoring medium. In that case, CFBC researchers found hydroton pellets to be most appropriate, though gravel, perlite and peat also have good anchoring properties.

The goal with growing media is to choose one that supports as many project objectives as possible, namely those related to the environment (biodegradable and recyclable), time, quality and efficiency. Growth media should not be chosen based on price or ease of supply but rather on the basis of what is safest for plants to grow in and what has a minimal environmental impact when the medium is discarded.

SHORT-TERM CROPS

Crops that will only last a few weeks in the system are considered short term, and with such crops it is advisable to use a medium that can be removed from the hydroponic system quite easily without affecting the overall functioning of the system. For crops like lettuce, cabbage, broccoli for example, coconut chips or rockwool cubes are best suited. These media are biodegradable, which ensures that the environment remains safe when they are eventually discarded. Also, a fresh seedling can be placed directly into the harvested slot simultaneously to maintain a scheduled harvesting cycle. Media like gravel, hydroton pellets, perlite and peat are not advisable for short-term crops simply because the frequency of recycling is too short, and the process can become very labour intensive.

LONG-TERM CROPS

Crops that will remain in a hydroponics system for 3–12 months, require a medium that can stand up to environmental elements, is recyclable, does not breakdown easily (which would affect the electro-conductivity (EC) readings), and allows a good gas exchange with the immediate environment. A medium that satisfies these characteristics is hydroton clay pellets, which have been tested and retested for more than six years of experiments at the CFBC. A variety of crops have been grown in the same hydroponics system and the initial pellets are still being used today. This medium also allows for the sowing of seeds like corn, peas, beans, cucumber, and peppers directly into the medium as is done in soil. After the crops are harvested, the cup of clay pebbles are simply taken out, and the old roots removed from between the pebbles, which are washed with a detergent, rinsed and replaced in the same cup which is returned to the system.

MANAGING THE NUTRIENT SOLUTION

Nutrient use and efficiency

Knowing how to mix minerals properly and adjust nutrient solution mixes is critical to successful hydroponic growing (LaPlace 2014). The nutrient solution to be used depends for example, on various indicators such as different planting scenarios and signs of nutrient deficiencies in plants to name a few. Although all plants of the same species respond similarly to nutrient stress, plants of similar species will often show significant differences in their nutrient use and efficiency. These result from differences in growth rate, root distribution, phase of development, and efficiency of nutrient uptake and utilization (as previously mentioned in the case of tomatoes and peppers growing together). In any given location, plants from one species may become nutrient-deficient, while those from another species, growing in the same environment right next to them, may not show any deficiency symptoms.

Growth rate also affects nutrient status. When the nutrient supply is low or barely adequate for growth under existing environmental conditions, many plants lower their growth rate to a level which can be supported by the available nutrient supply without displaying typical visual deficiency symptoms.

Plant competition and induced deficiencies

When observed symptoms are the direct result of a nutrient deficiency, the required corrective actions are relatively simple. However, symptoms are often the result of interactions with other plant species in the same hydroponic system. Cohabiting plants may limit the availability of the nutrients to plants with a lesser-developed root system, leading to the expression of deficiency symptoms. For instance, as discussed above, if tomatoes and bell peppers are planted at the same time in a hydroponic system, the tomatoes will outgrow the bell peppers. This happens simply because the vine crops grow much more rapidly and therefore their nutrient uptake will also be more vigorous. Transition metals such as copper (Cu), zinc (Zn) and nickel (Ni) compete with iron (Fe) and each other for plant uptake. Competition for uptake is not specific to Fe but holds true for all mineral nutrients that are chemically similar and have similar uptake mechanisms. For example, if the availability of Cu or Zn is relatively less than that of (Fe), then excessive concentrations of some other metal such as Ni will induce a deficiency of one of these nutrients rather than Fe. In the case of the macronutrients, excessive amounts of magnesium (Mg) will compete with potassium (K) for uptake and can possibly induce a K deficiency. High Mg concentration can also induce a calcium (Ca) deficiency. Thus, nutrient deficiencies can be induced by a number of different mechanisms that together compound the limited availability of a given nutrient.

Nutrient environment

The chemical make-up of the nutrient solutions is one of the most critical aspects of hydroponics production. Different plant combinations determine the mixture of nutrients and the ways in which plants both access and utilize the nutrients in solution. Plants remove substantial amounts of nutrients from the hydroponic solution during their normal growth cycle and many long-term environmental changes occur as a result of this process. The charge balance of the nutrient solution is maintained through the release of H^+ and/or OH^- ions. These H^+ and OH^- ions are released from the cations and anions contained in the nutrients absorbed by plants. For instance, when plants are fertilized with ammonia, they acquire most of their nitrogen in the form of the ammonium cation, rather than from the usual nitrate anion. Because nitrate is the main and only anion used by the plant in large amounts, the net result of this change is that during normal nutrient uptake the proton (H^+) excretion will far exceed that of hydroxyl ions (OH^-).

In the case of vigorously growing plants, the amount of excreted protons can be sufficiently large, so that a decrease in the pH results, making the nutrient solution more acidic. The immediate effect on the nutrient solution may be favourable for some plants, especially acid-loving plants, making iron (Fe^{2+}) more available, however, in the long run, lowering the nutrient solution pH can be deleterious to plants in that the availability of nutrients will change. A lower pH allows micronutrients to become locked out of solution, eventually resulting in deficiencies of nutrients such as Cu and Zn. Additionally, when the pH of the solution falls below 5, the solubility of manganese (Mn^{2+}) can increase to such an extent as to become toxic to most plant growth.

ORGANOPONICS

The second non-traditional technique examined in the CFBC model is organoponics. This section of the chapter defines the technique and describes the system design utilized by CFCB College researchers.

Defining organoponics

Vandermeer (2004) describes organoponics as ‘a system of urban organic gardens which often consists of low-level concrete walls filled with organic matter and soil, with lines of drip irrigation laid on the surface of the growing media. Organoponics provide access to job opportunities, a fresh food supply to the community, neighbourhood improvement and beautification of urban areas.’ In Cuba where the system originated, organoponics was developed as a community response to lack of food security. Although it began as a system of organic gardening, it can be modified to introduce chemical fertilizers to maintain optimum nutrients for plant growth, but compost, animal manure and other organic matter are recommended to keep down input costs. Use is also made of long cement planting troughs and raised metal containers that are filled with composted sugar waste. In experimentation and public outreach events conducted by CFBC, researchers found that any available containers (new or used) may be utilized, including buckets, barrels, and large water bottles.

Organoponics system design

At the CFBC, lettuce, tomatoes, basil, parsley, and seasoning peppers were grown intensively under this organic farming method, with the use of soil from abandoned sugarcane fields that were determined to be fertile based on simple field tests of soil (texture, moisture, structure, and presence of microbes). Planting trays were constructed from used marine plywood lined with construction plastic to prevent rapid decay of the plywood. The

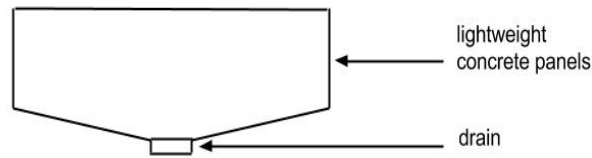
planting trays were filled with 1.3 cm gravel to a depth of 7.6 cm, and then overlaid with sand to a depth of about 5.1 cm to facilitate drainage (Figure 10.27).

The planting trays were filled with soil to a depth of about 20.3 cm. Drip irrigation lines were installed about 30.5 cm apart in parallel lines where plants were to be cultivated.

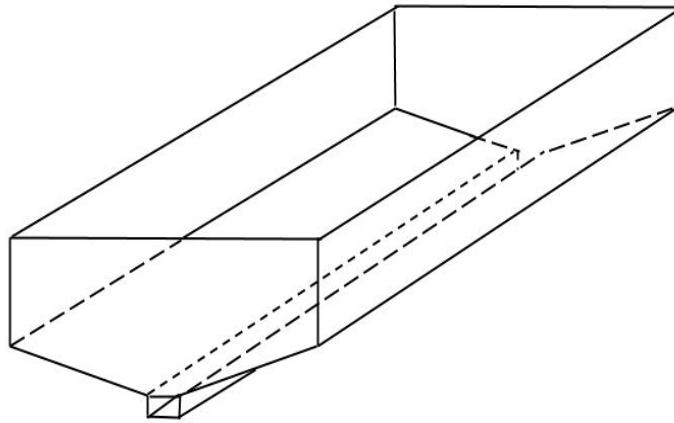
Based on the findings at the CFBC, it is recommended that trays should be constructed with light concrete panels with vertical sides and a V-shape at the bottom to accommodate a range of plants with varying root lengths. This design will also optimize drainage and lengthen the life-span of the trays. The growing systems were housed in a shade house in which the walls and roofing were comprised of 30 percent shade cloth/shademes. It is also recommended that the roof is covered with polyliner or plastic to prevent the direct impact of rainfall, but with water catchment that can be used for irrigation. With the containerised planting trays, shadehouse, and drip irrigation, the water requirement can be controlled to minimize the use of water. When organoponic and traditional cultivation of plants were compared, the organoponic did better than the traditional. The time to harvest was about 30 percent faster for active plant growth and fruiting; harvests were more productive in a shorter time-span, and stems, leaves, and fruits were also about 15 percent larger in size. Plant growth and fruiting in the hydroponic system occurred 17.5 percent faster, resulting in a reduction in the time to harvest by approximately 50 percent, when compared to traditional cultivation.

“HYBRIDPONICS”

This term, hybridponics, was coined to describe a system in which a seedling is removed from a hydroponic system and transplanted in an organoponics system to complete the growth process. Where plants were transplanted, they displayed significantly-enhanced growth and development compared to similar plants grown exclusively in organoponics. The dynamics of soil chemistry and physics limit seedlings access of nutrients, due to the relative immobility of nutrients in the soil matrix (Resh 2013). Plants generally would not be able to access certain nutrients based on their inferior root development. When plants of the same age and species were taken from hydroponics and transplanted to containerized soil they developed much faster because of the advanced rooting system during their hydroponic germination. These seedlings were able to access nutrients that would have been otherwise unavailable to them if they had grown strictly in soil. Hydroponics, then, can be used to promote a healthy start and robust seedling development for plants that will ultimately grow in a range of soil-based systems.

Figure 10.29: Sketch of lightweight concrete planting trays

A. End elevation



B. Perspective view of full length

In both organoponics and hybridponics growing systems, plants are grown intensively for optimum utilization of space. Intensive cultivation also provides for symbiosis in which the diversity of plants can benefit from each other with respect to varying light/shade requirements, nutrient requirements and uptake from various depths, and biological pest control mechanisms through which plants attract and/or repel various insects, both beneficial and harmful. Pest control can be enhanced by painting fence posts in various colours to attract a wider diversity of insects. While there was less incidence of pest infestation in the organoponics growing system than in the traditional system, natural pest control substances (e.g. solution from neem mixed with thyme and garlic) were adequate to deter white flies and black sooty mould. These occurred to a much lesser extent in this system compared to the traditional cultivation. In addition, caterpillars and cutworms were found in the traditional but not the organoponics growing systems.

COMMERCIALISATION

For any agricultural technique to have an impact on local food supply, it has to be implemented by growers and embraced by local retail and consumer networks. Along with optimizing the CFCB College model system, faculty-student teams from the CFBC and the University of Central Florida also used fieldwork marketing research to generate a model for commercializing crop outputs and estimating livelihood potential. Data collected on plant productivity and a commercial estimate of expected inputs and outputs associated with operating a hydroponic system are presented in the next section. The section then concludes with a discussion of macro- and micro-economic factors impacting this system when it is viewed as a business model.

Table 10.6: Plant productivity and water usage across three growing systems

System	Growth cycle (days)	Water used (l)	Shaded	Non-shade
Traditional	55	42.8	dark green/brittle	lighter/crisp
Oraganoponics	45	34.4	dark green/brittle	lighter/crisp
Hydroponics	25	9.5	dark green/brittle	lighter/crisp

Note: 50ml/min was the dripper rate for traditional and organoponics. Hydroponics was in circulation and lost 9.5 gallons of solution.

