PROTECTED AGRICULTURE IN JAMAICA

A REFERENCE MANUAL

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*Photographs courtesy of Luke Lee, Marci Spaw, Kim Williams, and Autopot Systems.

In Support of Protected Agriculture

Protected Agriculture strategies have proven to increase certainty for food production through adverse weather conditions while providing viable alternative livelihood opportunities to rural communities. As the revitalization of the agricultural sector continues, the Ministry of Agriculture is adopting new technologies and farming techniques to meet the evolving needs of the sector.

The United States Agency for International Development (USAID), in collaboration with the Rural Agricultural Development Authority (RADA), has created this manual- *Protected Agriculture in Jamaica*, at a pivotal time in the development of Protected Agriculture in Jamaica.

As the Ministry is promoting the ‘Grow What You Eat and Eat What You Grow’ campaign and USAID is working to revitalize and support the protected agriculture sector, this reference manual serves to fill the technical gap in the industry.

Minister of Agriculture cutting the ribbon at the HEART NTA Protected Agriculture Training site

It is a shining example of a bi-lateral donor and the Government of Jamaica collaborating to meet a need within the extension service and with growers alike. It is a homegrown effort that will serve not only USAID projects but the people of Jamaica and stakeholders who are investing their time, resources, and expertise in the development of Protected Agriculture.

USAID must be commended for its contributions to the revitalization of Protected Agriculture through the ‘USAID Jamaica Business Recovery Project’ which since Hurricane Ivan has reintroduced greenhouse technology for the production of fruits and vegetables. Through those endeavors, Jamaica has seen an increase in the number of greenhouses from 10 to 86. There are now over 14 acres under production in protected structures, a number that is sure to increase within the next year. As the numbers of greenhouses in production increase, a training manual such as this is even more crucial to ensure growers are able to reach their full potential.

In addition, the USAID-funded Rural Enterprise, Agriculture and Community Tourism Project sought to develop the greenhouse sector and built improved steel versions of the greenhouses after Hurricane Dean. RADA and the Ministry of Agriculture are thankful for the Jamaica Farmers Access to Regional Markets (JA FARMS) program for the introduction of low-cost units and its work with small-holding farmers across the country. JA FARMS validated the technology with small farmers and introduced this alternate method of greenhouse farming to hillside farmers and spearheaded the creation of this manual.

In addition, the Integrated Pest Management Collaborative Research Support Program (IPM CRSP) worked closely with the Caribbean Agricultural Research and Development Institute to develop the Exclusion Cages for environmentally-friendly production of callaloo which has positive food safety effects for the consumer.

Overall USAID and its partners have done a commendable job on this manual and the Ministry of Agriculture thanks them for their efforts. I fully endorse this reference manual and the validity of its usefulness among our extension staff and greenhouse growers alike.

Dr Christopher Tufton
Minister of Agriculture
October 26, 2008

TABLE OF CONTENTS

INTRODUCTION

In the 1980s, Jamaica's protected agriculture sub-sector primarily consisted of producing cut flowers for export. However, it experienced a shift when increased competition from South America and an influx of disease caused the majority of these agri-businesses to close.

More recently, increases in hurricane activity in the Caribbean Basin and other adverse weather conditions, international market competition, and plant disease have threatened the quality and consistency of Jamaican food production as well as domestic food security. As Jamaica works to meet new challenges in the global marketplace and seeks to address growing domestic and export market demand, the agriculture sector has the potential to benefit greatly from increased usage of agro-technologies such as greenhouses and other protected agriculture structures while developing a stronger, more reliable network of agricultural supply chains.

Protected agriculture technology includes more traditional style greenhouses as well as high tunnel houses and is the central component in the establishment of a more unified strategy for continued growth in the country's agriculture sector. The sustainability of such development will essentially rely on the effective transfer of knowledge. This manual is designed to build the knowledge base of the Jamaican agricultural extension service, the Rural Agriculture Development Authority (RADA), so that it in turn can provide support and training to the members of Jamaica's burgeoning agricultural sector.

Incorporated into this manual are North American concepts, the local Jamaican experience, and lessons learned from Central America to provide the most up-to-date knowledge and technology currently available. The manual has undergone extensive reviews by expert local practitioners, agriculturalists, researchers and academics. A Curriculum Review Committee was established comprising of local growers, agriculture officials from the Ministry of Agriculture (MOA), RADA officers and overseas specialists in the United States of America and Canada. This committee provided invaluable feedback to ensure that the content of this manual is suitable for the Jamaican context.

The Protected Agriculture Training Manual serves to close the present gap in knowledge and technology transfer in three ways:

1) It serves as a single repository of knowledge, best practices and lessons learned in protected agriculture;

2) It serves as a training manual designed to be implemented through the RADA training division to upgrade Extension Officers' skills; and

3) It serves as a reference point for a local comprehensive certification program in Modified Environment Agriculture at the HEART Ebony Park Academy, the first of its kind in Jamaica.

All three uses share the underlying goal of encouraging the local population to embrace the opportunities and benefits of the growing sub-sector. The following protected agriculture benefits are currently being realized in both North and Central America and are replicable in Jamaica:

- Increased yields;
- Improved quality and consistency of crops;
- Improved land and water use efficiency;
- Increased control over crop nutrition;
- Decreased use of chemicals and pesticides;
- Improved resistance to adverse weather conditions;
- Increased control over insects and diseases;
- Reduced external and biological crop threats.

The Protected Agriculture Training Manual seeks not only to ensure the sustainable use of the technology, but also to ensure that investors in greenhouse structures will receive the required technical assistance from RADA. The manual uses a holistic approach to protected agriculture and embraces agro-ecological principles. This approach is not only environmentally friendly in addressing food safety concerns, but also serves to further conservation objectives in ecologically significant areas of Jamaica.

The manual is deliberately designed as a "living document"; as Jamaica embarks on its plan to increase food security through use of appropriate agro-technology, the government will be able to update the manual to capture future lessons learned for both the short and long term. The modular design of the manual ensures that as technologies evolve and protected agriculture expands in Jamaica, this invaluable resource can be easily updated and allowed to grow with the sector. RADA extension officers participating in protected agriculture trainings will benefit from a well-integrated training curriculum consisting of crop bulletins, hands-on training in greenhouses, classroom training and additional technical hand-outs.

Capitalizing on these developments in protected agriculture will strengthen the agriculture sector in Jamaica and will subsequently generate growth in other sectors.

Module 1

PROTECTED AGRICULTURE STRUCTURES

INTRODUCTION

Throughout the world various structures have been used to manage the 'growing environment' in order to increase control over quality and productivity. In recent years, the recognition that Jamaica could benefit from such a managed environment has brought increased interest in protected agriculture structures. In Jamaica, these structures are being designed to achieve optimal growth conditions as well as to mitigate damage to the structure from external conditions and to speed crop recovery time in the event of a hurricane or other severe weather event.

In Jamaica, as in other parts of the world, the local climatic conditions as well as the topography are important in selecting the style of protected agriculture to construct. For example, at higher elevations (above 400 m/1,312 ft), such as the mountainous regions around Christiana (Manchester) and Mount Airy to Mavis Bank (St. Andrew) cooler temperatures prevail. These conditions are