Table 10.7: Profitability estimates for hydroponic production of 300 plants in the CFBC Plant Hydroponics System *

Crop	Average weight/pepper (kg)	Minimum item yield per plant (bi weekly)	Plant capacity for 44.6 m ²	Shade house (44.6 m ²) yield average (2 peppers) biweekly (kg)	Total yield/ annum (kg)	Total cost @ market price \$3.87/ Kg/ annum (US \$)	Monthly earnings (US \$)
Sweet Bell Pepper	0.14	2	136.08	163.29	4245.62	16,430.57	1,369.21
Tomato	0.23	2	136.08	272.16	7076.04	27,384.28	2,282.03
Okra	0.05	4	136.08	108.86	2830.42	10,953.71	912.81

*Fixed start-up cost: of US\$ 3,681; Annual Recurring fees (for nutrients) of US\$400.

Productivity data

One set of productivity data was developed in the following way. Three small systems were designed and constructed to determine which growing system was the most suitable. Iceberg lettuce was chosen as the crop of choice because of its short growth period. The results after three trials are displayed in Table 10.6, while table 10.7 presents the profitability estimates for hydroponic production.

The data presented above suggest that small-scale non-traditional agriculture has serious potential as a commercial endeavour that can improve livelihoods. Realizing that potential is a matter of entrepreneurship however, and the system must be operated as a business, shaped by macroeconomic and microeconomic forces. Based on interviews conducted among a number of local restaurants and store owners, it is clear that there is a preference for locally produced agricultural goods over those that were imported. At certain times of the year, because locally grown produce is simply not available, it becomes necessary to import produce. This however leads to a glut situation on the market, when there is a surplus of locally grown produce, which can be addressed by greater access to export markets. From a microeconomic perspective, the hybridponics system was found to be very profitable and easy to maintain. The start-up cost for a 6.1 m x 6.1 m system is divided into two parts: the hydroponics which cost EC\$5,400.00 (US\$2,000), and the organoponics, which cost EC\$10,000.00 (US\$3,704), totalling EC\$15,400.00 (US\$5,704). Although this may initially sound like a substantial amount of money, this sum is only paid once for start-up. The upkeep/maintenance cost of the system is EC\$520.00 (US\$193) monthly (i.e. EC\$200.00 (US\$74) for the organoponics system and EC\$320.00 (US\$119) for the hydroponics). A profit of EC\$15,000.00/month (US\$5,556/month) or EC\$180,000.00/annum (US\$66,667/annum) can be expected after the sum of EC\$2,000.00 (US\$740) is subtracted for labour costs. Another advantage of the system is that a labourer only spends maximum of two hours per day working in this system. To implement such a system, much less space is required compared to traditional farming methods. The yields from this system, however, can match those of traditional farms and the quality may even be better.

The main disadvantage of the organoponics growing system is that it can be more costly with respect to initial input cost, compared to traditional growing systems. However, due to advantages associated with greater productivity, organoponics may prove more effective than traditional cultivation, with additional consideration of improved reliability and consistency of supply to the market and less impact of climate variability and weather conditions. The practice of organoponics can also be potentially more productive, along with its suitability for more widespread participation by a wider cross-section of people in rural as well as urban areas. Moreover, organoponics is less dependent on the fertile land

and “hard” labour that characterize traditional cultivation. With such numerous advantages, organoponics appears to be a good adaptation strategy to climate change for food security, less impact on the environment, and less effect of the environment on food production than traditional food production systems.

CONCLUSION

Serious barriers face any efforts to provide local Caribbean communities with food that is consistently healthy, abundant, and affordable. The research findings presented in this chapter has been generated through a process of collaboration among academics, government agencies, NGOs, students, businesses, and community based stakeholders. Through such collaborations, such barriers can be effectively overcome to achieve impacts that improve local food security across the Caribbean. Inadequate baseline information, poor financing and poor management of growing environments plague the application of non-traditional techniques in the agriculture industry. Insufficient technical support also plays a role in the limited success of these systems in the region. It is clear that there have been many successes. A major obstacle to adoption of these techniques is farmer buy-in and the part-time nature of farming in many territories. It is also true that farmers must see themselves as business persons first and not mere labourers (Barker 2012). Therefore, attitudes and perceptions form a key arena to address, and ensure successful implementation. However, the research and productivity-profitability estimates presented above suggest that non-traditional agriculture is indeed a viable business option for small-scale growers in the Caribbean.

Protected agriculture already appears to be making an impact on local food supply in St Kitts and Nevis, as the improved figures for 2013 tomato and sweet pepper production suggest. Crucial to solidifying these gains locally will be fostering competent technical support and other forms of knowledge transfer, such as the ability to set-up and maintain non-traditional systems, reliable reporting on crop productivity and profitability, continuing development of agro-processing to deliver longer-lasting, value-added agricultural products to the local market, solid business planning at all levels of local agriculture, and more.

The CFBC model reviewed in this chapter works to integrate development on all these levels. But projecting an inclusive, community-based model for local food production throughout the region faces other barriers of language, distance, underdevelopment, and political will, which have fragmented the Caribbean historically and threaten to impede wider implementation of non-traditional agriculture. Fortunately, the Organization of American States (OAS) has agreed to support the expansion of this model to four other

Caribbean countries, and at a recent UNESCO meeting on climate change policy in Nevis, representatives from four additional island nations expressed interest in partnering with the CFBC research team. The prospect here is to confront barriers of regional fragmentation and vulnerability with regional collaborations that transfer knowledge, adapt it to community-based needs, and improve food security and social resilience at the local level throughout the Caribbean.

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Agroforestry Systems and Practices in the Caribbean

Ravindra Ramnarine and Denny Dipchansingh

AN INTRODUCTION TO AGROFORESTRY IN THE CARIBBEAN

OVERVIEW

Agriculture has been an important part of the economy of Caribbean countries from the colonial period when plantation crops such as sugar cane, cocoa, and coffee were grown for the European market. After emancipation and during indentureship, peasant farming became more prominent among freed slaves and ex-indentured labourers. The peasant farms were small in size and consisted mainly of a mixture of vegetables, root crops and fruit trees. To allow for the increase in agricultural production from large-scale plantation crops and small-scale peasant farming many of the forests areas were cleared. In recent times, increases in land pressure, growing rural populations, deforestation, and environmental degradation have resulted in more fragile and marginal lands being subjected to intensive agricultural operations. Forests areas are increasingly under threat as a result of these pressures, and in many Caribbean countries, the designation of protected areas to safeguard the remaining forest has further marginalized hillside farmers by restricting the practice of shifting cultivation. Consequently, there is an urgent need to find sustainable methods of hillside cultivation. Several alternative land-use systems have been suggested for increasing agricultural production in the Caribbean region such as mixed and multiple cropping systems.

In the mid-1970s, a number of ecologically sound and sustainable land-use systems integrating agriculture and forestry, were grouped together under the broad designation of ‘agroforestry’ (Nair 1993). This practice was initially promoted as an alternative to shifting cultivation in developing countries where increasing populations have effectively reduced the length of the cycle of forest regeneration or fallow. The incorporation of permanent tree crops into farming systems also assists small farmers in diversifying their production methods. Agroforestry systems also provide a source of food, job and income for many rural households. While agriculture is not a major source of income for the Caribbean countries (three to seven percent of GDP), it provides employment for about ten to 20 percent of the population across its two main sub-sectors - traditional and non-traditional. Countries produced many of their agricultural crops for local consumption and also exported some of their traditional or specialty crops which were mainly sugar cane, cocoa, and coffee.

Trees also contribute to the productivity and sustainability of farming systems on marginal lands by enhancing the production of organic matter, maintaining soil fertility, reducing erosion and creating a more favourable microclimate for associated crops and livestock. The mixing of trees and crops can also reduce the need for fertilizers and pesticides. These services are beyond the direct production roles trees can play in supplying food, fodder, fuel wood, building materials, medicines, handicraft and other raw materials for rural industries. In today’s modern world, there is competition for housing, industrialization, forestry, recreation and agriculture (both crop and livestock production). These must be balanced to have a harmonious relationship with the environment.

This chapter on agroforestry serves to highlight the historical evolution of the system, provide a description of agroforestry systems and describe potential benefits of adopting agroforestry in the Caribbean region. It also gives a broad overview of agroforestry from an international perspective. It should be noted that while agroforestry provides many exciting opportunities for farmers, it is not a ‘cure-all’ for all our land-use problems. As with any other land-use option, agroforestry involves trade-offs, that is, some short-term gains may have to be given up for the sake of long-term sustainability. Throughout the chapter, references and examples are provided for countries belonging to the Caribbean Community (CARICOM). These 15 countries include Antigua and Barbuda, The Bahamas, Barbados, Belize, Dominica, Grenada, Guyana, Haiti, Jamaica, Montserrat, St Kitts and Nevis, St Lucia, St Vincent and the Grenadines, Suriname, and Trinidad and Tobago. The justification for defining the Caribbean as countries within the CARICOM is that most of the studies on forestry/agroforestry were organized by the CARICOM secretariat together with other global organizations, mainly the Food and Agriculture Organization (FAO).

CONCEPT AND DEFINITION OF AGROFORESTRY

Agroforestry is often described as an age-old system with only a new name. This system of growing trees with crops and/or animals on the same piece of land is an ancient practice and has been used by farmers worldwide for many centuries. However, the term ‘agroforestry’ is recent and was first mentioned in a 1977 study investigating the role of trees in agriculture. This study formed the basis for establishing the International Centre for Research in Agroforestry (ICRAF) in 1978 (Nairobi, Kenya) to promote agroforestry research, especially in developing countries. In 2002, ICRAF (still the official name) was rebranded as the ‘World Agroforestry Centre’, since it was recognized globally as the leading institution in agroforestry research and development.

The World Agroforestry Centre (www.worldagroforestry.org, accessed 06 May 2014) defines agroforestry as ‘a sustainable land management system which increases the overall yield of the land, combines the production of crops, forest plants and/or animals simultaneously or sequentially, on the same unit of land, and applies management practices that are compatible with the cultural practices of the local population’. Agroforestry have also been defined as ‘a collective name for land-use systems in which woody perennials (trees or shrubs) are grown in association with herbaceous plants (crops or pastures) and/or livestock in a spatial arrangement, a rotation or both, and in which there are both ecological and economic interactions between the tree and non-tree components of the system’ (Young, 1989). The core concept of agroforestry is therefore based on the integration of agriculture and forestry production systems.

Agroforestry is differentiated from other land-use systems since it must have a tree component deliberately planted or retained; and there must be significant interaction between the woody and non-woody components of the system. Agroforestry therefore involves two or more plant species (at least one must be a woody perennial) and/or animals, with two or more outputs. Due to the variety of possible combinations, even the simplest agroforestry system is more ecologically and economically-complex than a monocropping system. Agroforestry is described as a sustainable, adaptable, multipurpose land-use system which allows for:

- Production of multiple products while protecting natural resources
- Emphasis on the use of indigenous trees/shrubs, crops and livestock
- Suitability for low-input farms and fragile ecosystems
- Provision of social, economic and environmental benefits to land users

The aim of agroforestry is to optimize production based on the interactions between the components and their physical environment. It is a science, whereby benefits will only be obtained from using the correct combination of tree species, crops and/or livestock, together with best management practices. Agroforestry should be viewed as more than just a combination of trees/crops/livestock, but should strive to meet the specific needs of the individual, community and/or population.

HISTORICAL BACKGROUND AND IMPORTANCE OF THE AGROFORESTRY SECTOR

Agroforestry has been a fundamental part of the traditional food production systems throughout the Caribbean region for many years. The system of land use in the Caribbean was greatly influenced by the early European colonizers, who used the available arable lands and cleared the natural forest for cultivation of large expanses of monoculture crops for the European market. This system of food production therefore resulted in a decrease of biological diversity of the forest species on the islands. The European settlers also introduced tropical crops that were not native to the region (e.g. breadfruit) to provide food and thus reduce the cost of sustaining the slaves and indentured laborers.

The traditional systems practiced in the Caribbean usually included forest, fruit, spice, and fodder trees, together with plantation crops such as cocoa, coffee, bananas and sugarcane. The main agroforestry systems in the larger acreages were cocoa/coffee grown under shade trees and forest plantations established using the Taungya system. This perennial system of cultivation was important due to the steep sloping hillsides/mountainous terrain found in some Caribbean islands. In smaller holdings, farmers practiced a system of multi-layered agroforestry using mahogany, cedar, breadfruit, mango, or coconut trees in the upper level; a middle layer of cocoa, coffee, bananas and fruit trees; and a lower level of vegetables and food crops (e.g. pigeon peas). This type of agroforestry allowed the farmer to have a regular source of income, until the perennial trees mature and producing economic products such as fruits or timber. Livestock was also used in the traditional systems, but mainly in the smaller Caribbean islands.

Agroforestry is also promoted as a more sustainable and environment-friendly alternative to the traditional ‘slash and burn’ agriculture, especially for sloping lands. Slash and burn which was once widely practiced is no longer accepted since it involves the removal of trees, loosens the valuable top soil and promotes erosion especially on hillsides. In addition, the land quickly loses its fertility and farmers usually move on after a few years without reforesting the land.

While ‘slash and burn’ agriculture involved moving from one location to another, more stable agricultural plantations existed in the form of estates. In managing cocoa and coffee estates in Trinidad, trees are planted for shade. In the early stages, immortalé was the species of choice. This was later replaced by more valuable timber species when it was realised that harvesting of the trees provided a good return. Factors such as larceny, scarcity of labour and urbanization were responsible for many estates becoming abandoned. Within recent times with a shortage of local hardwoods, many landowners seized the opportunity to sell their timber trees, for which they obtained good value. At present, several farmers have recognised the value of lumber and are reforesting their estates with valuable tree species as their main crop. While farmers await the maturation of the trees for harvesting, they plant cash crops such as plantains and bananas among the trees. Since the cash crops ensure that the farmer is more often on the estate, more attention is placed on other agronomic activities such as tree re-planting.

The Caribbean region has seen limited development in the agroforestry sector over the decades. The focus on developing agroforestry systems began at a 1987 workshop in Jamaica, where various Caribbean countries reported on the status of the forestry/agroforestry sector. This workshop led to a joint CARICOM/FAO project to conduct studies on the status of the forestry sector (including agroforestry) in the Caribbean region. During the last 25 years there has been more attention to agroforestry as a sustainable land-use system in the Caribbean region. However, there is no established standard or criteria to promote agroforestry specifically, or to use it as a tool in land use planning.

GENERAL DESCRIPTION OF THE CARIBBEAN REGION

The CARICOM region spans a distance of over 4,000 km from the Bahamas in the north to Suriname in the south. The Bahamas consist of many islands located SE of Florida, USA and are mainly low-lying, dry and contain soils derived from limestone parent material. Most of the other CARICOM countries are located in the Caribbean Sea within latitudes of 10–20°N and longitudes of 59–78°W (figure 11.1). They form part of the Greater Antilles (Jamaica and Haiti), The Leeward Islands (Antigua and Barbuda, St Kitts and Nevis, Montserrat, and Dominica), and the Windward Islands (St Lucia, St Vincent and the Grenadines, Barbados, Grenada, and Trinidad and Tobago). The Leeward and Windward Islands make up the Lesser Antilles. Belize is found in Central America while Guyana and Suriname are part of the South America mainland. The islands of St Kitts, Montserrat, and St Vincent forms part of the ‘inner volcanic arc’ and have active or potentially active volcanoes, while low-lying coral limestone islands such as Antigua and Barbados form part of the ‘outer limestone arc’.

In general, Caribbean landscapes were changed as native forests were cleared for plantation agriculture, especially sugarcane. This deforestation increased the risk of erosion and changed the nature of the land resources. When the land is cleared of vegetation it results in declined soil fertility due to increased organic matter decomposition and plant nutrient leaching. Presently, the land area covered by forests for Belize, Guyana and Suriname (continental countries) is 87.5 percent, while for the Caribbean islands (excluding Haiti) it is 40.4 percent (Table 11.1). Only 0.8 percent of Haiti's land area is under forest. In Haiti, impoverished peasant farming has enhanced environmental degradation. Forest trees are cut to provide firewood and steep slopes are cultivated which promote soil erosion and further environmental degradation. The total forested area in Trinidad and Tobago occupies about 226,000 ha or 44 percent of the total land area. The government (state) possesses about 80 percent of these forested lands while the remaining 45,000 ha are privately owned. Several of these private owners are being targeted by the Forestry Division to adopt more sustainably managed systems such as agroforestry.

Most of the Caribbean islands have a marine tropical environment and average annual temperatures are about 26.7°C with little seasonal variation. The Northeast (NE) Trade winds modify the tropical heat year-round and produce most of the precipitation. Rainfall not temperature usually distinguishes the season. For example in Trinidad, there is a dry season from December to April and a rainy season from May to November.

Figure 11.1: Map of the Caribbean showing location of the 15 CARICOM countries (underlined)



The rainfall varies between the countries with low-lying islands receiving little rainfall, while islands such as Dominica with high volcanic peaks receive over 2500 mm of annual rainfall. Within the islands there is usually heavier rainfall on the northeast side (windward slopes) and less rain in the southwest side (leeward slopes). The distribution of rainfall is important since it determines if irrigation is necessary for agriculture and agroforestry systems. Almost every year from June to November, the Caribbean experiences hurricanes bringing heavy rains and destructive winds. The 2008 hurricane season was particularly severe, causing extensive damage of crops and trees, particularly in Haiti, together with several hundred deaths. Other natural disasters such as volcanic activity and earthquakes are less common in the Caribbean, but can affect the establishment of agroforestry systems in the region.

Table 11.1. Forest types and percent of land area occupied for Continental (Belize, Guyana, and Suriname) and Island countries in the CARICOM Region

Country	Total Land Area (ha)	Natural forests (ha)	Plantations (ha)	Total (ha)	% of Land Area
Belize	2,280,000	1,731,820	3,260	1,735,080	76.1
Guyana	21,497,000	18,500,000	700	18,500,700	86.1
Suriname	16,380,000	14,900,000	13,377	14,913,377	91.0
<i>Continental Countries</i>	40,157,000	35,131,820	17,337	35,149,157	87.5
Antigua and Barbuda	44,000	15,600	0	15,600	35.5
The Bahamas	1,007,000	466,241	0	466,241	46.3
Barbados	43,100	1,700	40	1,740	4.0
Dominica	75,100	51,770	100	51,870	69.1
Grenada	33,900	18,414	570	18,984	56.0
Haiti	2,756,000	21,000	0	21,000	0.8
Jamaica	1,142,400	335,900	8,187	344,087	30.1
Montserrat	10,100	4,000	20	4,020	38.9
St Kitts and Nevis	26,800	11,000	0	11,000	41.0
St Lucia	61,500	23,157	263	23,420	38.0
St Vincent and the Grenadines	39,000	12,689	241	12,930	33.1
Trinidad and Tobago	512,800	248,000	13,225	261,225	50.9
<i>Islands (incl. Haiti)</i>	5,751,700	1,209,471	22646	1,232,117	21.4
<i>Islands (excl. Haiti)</i>	2,995,700	1,188,471	22646	1,211,117	40.4

Source: Adapted from Lackhan, N. (2000)

TYPES OF AGROFORESTRY SYSTEMS AND PRACTICES

Agroforestry systems can be classified based on the following four criteria (Nair 1993):

- Structural – refers to the composition of the system and the arrangement of the components in space and time.
- Functional – based on the main function or use of the components, such as soil conservation or soil fertility improvement (i.e. protective or productive).
- Socioeconomic – this refers to the purpose of the system with regard to human livelihoods such as poverty alleviation and food security.
- Ecological – refers to the suitability of the agroforestry system for a given environment and ecological conditions (e.g. tropical or temperate).

The three components of any agroforestry systems are woody perennials (trees/shrubs), herbaceous plants (crops/pasture), and animals/livestock. Based on these three components, agroforestry systems are classified for practical purposes into three broad groups (Nair 1993):

- **Agrosilvicultural** – Crops + Trees
- **Agrosilvopastoral** – Crops + Trees + Livestock
- **Silvopastoral systems** – Trees + Pasture/Livestock

Numerous tree and crop species can be used in agroforestry systems (Table 11.2) and their selection is critical for successful establishment and production. Some of the factors affecting the choice of trees include (Blanco and Lal 2008):

- type of agroforestry system
- growth rate and regrowth potential
- plant canopy and root system
- use of trees (e.g. fruit or timber)

Table 11.2. Some traditional tree and crop species used in Caribbean agroforestry systems

Common name	Scientific name	Common name	Scientific name
Forest Species (Timber)		Tree Crops/Fruit Trees	
Balata	<i>Manilkara bidentata</i>	Ackee	<i>Blighia sapida</i>
Caribbean pine	<i>Pinus caribaea</i>	Anar	<i>Punica granatum</i>
Cedar	<i>Cedrela odorata</i>	Avocado	<i>Persea americana</i>
Crappo	<i>Carapa guianensis</i>	Banana/Plantain	<i>Musa</i> spp.
Cypre	<i>Cordia alliodora</i>	Bilimbi	<i>Averrhoa bilimbi</i>

Common name	Scientific name	Common name	Scientific name
Forest Species (Timber)		Tree Crops/Fruit Trees	
Mahogany	<i>Swietenia macrophylla</i>	Brazil Nut	<i>Bertholletia excels</i>
Mora	<i>Mora excelsa</i>	Breadfruit	<i>Artocarpus altilis</i>
Poui	<i>Tabebuia rufescens</i>	Caimite	<i>Chrysophyllum cainito</i>
Purple heart	<i>Peltogyne porphyrocardia</i>	Calabash	<i>Crescentia cujete</i>
Teak	<i>Tectona grandis</i>	Carambola	<i>Averrhoa carambola</i>
Forest Species (Other)		Cashew	<i>Anacardium occidentale</i>
Bamboo	<i>Bambusa vulgaris</i>	Cerise	<i>Flacourtia indica</i>
Cocorete	<i>Attalea maripa</i>	Chataigne	<i>Artocarpus camansi</i>
Fat pork	<i>Chrysobalanus icaco</i>	Chalta	<i>Dillenia indica</i>
Flamboyant	<i>Delonix regia</i>	Chennette	<i>Melicoccus bijugatus</i>
Grugru palm	<i>Acrocomia aculeata</i>	Chinee pommerac	<i>Syzygium samarangense</i>
Hog plum	<i>Spondias mombin</i>	Chinee tamarind	<i>Vangueria madagascariensis</i>
Immortelle	<i>Erythrina poeppigiana</i>	Citrus	<i>Citrus</i> spp.
Indian almond	<i>Terminalia catappa</i>	Cocoa	<i>Theobroma cacao</i>
Neem	<i>Azadirachta indica</i>	Coffee	<i>Coffea arabica</i>
Tonka bean	<i>Dipteryx odorata</i>	Coconut	<i>Cocos nucifera</i>
Spice Trees		Dunks	<i>Ziziphus mauritiana</i>
Bay	<i>Pimenta racemosa</i>	Guava	<i>Psidium guajava</i>
Cinnamon	<i>Cinamomum zeylencium</i>	Jackfruit	<i>Artocarpus heterophyllus</i>
Clove	<i>Eugenia caryophyllus</i>	Jamoon	<i>Syzygium cumini</i>
Nutmeg	<i>Myristica fragrans</i>	Lychee	<i>Litchi chinensis</i>
Legume Trees		Mamey apple	<i>Mammea americana</i>
Acacia	<i>Acacia</i> spp.	Mamey sapote	<i>Pouteria sapota</i>
Gliricidia	<i>Gliricidia sepium</i>	Mango	<i>Mangifera indica</i>
Leucaena	<i>Leucaena leucocephala</i>	Pawpaw	<i>Carica papaya</i>
Sesbania	<i>Sesbania</i> spp.	Peewah	<i>Bactris gasipaes</i>
Food Crops		Plantain	<i>Musa balbisiana</i>
Black Eye Pea	<i>Vigna unguiculata</i>	Plum	<i>Spondias</i> spp.
Cassava	<i>Manihot esculenta</i>	Pois doux	<i>Inga edulis</i>
Corn	<i>Zea mays</i>	Pommerac	<i>Syzygium malaccense</i>
Dasheen	<i>Colocasia esculenta</i>	Pommecythere	<i>Spondias dulcis</i>
Melongene	<i>Solanum melongena</i>	Sapodilla	<i>Manilkara zapota</i>
Ochro	<i>Hibiscus esculentus</i>	Sour cherry	<i>Phyllanthus acidus</i>
Pigeon pea	<i>Cajanus cajan</i>	Soursop	<i>Annona muricata</i>
Pumpkin	<i>Cucurbita maxima</i>	Sweet sop	<i>Annona squamosa</i>
Sweet potato	<i>Ipomoea batatas</i>	Tamarind	<i>Tamarindus indica</i>
Yam	<i>Dioscorea</i> spp.	West Indian cherry	<i>Malphigia glabra</i>

Agrosilvicultural systems

This agroforestry system refers to production of agricultural crops with woody perennials on the same unit of land. The tree component can have either a productive or a service role, and the components can have a spatial (simultaneous) or temporal (sequential) arrangement. Agrosilvicultural systems include alley cropping (hedgerow intercropping), shade trees for plantation crops, multi-storey cropping, Taungya system, windbreaks, improved fallow, intercropping trees and crops, and a mixture of plantation crops. The systems most commonly practiced in the Caribbean are described below.

Plantation crops and shade trees

This agroforestry system refers to the simultaneous production of agricultural crops (perennial species) and forest trees. In the Caribbean, cocoa and coffee are important plantation crops grown under shade trees because of their sensitivity to direct sunlight. Shade is provided by permanent trees which are planted at a spacing which allows between 25 percent shade (high altitudes) and 35 percent shade (low altitudes) for the cocoa and coffee plants. The planting density (trees/ha) of the shade trees will vary according to the species of trees used (i.e., its crown size when mature) and the percentage of shade required. Some of the common shade trees grown in cocoa plantations are immortelle, cedar, tonka bean, breadfruit and hog plum. The immortelle tree provides nitrogen (N), in addition to shade from the plant canopy. The root nodules, leaves, and flowers of the immortelle contain between four and six percent N, contributing to higher soil N levels and cocoa yields when compared to other shade trees. The major cocoa producing countries in the Caribbean are Trinidad and Tobago, Grenada, St Vincent, Haiti, and Jamaica.

Alley cropping (hedgerow intercropping)

Alley cropping refers to an agroforestry intercropping practice in which fast-growing species of trees/shrubs are planted closely within the row ('hedgerows'), and wide between the rows ('alleys') to allow for planting of agricultural crops. Therefore, trees and crops are grown together in the same field at the same time (Nair et al. 1999). Leguminous, high-value and/or short-duration crops are ideal for use in alley cropping. Depending on the tree species used (e.g., fruit trees) crops are not replanted when the trees mature and an orchard is established. When legume trees are used (e.g., *Leucaena* spp.), the hedgerows are cut back at the time the crop is planted. The hedgerows are also periodically pruned during the crop cycle to prevent shading and reduce competition for nutrients/water with the associated food crops. Root pruning is sometimes practiced during the early stages of hedgerow establishment. When there are no crops, the hedgerows are allowed to grow

unrestricted and cover the land. Alley cropping also enables cropping and fallow periods to occur simultaneously on the same unit of land. This means that the farmer can crop the land for a longer time before leaving it to fallow. Alley cropping is ideal for small-scale farmers but it is also adaptable to mechanized farming in larger holdings.

Contour planting and Conservation buffers

Contour planting is one of the most common agroforestry systems practiced in the Caribbean. It involves the planting of trees along the contour line in moderately steep to steep slopes (Figure 11.2). Conservation buffers are strips or small areas of land in permanent vegetation. Filter strips, field borders, grassed waterways, contour grass strips, and riparian buffers are all examples of conservation buffers. They are used to protect ground/surface water quality and to reduce erosion (Figure 11.3) on cropland.

Conservation buffers can also be used along streams and around lakes or wetlands. Buffers are most effective when they are included as part of a comprehensive conservation system.

Some of the more common types found in the Caribbean are contour grass strips, filter strips, and grassed waterways, all of which function in a similar manner. Contour grass strips are narrow bands of perennial vegetation established across the slope of a crop field and alternated down the slope with strips of crops. Properly designed and maintained contour grass strips can reduce soil erosion and minimize transport of sediment pesticides, and other potential pollutants before they reach a body of water. These practices are used in many traditional Caribbean farming systems across hillsides to control runoff and soil erosion.

The vegetation consists mainly of perennial grasses established parallel and perpendicular to the dominant slope of the field. However, combinations of trees, shrubs and grasses can be planted along the contour (Figure 11.4).

These practices result in greater structural stability of the soil and can provide a higher yield and diversity of useful products. The contour grass strips are also known as horizontal vegetation strips/barriers. Grassed waterways are strips of grass seeded in areas of cropland where water concentrates or flows off a field. While they are primarily used to prevent gully erosion, waterways can be combined with filter strips to trap contaminants or field sediment.

Riparian forest buffers, whether natural or man-made, have a dominant woody component, which sets them apart from vegetative filter strips that are used to intercept surface runoff in agricultural crop lands.

Windbreaks

Windbreaks are linear plantings of trees or shrubs (in single or multiple rows) which are planted on the border of crops. They are designed to improve crop production and assist

in soil and water conservation. The Caribbean region can be subjected to strong prevailing NE Trade winds, and the establishment of windbreaks is important to crops which are sensitive to wind damage (e.g. cocoa and citrus). The tree species that are commonly used for windbreaks include nutmeg, clove, cinnamon, mango, neem, and pommerac.

Some windbreaks can also provide an additional benefit of controlling pests and diseases to the economic crop, based on their ability to filter bacterial inoculum and deter the spread of viruses by aphids. Windbreaks established using *Leucaena* spp. is believed to prevent bacterial stem canker in papaya. Windbreaks are also favorable because they are unobtrusive to the various management practices for the cash crops grown. Windbreaks can help protect young crops, maintain soil fertility, reduce soil loss by wind erosion, and pruned vegetation and fallen leaves from the trees can act as mulch.

The many benefits of windbreaks, makes it very applicable for extensive use in the Caribbean, especially in the Windward Islands. However sometimes hurricanes can cause destruction to both the windbreaks and the agricultural crops. When the wind speed is high, it can cause physical damage to crops (broken branches and uprooting) together with shedding of flower/fruits resulting in reduce crop yield. To minimize this risk to fruit and tree crops, windbreaks are established using various tree species.

Improved fallow

This is an agroforestry practice in which fast-growing trees/shrubs are planted after harvesting crops, so that when the land is next cleared for cultivation (i.e. after the fallow period) products are available for household use or marketing. The crops and trees therefore occupy the same piece of land at different periods in time (sequentially). The trees and shrubs may be left to occupy the site for several months or years. The tree species grown in natural fallows can produce high-value products such as fruits, medicine, or high-grade timber to provide economic benefits during the fallow period. Alternatively, leguminous trees and shrubs can be planted to improve soil fertility. The leaf litter from the trees also suppresses weeds, enrich the soil, conserve soil moisture, and after tree removal their roots decompose and release additional nutrients. This practice therefore has the potential to restore soil fertility more quickly than natural fallows, and to reduce fertilizer costs for subsequent crops.

Traditionally, farmers left the croplands ‘fallow’ after a period of cultivation so that they can regain their fertility naturally. However, improved fallows accelerate the process of rejuvenation and thereby shorten the length of the natural fallow period. Even though improved fallow has its origins in ‘slash-and-burn’ agriculture, the practice can be applied to any agricultural land that is not under cultivation in order to rehabilitate and increase

the nutrient status of the soil. The effect of improved fallow depends on the length of the fallow period and the type of tree species. The recommended tree/shrubs should be fast-growing, nitrogen-fixing, and easy to propagate. Examples include various species of *Leucaena*, *Sesbania*, and *Gliricidia*. The benefits of improved fallow is that it allows for quick restoration of soil fertility (nutrient and organic matter content), nutrient recycling from deeper soil horizons, protecting the soil from erosion, reduces weed growth, and allows for production of fuelwood thus reducing the burden on the natural forests. Therefore, it has great potential for promoting food security through increased soil productivity.

Taungya

The Taungya system consists of growing annual agricultural crops along with the forestry species during the early years of establishment of the forestry plantation. This agroforestry system is usually used by Government Forestry Divisions to establish large acreages of forest trees, usually for the timber industry. The land belongs to the government or large-scale estate owners, who allow the subsistence farmers to raise their crops. The farmers are required to tend the forestry seedlings and, in return, retain a part or all of the agricultural produce. This is beneficial both to the State and to the private farmer.

The Taungya system was introduced in Trinidad in the early 1900's when the State began to establish commercial timber plantations using teak and later Caribbean pine (Figure 11.5). This system involved short-term contracts to farmers to plant food crops (bananas and plantain) on state lands chosen for teak and pine establishment. In the 1980s the method was used in Trinidad to establish about 9,000 ha of teak and 4,000 ha of Caribbean pine (Lackhan 1992).

In the past and up to the present time, livestock farmers have planted shade trees in their pastures. These pastures were also bounded by trees, which were used as fencing. As farmers increasingly realised the value of trees, the feasibility of trees as the main crop became more apparent with the use of smaller livestock (sheep and goat) to control the grass beneath. Trees were formerly not planted as the main crop, but used more in a supplementary role. Today, this is different, as farmers in recognition of the value of trees, have made them the main crop on many estates, with other forms of agriculture revolving around the tree plantations.

Food crop production takes place during the period between land clearing and the plantation establishment phase. The Taungya system can sometimes appear unattractive to farmers, as its main objective is wood production, not food. Taungya persists in areas with high population pressure and where there is adequate government support and incentives. The adoption of this system varies among the Caribbean countries, with Trinidad showing some success (Figure 11.6).

Trees in cropland

In this agroforestry practice, trees are grown in combination with annual crops. It is a type of intercropping and is widely-used by small-scale farmers in the Caribbean. Farmers usually plant a variety of crops integrated with perennial fruit and spice trees. This diversity is especially important in prevent land degradation in the smaller islands, which are dominated by mountain slopes. Trees with narrow crowns and deep root systems are preferred; while the annual crops should require minimum or no-tillage and have a low light requirement. In Grenada, food crops such as yam, corn, pigeon peas, sorrel, dasheen and tannia are integrated with spice trees such as nutmeg, clove, and cinnamon. Grenada is the world's second largest producer of nutmeg and the sustenance of the spice industry is important in providing socioeconomic benefits and food security for the country's population. In Haïti, peasant farmers will traditionally leave the occasional forest trees such mahogany, guaiac wood (*Guaiacum officinale*) and Haitian catalpa (*Catalpa longissima*) in the areas that they cultivated crops.

Other Agrosilvicultural practices

These include tree gardens (in Trinidad) whereby combination of several fruit and other useful trees are cultivated, sometimes with the inclusion of annual crops. In this practice the plant components are of differing stature so that several layers of canopy are formed (Figure 11.7).

Silvopastoral system

This is an agroforestry system where trees (shrubs), pastures and/or livestock are integrated on the same piece of land. The components can be arranged as a pure stand with fodder trees/shrubs (cut-and-carry fodder production) and/or mixed in different configurations (e.g. living fences of fodder trees). Silvopastures can be created by planting trees in existing pastures or by establishing pastures under existing trees. This system can be used on both range and forest lands for the production of forage and tree products. The system can also help with soil conservation by growing grasses and trees/shrubs on sloping ground. The silvopastoral system can produce high quality forage and timber, together with conservation of the environment.

It is important to consider potential markets, soil type, climatic conditions, and species compatibility when selecting trees and forages for use in the silvopastoral system. The trees grown for timber should be marketable, fast growing, deep rooted, and drought tolerant (e.g. Caribbean pine and cypre). Ideally, the forage component should be a perennial which is suitable for livestock grazing, compatible with the site/soil, and productive under partial shade (e.g. guinea grass - *Panicum maximum* and signal grass - *Brachiaria decumbens*). Potential livestock choices include cattle, sheep, goats, ducks, turkeys, and chickens.

Silvopastoral systems can be established on any land capable of supporting tree and forage growth at the same time. However, they require a relatively large land area to sustain timber and livestock production. The spacing and arrangement of the tree species is important for silvopasture success. Trees can be evenly distributed to optimize growing space and light for both trees and forage. If desired, they can be planted in rows or clusters to limit their shade and root effects, while providing open spaces for pasture production. Furthermore, an understanding of forage growth characteristics and the timing/duration of grazing is important in silvopasture management. Since the livestock and tree components can be arranged in many combinations, silvopasture is ideal for sites where mechanized farming or a structured system is difficult or not required. Examples of silvopastoral systems include:

- Trees on pastures – traditionally used for providing shade to livestock
- Fodder banks – planting of leguminous fodder trees around farmlands e.g.
- Living fences – Fodder trees are planted on farm boundaries or pasture borders
- Plantation crops with pastures and animals - Plantation trees such as coconut can be planted in a scattered manner on pasture land to provide light shading under which cattle and small ruminants can graze (Figure 11.8).

Agrosilvopastoral system

This agroforestry system integrates trees, crops, and livestock (pastures). This allows for multiple outputs such as fodder, fuelwood, and food for human consumption. The system represents a combination of components in the same unit of land and in a spatial sequence. This system is practiced when the farmer wants to reap all the benefits that would be obtained from silvopasture and agrosilviculture systems. Agrosilvopastoral systems usually consist of overstory trees, understory crops and grazing animals. The trees on the land may be native (spontaneous) or planted; the crops may include cereals or forage crops; and the grazing animals may include sheep, goat or cattle. The main type of agrosilvopastoral system practiced in the Caribbean is homegardens. The word ‘homegarden’ has been used loosely to describe diverse practices, from growing vegetables behind houses to complex multi-storeyed systems. It usually refers to a land-use system on private lands surrounding individual houses with a definite fence, in which several tree species are cultivated together with annual and perennial crops; often with the inclusion of small livestock. The homegarden consist of a small acreage, and planted with various plants from herbaceous vegetable crops to medium size trees. There are many forms of such gardens varying in how intensively they are cultivated and their location with regard to the home. The home garden provides plant and animal food for home consumption, and is usually located close to dwellings

for security and convenience. They are also characterized by low capital input and simple technology or equipment. Fish farming or aquaculture combined with the growing of crops and trees represents a unique agrosilvopastoral system. Aquaculture in agroforestry practices can involve rice cultivation with fish and trees, as well as fish ponds in farmland with trees (Figures 11.9 and 11.10).

BENEFITS OF AGROFORESTRY

Agroforestry is practiced throughout the world, in order to address some form of national socio-economic development, such as, increased food production, natural resource conservation, environmental protection and poverty alleviation. In some countries, the primary motivating factor in the adoption of any agroforestry system is the economic gain. Agroforestry systems have been successfully established and maintained in countries such as India, China and Papua New Guinea. These countries have humid tropical environments that are similar to the Caribbean and a brief description of their success given below to highlight their applicability to the Caribbean region.

In India, agroforestry systems have played an important role in programmes for controlling shifting cultivation. In West Bengal and Karala, the Taungya system was used successfully, thus creating forest villages, which provided labour for forestry operations (Singh 1987). The farmer generally leaves useful trees, such as mango, tamarind and jackfruit in the areas being cultivated to provide them with edible products. In suitable areas, along with rice and millet, crops such as coffee are planted under the shade of silver oak (*Crevillea robusta*) and other crops such as tobacco and tumeric are grown.

In China, increased industrialization activities have resulted in increased demand for timber and energy, which has led to more pressure on the land. In order to reduce problems such as soil erosion, siltation, flooding and desertification, agroforestry policies and legislation was created. These policies were designed to enhance the farmer's ability to produce more food, to put land to multiple use, to reforest the bare lands and, to expand forested areas for conservation.

In Papua New Guinea, a programme called the 'Atzera Range Conservation Programme' was developed to address the problem of excessive soil erosion and runoff which causes flood damage to roads, bridges and the sewage system of the city (Harris 1979). These problems were caused by the migrants coming to the city from rural areas that establish squatter settlements and felled many trees for fuel and house-building. Since the Atzera Range is an extensive steeply sloping hill system adjacent to Lae, the second largest urban centre, a corrective programme was developed and implemented, based on the use of agroforestry techniques and sound ecological planning.

In the Caribbean region, agroforestry features prominently in traditional farming systems. These systems involve use of various tree species such as forest, fruit, fodder, cocoa and coffee. Food forests have been described as a good example of agroforestry, and occur in islands such as St Kitts, Montserrat and Jamaica, where dry ravines called guts (or ghants) are used for growing mangoes, breadfruit, ackee, avocado and other fruit trees (Lackhan 2000). The Taungya system has been utilised by several forestry departments within the region for establishing forest plantations. Livestock are also reared in association with tree crops and forests trees. The leaves and stems from *Gliricidia* are used for feeding sheep while *Leucaena* is used for dry season feeding of livestock in the region. Kudzu (*Pueraria lobata*) has been used to improve the traditional system of shifting cultivation in Belize, and has the benefit of improving soil nitrogen.

Agroforestry involves the production of multiple outputs which provide subsistence/income to farmers and minimizes the risk of total failure by the production system (Nair 1993). It also aims to create a balance between increased agricultural development and environment conservation, and provides many benefits such as improving soil fertility, soil conservation, stabilizing river banks, and providing various tree products (fuelwood, timber, fruits). Agroforestry can be a viable option for reducing land degradation and increasing agricultural productivity in the Caribbean. Agroforestry systems are important because they provide many socioeconomic and environmental benefits. Agroforestry is seen as a tool that can enhance food security and improve rural livelihoods, increase soil fertility, improve soil and water conservation, aid in carbon sequestration, and help in the restoration of degraded lands. Agroforestry systems also increases biodiversity, creates additional wildlife habitat and support farmers in rural communities (Nair 1993). They also provide additional farm products such as timber, pulpwood, firewood, posts, fruit, nuts, and fodder. Agroforestry represents a collection of multipurpose practices that are enduring and help achieve a sustainable agriculture. It is a concept based on the interface between agriculture and forestry and it is a land-use approach of great potential value. Forests provide a wide range of productive as well as protective functions, contribute to socio-economic development and represent an important cultural asset. In terms of their protective functions, forests are important for their favourable impact on soil and hydrological systems, maintaining clean water and reducing the risks and impacts of floods, erosion, and strong winds. Forests also play a key role in carbon sequestration and mitigation of climate change. In the subsequent sections, three major categories of benefits, namely ecological/environmental, economic and sociological/psychological, will be described.

Ecological/Environmental

Soil fertility and nutrient cycling

Soil fertility refers to the capacity of a soil to support plant growth on a sustained basis under given climatic conditions and land characteristics. Agroforestry systems can be critical in improving soil fertility. For example, leguminous trees planted as fallows can accumulate significant amounts of nitrogen in their leaves and roots, which is then made available to crops. Some of the species used to improve soil fertility also have nutritive value as fodder and can improve the quality of animal manures. Agricultural crops utilize nutrients from the surface layers of the soil while forest crops make use of the nutrients at the lower horizons. There is little need for chemicals as the presence of trees shade out weeds, thus reducing the need of chemical herbicides which destroy beneficial soil organisms. Fast growing trees e.g. *Acacia* and *Leucaena* aid in nitrogen fixation by absorption of nitrogen from the air thus making it available to other plants present.

Continuous cropping of the soil (especially by monoculture) without adequate replacement of nutrients can lead to a decline in soil fertility. In the Caribbean region many soils lack adequate plant nutrients and organic matter. While artificial fertilizers can provide major nutrients (N, P, K), plants require 16 essential nutrients for adequate growth and yield. The incorporation of woody perennials (deciduous) and multiple crop species (with various rooting depths) allows for the recycling of nutrients. Soil fertility can be improved or sustained from the decomposition of above and below ground plant biomass (such as fallen leaves, crop residues, and roots from harvested trees). When leguminous species are integrated in the agroforestry system, soil fertility also increases as legumes convert atmospheric nitrogen to the plant available form (nitrates).

Soil and water conservation

Agroforestry systems can improve soil and water conservation by reducing soil erosion caused by wind and water. They also reduce the transport of non-point source pollutants (e.g. chemicals and sediment) to water bodies (e.g. rivers and lakes), while retaining fertilizers and nutrients on the farmland. Agroforestry systems reduce surface runoff, improve water infiltration and stabilize the soil.

Due to the humid tropical environment of the Caribbean, there can be periods of intense rainfall and flooding leading to soil erosion. Soil erosion removes the nutrient and organic matter rich topsoil, resulting in a decline in soil fertility. In agroforestry systems, woody perennial plants (with deep root systems) can be planted on steep slopes which are unsuitable for crop cultivation or grazing. When the woody perennials are established they provide a micro-environment conducive to the growth of other plant species. Trees and shrubs can

improve the infiltration of water in the soil thus reducing surface runoff. Trees also reduce wind speed and improve soil structure which helps to reduce soil erosion. Agroforestry is relevant to soil conservation since the initial cost of establishing erosion control is usually lower than engineering methods (Young 1987). In addition, crop yields can be maintained or increased due to control of soil loss. Agroforestry can also reduce the cost of reclamation for degraded lands by using trees which improve soil fertility. Examples of agroforestry practices that have the potential to control erosion include alley cropping and conservation buffers. Agroforestry systems are usually practice on slopes of 10° – 40° using suitable soil conservation practices. They have also been an integral part of watershed management plans in several of the Caribbean countries, thus improving water quality and quantity.

Trees also assist in soil and water conservation as soil structure is improved by the presence of tree roots, resulting in increased infiltration of water into the soil. Leaf litter produced by trees protects soil from the impact of rains, while tree roots help to hold the soil in place. Trees are soil builders and soil protectors, they can be used to rebuild poor soils, stabilize steep slopes and reduce soil erosion, thus enhancing agricultural production (Sanchez 1987). Agroforestry has potential for erosion control since the canopy and leaf litter cover the soil, the tree roots stabilize the soil and the trees also act as barriers to runoff. The use of contour strips in agroforestry systems is cost effective (with low initial establishment and annual maintenance costs compared to engineering methods).

Carbon sequestration and climate change

Increasing concentrations of greenhouse gases in the earth's atmosphere are linked to global warming and climate change. CO_2 is the principal anthropogenic greenhouse gas with emissions arising from fossil fuel combustion, cement production, land use change and deforestation. The atmospheric CO_2 concentration has increased from 280 ppm in 1750 (onset of industrialization) to 315 ppm in 1958, and to 396 ppm in 2013, mainly due to the burning of fossil fuels. As global greenhouse emissions increase, they can affect human health, food security and contribute to environmental degradation. Forest lands are important to the carbon cycle since 610 Pg (1 Pg = 10^{15} g) of carbon is stored in the global vegetation biomass (Lal 2004). Carbon sequestration refers to the uptake of atmospheric CO_2 during photosynthesis and the transfer of accumulated carbon into vegetation and soil pools for long-term storage. Plants also act as a sink for CO_2 ; therefore any decrease in forest area reduces the carbon stock of the forest ecosystem. During the past 25 years, agroforestry has been recognized as a sustainable, integrated land-use system with the potential of sequestering carbon. Nair et al. (2010) reported that the carbon sequestration potential varies due to ecology and management, and ranges from 0.3 to 15.2 $\text{Mg ha}^{-1} \text{ year}^{-1}$

aboveground, and 30–300 Mg C ha⁻¹ up to 1-m depth in the soil (belowground biomass). Woody perennials (trees) represent the most important C pool in aboveground biomass. Therefore integrating more trees in the agricultural landscapes by adopting agroforestry can increase the potential for carbon sequestration and reduce the effects of climate change. Agroforestry systems can further contribute to the mitigation of climate change by providing a permanent soil cover, ensuring long term stability of carbon storage in fluctuating environments, and improving the efficiency of use of soil, water and climatic resources.

Agroforestry systems can play an important role in climate change adaptation and mitigation in Caribbean countries. The increase biodiversity of agroforestry systems provide a safety net during periods of climate induced vulnerability and increases resilience to climate change. Adoption of agroforestry systems by Caribbean farmers can help ameliorate the effects of climate change by helping to stabilize erosion, improve soil and water quality, indirectly increase crop yields, increase biodiversity, reduce greenhouse gas emissions, and increase carbon sequestration. Agroforestry is also an important component of sustainable land use and development.

Economical

The inclusion of agricultural crops often results in increased tree production and less costs for tree management e.g. fertilization of agricultural crops in Taungya also benefits tree growth. Income can be generated for the farmer through the provision of by-products, which can be obtained from trees such as fruits and medicine. Composting of leaves, branches and twigs can provide a source of nutrients thus saving on the purchase of fertilizers. Agroforestry systems can provide economic benefits for the farmer both in the short-term (e.g. food) as well as the long-term (e.g. timber). Forages from leguminous trees such as *Gliricidia* and *Leucaena* can be a digestible source of protein-rich fodder as well as shade for livestock. It can also be used for supplementary feeding when grasses may be in shortage as in the dry season. The fodder trees and shrubs can be given to the livestock using a ‘cut and carry’ system or the animals may be allowed to graze the fields. A few countries in the Caribbean (e.g. Haiti) use firewood as the main source of energy. An increase in the number of trees planted and better management of existing resources can provide both fuelwood and other tree products. If fuelwood is limited, it can influence the amount and type of food cooked, thus affecting the family’s nutrition. If wood production is increase for fuel use, other energy sources such as cow-dung and crop residues can be left in the fields. Fuelwood is mainly collected by women and the further the source of the fuel wood, the greater the workload. Agroforestry enables rural households to produce firewood which is easily accessible and close to the family farm.

Social/Psychological

Agroforestry practices can help in the prevention of environmental degradation and contribute to sustainable rural development, especially in regions where human-induced activities have resulted in a fragile ecosystem. Agroforestry can provide a source of employment and generate income for small-scale farmers in rural communities. Since agroforestry is an alternative land use system, it may be used as a tool by farmers practicing shifting cultivation as a means to provide them with better social service and improved living conditions. Tree products can be obtained throughout the year giving year round labour opportunities and regular income. In areas of shifting cultivation, a modernized agroforestry system can be implemented, where tree crops are rotated with a short period of agricultural production. This may be more acceptable than a shift to permanent annual crop production. Also, a sense of pride and fulfilment that one is contributing to the environmental and socio-economic welfare of the nation can contribute to an individual's esteem.

AGRICULTURAL PERFORMANCE UNDER AGROFORESTRY SYSTEMS

A number of factors influence agroforestry development since systems can exist under a range of biophysical and socioeconomic conditions (Nair 1993). Factors that can influence the land owner's decision to adopt agroforestry or to select a particular system include:

- Biophysical conditions such as climate, soil type, slope, and water availability.
- The types of government policies and incentives for developing agroforestry systems.
- The tenure of land, crops and trees, which determine if it is beneficial for farmers.
- Technical support and extension services for the supply of inputs and for market delivery.
- The needs, skills and education level of the land owner together with labor availability.

Agroforestry Policy and Legislation

This is necessary in order to protect and conserve the forest and wildlife resources in the region. It serves to safeguard against the exploitation of marketable species in the natural forests. There are no specific agroforestry policies, but agroforestry is covered under the forest policy and legislation in each country. The status of forest policy and legislation varies greatly between the CARICOM countries. All of the CARICOM countries implement some type of forest policy except Barbados, which has passed a number of Acts relating to tree conservation. Belize has a National Forest and Wildlife Policy which is over 50 years old

but still relevant. Legislation in Belize includes the Forest Ordinance, Forest Fire Protection Ordinance, Private Forest (Conservation) Ordinance, National Park Systems Act and the Wildlife Protection Act. In Trinidad and Tobago, forest policy includes the Forest Act and the Conservation of Wildlife Act.

Adoption of Agroforestry systems

Compared to monocropping, agroforestry can be a more economical option (due to lower expenditure on large machinery, equipment, and fertilizers) for small-scale farmers to support food production while preserving the environment. However, there are some factors which can affect the adoption of agroforestry by farmers such as access to information on agroforestry, training opportunities, good quality planting material, land tenure, and size of available land.

Agroforestry have been practiced on a limited scale in the Caribbean islands of Antigua, Dominica, Jamaica, St Kitts and Nevis, and Trinidad and Tobago. The other Caribbean islands have very little experience in agroforestry. In Antigua, agroforestry has been developed into an intensive form of land use combining agricultural crops, shrubs and trees. In Dominica, multiple storey cropping systems have been established in large estates and consist of coconut, banana, citrus, coffee, and cocoa. In small farms, fruit trees, root crops and vegetables are more common. In Jamaica, agroforestry have been practiced for several decades, mainly using a multi-storey system. The top storey usually consists of cedar, breadfruit, mango and/or coconut, the middle layer has cocoa, coffee, bananas and/or guava, and the ground layer contains peas, vegetables, sweet potato, yam or hot peppers. In Trinidad and Tobago, the Taungya system is used for the establishment plantations of teak and Caribbean pine. The next most common agroforestry practice is the establishment of an upper storey of cedar, mahogany or immortelle with a lower storey of cocoa, coffee and/or bananas.

Current challenges in agroforestry systems

Agroforestry activities have not been well-documented or differentiated from forested lands in many of the Caribbean countries. Research and analysis of agroforestry systems have focused on the physical aspects of the systems but the economic contributions at the farm level have not been systematically assessed. The financial benefit of agroforestry systems are rarely the primary objective for promoting agroforestry or on-farm tree establishment. Therefore, farmers lack the motivation to establish agroforestry systems since it is viewed as a form of subsistence farming and not a generator of income and this may have contributed to project failures. Therefore, agroforestry systems must be advertised

as profitable by providing examples of crop production increases, commercialization of tree-derived products, and provision of financial incentives to farmers.

There is also need for further research on the development of agroforestry systems specific to the Caribbean. This includes research in silviculture, natural forest management, hydrology, land use and wildlife management. Extension officers are usually trained in the field of agriculture and may not have the knowledge and experience to influence adoption of agroforestry systems by farmers. In terms of practical limitations, farmers may not be aware of tree-crop interactions in agroforestry systems which may influence the success of the operation. Therefore some key considerations when designing an agroforestry system include:

- Increasing the overall value of the system,
- Ensuring trees and crops are complementary
- Decreasing or eliminating competition
- Minimizing crop displacement, through appropriate tree management.

There are many constraints in the Caribbean region which influence agroforestry and forestry in general. These include the limited size of the Caribbean islands, high and increasing population density, uncontrolled grazing and shifting cultivation, soil erosion and sedimentation, decreasing forest resources (which are not replaced), not utilizing lands to its productive potential, decline in fuel wood, and natural disasters (e.g. hurricanes and earthquakes). Preference for cultivation of plantation crops (e.g. bananas) because of market demand also represents a constraint to the implementation of agroforestry systems.

Improvement in technical knowledge and skills

In 1997, the Forestry Division of Trinidad and Tobago received funding for a community-based forestry and agroforestry project under the Public Sector Investment Programme (PSIP). The project was implemented to assist in preventing and reversing the cycle of deforestation and land degradation on private lands, particularly landowners with large parcels of land, and who were willing to commit land and other resources to relatively long-term forestry and agroforestry projects. Community-based groups were also encouraged to participate in the programme. Specific objectives of the project included:

- The promotion of sustainable land-use practices
- The development of economically and ecologically viable forestry and agroforestry systems
- The restoration of degraded private lands

- The optimization of timber production on private lands
- The generation of employment opportunities in rural/agricultural communities

In 1999, a revised Agricultural Incentive Programme was introduced, in which for the first time, incentives for forestry operations were included. These incentives have increased the implementation of forestry-related activities on private lands, specifically agroforestry. Within this context the Forestry Division assisted in the following ways:

- Providing technical assistance to farmers, community groups and other organizations
- Processing incentives to assist farmers in establishing and maintaining plots
- Monitoring and assessing projects
- Conducting basic training in forestry and agroforestry practices

Legislation and policy reform

In the region there is the need to modify existing legislation to reflect recently adopted policies aimed at protecting and promoting agroforestry systems. In order to promote agroforestry, there must be legislation to provide security of tenure for small-scale farmers, which can be achieved via policies which guarantee equal access to land resources. The establishment of a system which allows the separation of the ownership of land from the ownership of trees would open new possibilities for farmers without land. In order to be effective, agroforestry requires that the farmers are given clearly established rights to the land and to the trees they plant.

The Government of the Republic of Trinidad and Tobago has approved a new National Forest Policy and National Protected Areas Policy (2011), which provides the guidance for the development of appropriate legislative and administrative framework for the sustainable management of the forest resources of Trinidad and Tobago. The Policy recognizes that forests, forest resources and forest use contribute significantly to national development, livelihoods and human well-being, and seeks to encompass all the main dimensions of forest conservation, use and management, given that the functions of forests are varied and the relationships between forests and other sectors are complex.

Potential for Food and Nutrition security

In developing countries, agroforestry can contribute towards alleviating poverty and advancing food security by increasing crop and livestock production through innovative technologies. In many Caribbean countries, introduction of agroforestry systems to rural communities can reduce hunger by increasing crop production through improved soil

fertility. The increase in population size and continued environmental degradation in the Caribbean region has resulted in reduced food production and the inability of countries to meet their food demands. The total population of the CARICOM countries (excluding Haiti) has increased from 5.9 million in 1990 to 6.85 million in 2010 (a 16 percent increase); and is projected to reach 10 million by 2050. Haiti conducted its two previous population census in 1980 and 2004; however, the population for 1990 and 2010 has been estimated at 7.1 million and 9.7 million, respectively, representing an increase of 37 percent (Table 11.3). Haiti's population is larger than all the other CARICOM countries combined and is the most affected by environmental degradation.

Food security is defined as the physical and economic access to food for all people at all times. Agroforestry have tremendous potential in providing food for local consumption and reducing the food import bill. Agroforestry systems include growing a variety of useful trees, annual crops and livestock thereby preventing micronutrient malnutrition in regions where nutrient deficiency may occur from consumption of a single or few food source (dietary diversity or quality).

An important aspect of agroforestry is crop diversification which allows for a wider range of food products to eat and sell, improved nutrition, and the ability to spread the risk in production due to varying weather conditions. The production in agroforestry systems can be complementary, where overall yields are greater for the system as a whole than if one species only was present. Also agroforestry systems can be synergistic, where total yields are greater than the sum of the individual components if grown separately (Nair 1993).

Agroforestry systems allows for symbiotic economic and ecological interactions between components to maximize, sustain and diversify the total land output. They incorporate perennial trees which are useful for fuelwood, fruit and fodder, together with annual crops. Agroforestry systems can be established on soils of low fertility or degraded soils, as well as recuperating soil nutrients over a period of years. They can reduce farmer's risk to seasonal environmental variations and in the long-term maintain and increase soil quality. Agroforestry allows farmers to make the best use of their land, can boost field crop yields, and diversify income. Thus it can help in bringing previously unsuitable land into production, therefore increasing the food supply and provide food and nutrition security for the developing countries in the Caribbean.

Table 11.3. Population for each CARICOM country for the 1990/91 and 2010/11 census years.

Country	1990/91	2010/11	% Change
Antigua and Barbuda	60,840	90,801	49.2
The Bahamas	255,049	346,900	36.0
Barbados	260,491	272,112	4.5
Belize	189,392	312,698	65.1
Dominica	71,183	72,729	2.2
Grenada	85,123	109,553	28.7
Guyana	723,723	763,322	5.5
Jamaica	2,380,666	2,702,300	13.5
Montserrat ¹	11,314	5,020	-55.6
St Kitts and Nevis	40,615	52,650	29.6
St Lucia	133,308	163,229	22.4
St Vincent and the Grenadines	107,598	101,352	-5.8
Suriname	355,240 ²	531,170	49.5
Trinidad and Tobago	1,213,733	1,324,699	9.1
Subtotal	5,888,275	6,848,535	16.3
Haiti ³	7,110,000	9,719,932	36.7
Total	12,998,275	16,568,467	27.5

¹ Population decreased due to external migration from the unsafe zone of the Soufrière Hills Volcano

² Value from 1980 Population census

³ Estimated values

Sources: www.caricomstats.org and www.cia.gov/library/publications/the-world-factbook/ (Accessed 28 April 2014)

CONCLUSION

Agroforestry is only a new word for an old practice: it is based on forestry, agriculture, animal husbandry, land resource management, and other disciplines that all form the systematic background of land use. Furthermore, it encompasses an awareness of interactions between humans and the environment and between demand and available resources in a given area. Although science can improve agroforestry practices, an important aspect for the Caribbean region is to mobilize and implement what is already known. Agroforestry can significantly increase the production of forest and agricultural products (multiple outputs), while at the same time ensuring the land is used at its maximum potential. Agroforestry is therefore a sustainable approach to land-use management whereby agriculture and forestry

are combined into an integrated production system resulting in maximum benefits to the land owner. It has great scope and potential in providing social, economic and environmental services to improve the lives of the people in the Caribbean region.

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A Method for Growing Tilapia in Atlantic Seawater in St Kitts: A Sustainable Alternative to Traditional Coastal Fishery Systems

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INTRODUCTION

Aquaculture is the fastest growing animal food-producing sector, with the per capita supply increasing from 0.7 kg in 1970 to 7.8 kg in 2008; an average annual growth rate of 6.6 percent (Murray 2014). Aquaculture is set to overtake capture fisheries as a source of food fish globally. Between 2006 and 2008, aquaculture consumption increased from 42.6 percent to 45.7 percent worldwide. In the Latin American and the Caribbean (LAC) region, Chile, Brazil and Ecuador have been the leaders in aquaculture production with a production rise from 0.1 percent to 9.6 percent in 30 years.

The aquaculture sector is not well developed in the CARICOM region. The main reason is that most CARICOM states have limited land and fresh water resources. In the mid-1990s, the Organization of Eastern Caribbean States (OECS) members of CARICOM recommended that land-based aquaculture should not be the focus of their fisheries development thrust, but instead should be a subsistence activity for small farmers. Some CARICOM states, such as Suriname, Guyana and Belize, however, have ample supplies of land and fresh water which can support aquaculture. In contrast, most island states in the Caribbean have large expanses of marine space, which have the potential for development of the marine-based aquaculture or 'mariculture'. Because of the limited potential growth of wild catches in the Caribbean region, sustainable expansion and intensification of fish production through responsible aquaculture development should be a major objective for intensification of fish production. The CARICOM approach to aquaculture development will have to be multifaceted to address the range

of available natural land and fresh water resources in the region, while incorporating the commercial elements. St Kitts and Nevis, however, has concluded that an aquaculture sector will create investment opportunities, and could, in its most developed version, create many job opportunities for highly skilled people both at the production and management levels.

The CRFM identified aquaculture as a priority since 2002 and an aquaculture development policy formulation was identified as one of the areas to be addressed under the CRFM/JICA Master Plan Study (2009–2011). Recognizing the need to put in place a mechanism to promote and provide support for the development of aquaculture in the region, the CRFM Secretariat, in 2012 established a Working Group to Promote Sustainable Aquaculture Development (WGA) at the national and regional levels, mainly for the purposes of: increasing food production and security; improving rural income and employment; diversifying farm production; and increasing foreign exchange earnings and savings, as well as, advising the Caribbean Fisheries Forum on policies, programmes and projects to promote the development of aquaculture. It is however important that the WGA considers the major challenges for aquaculture development in the Caribbean, which include: availability of freshwater; technology transfer; feed access and availability; innovative technical assistance for small-scale farmers; governance and political willingness; and application of the Ecosystem Approach to Aquaculture.

Globally, tilapia is the third most important fish in aquaculture after carp and salmon; worldwide production exceeded 1,500,000 metric tons in 2002 and increased annually. Because of their high protein content, large size, rapid growth (six to seven months to grow to harvest size), and palatability, a number of tilapiine cichlids—specifically, various species of *Oreochromis*, *Sarotherodon* and *Tilapia*—are the focus of major aquaculture efforts. The species raised in fish farms include salmon, trout, cod, carp, catfish, sea bass, tilapia and others. Today, the vast majority of Atlantic salmon and rainbow trout are farmed intensively in fish farms.

The Nile tilapia has distinctive, regular, vertical stripes extending as far down the body as the bottom edge of the caudal fin, with variable coloration. Adults reach up to 60 cm (24 in) in length and up to 4.3 kg (9.5 lb) and lives for up to nine years. It tolerates brackish water and survives in temperatures between eight and 42°C (46 and 108 °F). It is an omnivore, feeding on plankton, as well as, on higher plants. Introduced tilapia can easily become an invasive species (see *Tilapia as exotic species*). It is a species of high economic value and is widely introduced outside its natural range, (which is similar to the Mozambique tilapia (*O. mossambicus*), and is the most commonly cultured cichlid (Cook 2007). Recent studies in Kenya showed that this fish feeds on mosquito larvae, making it a possible tool in the fight against malaria in Africa.

PRESENT SITUATION

Small islands with no significant rivers, streams, brooks or suitable freshwater ponds and clay have always had to forgo assistance to develop aquaculture. With the rapid depletion of reef fishes in the Caribbean, St Kitts imports fish for the local tourism industry as well as for local consumption.

In the Federation of St Kitts and Nevis (SKN), solutions are being sought and developed through the St Kitts and Nevis Aquaculture Pilot Project & Environmental Research (SNAPPER). This project was conceptualized as a research, development and training entity in 1999 and commenced Research and Development (R&D) in 2006 in response to the reality that marine capture of fish was on the decline, while aquaculture yields and sales were increasing at a phenomenal rate. In addition, the real possibilities of employment creation, food security and economic viability, presented a lucrative development opportunity.

CHALLENGES THAT LED TO THE CHOICE OF ATLANTIC SEA WATER

The absence of suitable clay deposits required for pond lining further complicated aquaculture development initiatives in St Kitts, which is one of the smallest islands in the Caribbean, with no running rivers or pond sealing clay. In addition, the public water supply is expensive and relies heavily on available aquifers for good fresh water sources. The island is surrounded by the Caribbean Sea on one side and the Atlantic on the other. The first challenge to start the project of tilapia production in the Atlantic sea water was to find a suitable site for establishing the research ponds. Because official endorsement was not given, and international experts advised against this aquaculture project, land access was as a problem. Eventually, private sector benevolence provided a peppercorn lease for 1/8 of an acre of land bordering the Atlantic and the project was initiated.

This project began in 1999 after it was discovered that a fisherman in Jamaica caught a tilapia in his seine net. Further investigations were carried out at the fisheries complex at Twickenham farm in Jamaica, where experimental brood ponds were in operation. The information received provided a departure towards a non-traditional approach and technique for farming tilapia. The site on the Atlantic coast was more appropriate because waste water from city buildings and dwellings along the several ghauts running through Basseterre made their exit in the Caribbean Sea. Other private sector donors have since provided additional lands and the Government of Australia has contributed substantial project development funds. Locally, duty-free concessions on an item-by-item basis have been also granted to the project. The project currently farms freshwater tilapia in 100 percent Atlantic seawater.

DEVELOPMENTAL ISSUES THAT MUST BE ADDRESSED

Any attempt to successfully develop an aquaculture industry must ensure that consideration is given to policy, funding, land availability, water quality and suitable feed. Some of these issues are now discussed.

National Policy

The introduction of Aquaculture as an industry or sector must be developed within the context of a national policy. Without a sound policy, allied government departments will not acknowledge their required input, or commitment. Unfortunately, the practice of divorcing aquaculture from agriculture is a not a well-informed practice, certainly not an industry best practice. This situation can be corrected by any Ministry of Agriculture through its programme development department, or as a planned and funded aspect of a Department of Marine Resources.

Water quality and availability

In the aquaculture project in St Kitts, the principal operational challenges included water quality and availability. The seawater environment necessitated the use of corrosion resistant water pumps. However, the turbulence in the ocean at times resulted in PVC pipe abrasion, due to incessant wave action and pipe contact with reefs. Other minor problems included draft tides and excessive seaweed flow at the intake point. The Atlantic is never calm, and the threat of a devastating hurricane has been heavily factored in the design of the fish ponds. They are 5' above ground, with a protective canal on the periphery as a flood/sea defense. This canal also serves as a capture facility for total pond harvesting.

Praedial larceny

Praedial larceny also presents a challenge both at the fingerling and adult stages. There is need to strengthen the relevant laws and ensure their enforcement. To a lesser degree, there is also competition from birds. Many creative solutions have been attempted, but the most effective deterrent has been the introduction of large eyes and scarecrows, strategically located around the periphery of the fish ponds.

Adequate funding

Adequate funding for the project was a major challenge as the banks were skeptical when told of the plan to grow freshwater fish in seawater. This would not be quite as difficult if fresh water aquaculture was proposed. Funding agencies also preferred to work with cooperatives or associations. Traditionally, research and development activity depend to a large extent

on grant funding. Unfortunately, due to the global economic dilemma, such funding sources have suffered drastic contraction. It is hoped that the successes of SNAPPER will encourage government's participation towards establishing a national aquaculture sector.

BACKGROUND TO THE INVENTION

The present invention relates to the employment of new techniques in the acclimatization of the freshwater fish (tilapia). Through a structural configuration and manipulation, the processes enabled 15-day tilapia fry to be transferred to full strength seawater, resulting in their ability to drastically reduce chances of mortality. The invention is based, not only on concepts developed previously, but also on researcher observations.

Based on the fact that seawater was the only water in abundance, primary assumptions were made and subsequent assumptions evaluated. These evaluations and successes resulted in a more resolute approach to experimentation.

The initial evaluations entailed experimenting with species of tilapia (namely *O. mossambicus* & *O. niloticus*). The inventor was able to test the efficacy of assumptions on two selected species cross between *O. mossambicus* and *O. niloticus*, on a research farm in Conaree, St Kitts, West Indies.

Salinity, temperature, dissolved oxygen and the maintenance of a pH of between 6.5 and 7.5 were continuously monitored. Acclimatization was the most problematic hurdle as challenges in the research to determine a suitable stage of commencement, and all the other factors that had to be solved. At seven years into the project cycle, acceptable success began to emerge. In year nine, a reliable and proven acclimatization process was perfected. This is now known as 'trickle acclimatization'.

The Jamaica red snapper was the fingerling of choice. This invention involves the acclimatization of a cross between *O. mossambicus* and *O. niloticus*, for use on islands where suitable freshwater resources are limited.

PROJECT OBJECTIVES

The main objectives of the project were to:

- develop an appropriate technological procedure for small island states aquaculture development, where natural freshwater supply is limited or non-existent;
- establish the shortest time frame for acclimatization;
- minimize the mortality rate in the conversion process and
- encourage reproduction and satisfactory growth in seawater.

PROJECT START-UP AND CHALLENGES

The following is the approach to implementation that was used in St Kitts:

- Lining up the ponds in the traditional wind flow in order to reduce energy consumption for aeration purposes.
- Ensuring that ponds were above ground level, in order to counter hurricane flooding. Five ponds 100' x 25' x 4' were lined with the thick non-leaching polyurethane plastic (*geo membrane*). The lining was laid seamless by tucking the corners up and tacking the material when the sun was hot, on a frame, then backfilling to the required height.
- Piping was the next challenge. Initially the Atlantic feed was difficult to stabilize, but a 4' cast iron sleeve with a 2" schedule 40-PVC pipe threaded into it proved to be successful. A foot valve and strainer were attached to the end, which was cleaned regularly, due to seaweed and sand. At 150' from foot valve to draft pump, priming was problematic, but solutions were found. One and a half miles of pipe were laid for freshwater, saltwater, groundwater, and included a 4" manifold reduced to 2" and then to 1/2" for aeration distribution.

In the third year of the project, saltwater research began. Expertise from universities in Taiwan, Norway and the SKN local fisheries department advised that the level of tolerance to be expected should be 50/50 or at most 60/40, the greater being seawater.

There were massive fish kills on numerous occasions, due to excessive algal growth (green water culture constituted the first experiment), heat during June–August, and excessive salinity. Each of these problems had to be solved as they occurred. Water quality, pH levels, temperature and other measurements were also monitored and addressed. The salinity increased which resulted in 'corned fish' due to topping up the ponds with Atlantic sea water. The continuous evaporation by wind and sun removed the fresh water, resulting in increased salt levels. The heat problem was easy to solve. Partial shade using shade cloth reduced high temperatures and a continuous flow of water, (the flow-through system) addressed salinity, pH, aeration and temperature. A return path through the sand under the ponds and back to ground water, addressed the environmental problem. Contamination of the reef and reef life was also avoided. As a plan 'B', a powerful Rotron Regenerative blower which powers eight air stone ponds is used on windless days.

Acclimatization was the biggest research problem; to determine commencement acclimatization stage, and all the other associated factors that had to be solved. It is now ten years into the project cycle with acceptable success, except for petty larceny of fish and visits from fishing birds. The bird problem has been solved with dogs on pond long length

guide wires and anti-predator piano wire covering the area at 6” apart. The following details patent application information, which describes the SNAPPER process and claims.

SUMMARY OF ACTIVITIES

This invention relates to a trickle regime of one part per thousand of seawater over 14 days with tilapia cross (*O. mossambicus* and *O. niloticus*) fry 9–14 days old, and fed a powdered tilapia fry feed at the rate of one percent of body weight, every two hours for 14 days, or the encouragement of a suitable algal growth in the nursery pond.

Other objects and features of the present invention include piggy-backing during the sex-reversal process whereby sex-reversal and ‘trickle acclimatization’ can be a simultaneous procedure. Two methods of doing this are now described.

Example 1

Five hundred tilapia fry were selected from a freshwater brood pond at two to nine days and transferred to an algae rich pond. After seven days, the trickle acclimatization process begins and continues for 14 days. When the salinity level of the conversion pond and the pumped-in seawater synchronize, the fry are moved to a flow-through holding pond and then allowed to grow to fingerling size for final sexing.

Example 2

The protocol of Example 1 was repeated with the inclusion of sex reversal feed. Five hundred fry were selected from a freshwater brood pond at two to nine days and transferred to a clear seawater pond. Simultaneously, trickle acclimatization and sex-reversal (feed at a ratio of one part sex-reversal formula to nine parts regular powdered tilapia pellets, are fed at one percent of body weight every two hours) were done. After 14 days, the trickle acclimatization process is subjected to a salinity test. When the salinity level of the conversion pond and the pumped in seawater are synchronized, the fry is moved to a flow-through holding pond and they are then allowed to grow to fingerling size for final sexing.

Evaluations with Jamaica red snapper cross between *O. mossambicus* and *O. niloticus* have revealed positive results, including good colour, good appetite and brisk swimming movement.

The results of evaluations of the application of sex-reversal feed in the process, revealed no significant difference in the adaptability of the fry to full strength seawater.

It should also be noted that although the growth rate could be considered slower in seawater, and fry production somewhat less, the results were largely positive.

PATENT APPLICATION

Below is an extract of the Patent application of the invention.

**Method of Growing Tilapia in Full Strength Atlantic Seawater in St Kitts
The St Kitts and Nevis Aquaculture Pilot Project & Environmental Research (SNAPPER)
(First Published March 03/04/06)**

Abstract

Small islands with no rivers, running streams, freshwater ponds or clay, have always had to forego initiatives to develop aquaculture (fish farming). With the rapid general depletion of fish in the Caribbean, and St Kitts in particular, the island was forced to import fish for their growing tourism industry, as well as domestic consumption. It was, therefore, critical to develop appropriate technology which facilitated the use of available seawater. In addition, the system aids replication. As a result, the inventor developed a system which is called 'trickle acclimatization'. This system is applied during two processes namely, during (a) sex-reversal or (b) mixed sex acclimatization. This included basic management of factors such as pH, dissolved oxygen, temperature and salinity. After grow-out, the fish was able to reproduce in seawater, albeit at a general reduction rate of 20 percent.

This application was presented as a primary document for a patent search and processing.

Inventor: Barrington E. O. Brown Ph.D. (St Kitts, West Indies)

Assignee: The St Kitts and Nevis Aquaculture Pilot Project & Environmental Research (SNAPPER)

Appl. No.: XXXXXXXXXXXXX

Filed: March 2011

Current U.S. Class:

Current International Class:

Field of Search: International

Claims

1. What is claimed?
2. A method of “trickle acclimatization” to full strength seawater of the Jamaica Red Snapper (*O. mossambicus* and *O. niloticus*).
3. A method for increasing the rate of survival and commercial growth
4. Methods of ensuring commercial reproduction in seawater

Areas of Analytic Focus

- the acclimatization of a cross between *O. mossambicus* and *O. niloticus*, for application on islands where limited suitable freshwater resources exists.
- appropriate technological procedure for small island states aquaculture development, where natural freshwater supply is limited or non-existent.
- to provide the shortest time frame for acclimatization
- to minimize the mortality rate in the conversion process
- to encourage reproduction in seawater.

SHARING EXPERIENCES AROUND THE REGION

In the CARICOM region, Jamaica, Trinidad and Tobago, and Guyana have developed significant freshwater tilapia farms and have expressed interest in the developments.

For general Aquaculture Technical assistance, arrangements can be made through each country’s Ministry of Agriculture, or Department of Marine Resources, or the Department of Marine Resources in the Federation of St. Kitts and Nevis, through the St Kitts and Nevis Aquaculture Pilot Project which is available for any follow-up that you may require. The author’s contact information is included in this chapter.

SNAPPER would be prepared to share experiences with anyone who is interested.

CONCLUSION

The foregoing discussion was presented for both traditional freshwater aquaculture aspirants, as well as for those persons who live in countries or islands with only seawater. The saltwater technology and processes are unusual with attendant drawbacks, but possible. It is presented here as an alternative to traditional inland aquaculture systems.

Both approaches require basic knowledge and a serious commitment to routine attention. However, a disciplined approach ensures predictable results. An attachment to a working farm or advice from a knowledgeable person is advised before starting a project.

The Aquaculture industry has grown by leaps and bounds over the past ten years and is poised to increase faster as the depletion of marine fish escalates. A proper research of the local market would be a prerequisite to develop a market-driven approach to planned production; this will help producers to match growth with local demand.

The SOFRECO consulting team observed that, ‘currently, fishing is not attractive to the younger generation, but Aquaculture however, may show business qualities which the next generation may be attracted by.’ It was further observed, that, ‘a higher domestic supply of seafood would obviously create competition’. However, it is predicted that the consumption of seafood would increase with a higher quality supply of marine fish, and this could possibly push down prices of freshwater fish fillet imports, which could eventually lead to these fish fillets being more competitive against imported chicken broilers. Whether this will actually materialize or not remains to be seen. It was further thought that freshwater or farmed fish was likely to become more important.

Aquaculture contribution to food security, as a protein source worldwide was also examined, with the opinion offered that unlike its current status, farmed fish could be produced more cheaply than other animal proteins. The team also felt that: ‘The question however is: can freshwater fish be sold at the same profit margins as chicken broiler?’ Only time will tell!

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Figure 10.4: Shade house with tomato crops, Dekade, Haiti



Figure 10.5: Shade house with cabbage crops, Makaya, Haiti



Figure 10.6A: Greenhouse with vertical hydroponics system



Figure 10.6B: Outdoor irrigation controller



Figure 10.10: XPSM 300 designed by S. LaPlace (aeroponics/nutrient film technique and ebb flow)



Figure 10.11: Sweet Bell Pepper and Cucumber 2011



Figure 10.12: Hydroponics system used by students and faculty for on-going research in crop production



Figure 10.13: Initial system run with 17 different crops

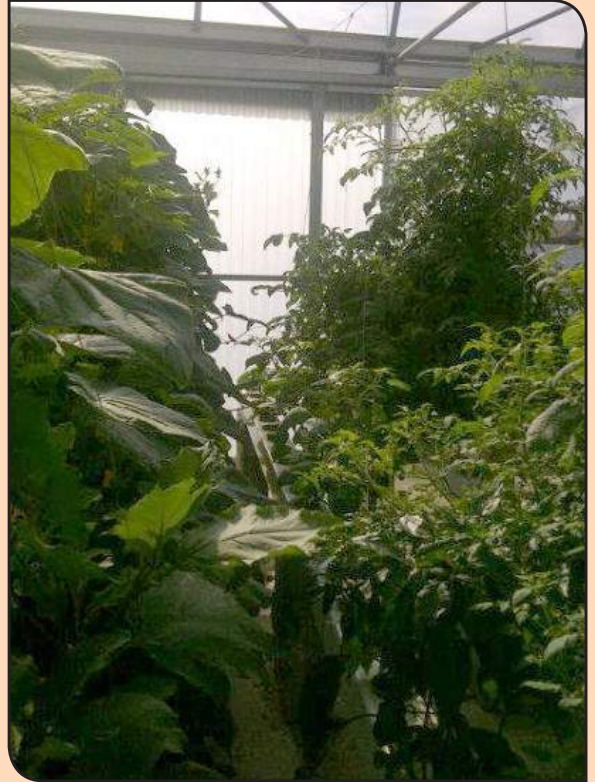


Figure 10.14: Strawberries with limited phosphorus



Figure 10.15: Eggplants blooming



Figure 10.16: Lettuce in hydroponics in 2008



Figure 10.17: Kentucky String Beans in 2012



Figure 10.18: Cabbage 2009



Figure 10.19: Yellow Bell Peppers in 2013



Figure 10.20: Student observing plant growth in hydroponic system at CFBC Plant Research Facility



Figure 10.21: Detail of recent price-saving adaptation of hydroponic system using 5-gallon buckets to contain nutrient solution.



Figure 10.22: Students at CFBC sowing seeds in a hydroponics system



Figure 10.23: Lettuce under 30 percent shade @ 23days in hydroponics system



Figure 10.24: Lettuce under 50 percent shade @ 23 days in hydroponics system



Figure 10.25: Iceberg lettuce under 30 percent shade @ 38days in hydroponics system



Figure 10.26: Iceberg lettuce under 50 percent shade @ 38days in hydroponics system



Figure 10.27: CFBC students preparing organoponics planting trays with plastic lining



Figure 10.28: CFBC shade house design with hydroponics to the right and organoponics to the left



Figure 10.30: CFBC students transplanting seedlings from hydroponic to organoponic planting trays



Figure 11.2: Fruit trees planted on hillside terracing with forest species at the St. Michael's Station, Tacarigua, Trinidad



Figure 11.3: Fruit trees (mango) and forest species used for soil erosion control



Figure 11.4: A mix of coconut, fruit trees and forest species planted on a sloping hillside



Figure 11.5: Caribbean pine grown with other fruit trees



Figure 11.6: Taunga system in which cocoa and bananas are planted with forest species (cedar and mahogany)



Figure 11.7: Breadfruit intercropped with Caribbean pine



Figure 11.8: Livestock (cattle farming) under coconut trees in Cocal, Trinidad



Figure 11.9: Aquaculture with food crops (bananas and plantain) and forest species (cedar). The agroforestry system belongs to Mr. Jagessar Dan of Rio Claro, Trinidad.



Figure 11.10: Tilapia fishes grown in agroforestry system are an important and healthy food source



Figure 12.1: Pond at SNAPPER project



Figure 12.2: Tilapia Feeding



Figure 12.3: Demand Feeder System



Figure 12.4: Jamaica Red Snapper (Tilapia Hybrid)



Figure 12.5: Typical Tilapia Farm Tour



Figure 12.6: Snapper Project Coordinator Conducting Farm Tour



Figure 12.7: Dr Barrington Brown (L) Project Coordinator (SNAPPER) and Mr Samuel Heyliger, Senior Fisheries Officer, Department of Marine Resources, St Kitts

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Dr. Mark Wuddivira is a Senior Lecturer in Soil Science (Soil Physics) at the University of the West Indies (UWI), St. Augustine Campus, Trinidad and Tobago. Dr. Wuddivira obtained his B.Sc. General Agriculture and M.Sc. Soil Science from Ahmadu Bello University, Zaria, Nigeria, and Ph.D. Soil Science from the UWI. He is a member of the Soil Science Society of America and an executive member of the Caribbean Academy of Sciences, Trinidad and Tobago Chapter. His research interests are in the area of soil water management, intense tropical rainfall effects on soil physical behaviour, soil water characteristic in tropical ecosystems, and soil geophysical imaging using electromagnetic induction. He has co-authored several peer-reviewed articles in respectable journals.

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SUSTAINABLE FOOD PRODUCTION PRACTICES 2 in the Caribbean

In this second volume on *Sustainable Food Production Practices* appropriate for the Caribbean region, Editors Wayne Ganpat and Wendy-Ann Isaac have achieved a seamless transition from the first volume in putting together a blended collection of sustainable best management practices that were not previously covered.

The topics in this volume range from a focus on small producers, family farms and women farmers, and the role of youth in agriculture to appropriate agro-systems and agricultural diversification and non-traditional systems. Sustaining the environment while increasing and improving production is a major concern and this is addressed by chapters on natural and indigenous crop protection methods and sustainable water management systems, among others.

The quality and relevance of the information in the 12 chapters making up this volume provide essential reading for students in agriculture both as reference material at the undergraduate degree level, and as a main course text, particularly for those pursuing diplomas in agriculture, and students preparing for the CXC® Caribbean Advanced Proficiency Examination (CAPE®) in Agriculture and Food Production.

Although the two volumes provide useful resources for the Caribbean region's Extension practitioners, their content is also relevant and appropriate for tropical agriculture, generally. As in volume one, the emphasis in the text is on simple jargon-free descriptions, instructions and recommendations, supported by a variety of charts, tables and diagrams and numerous full-colour photographs.

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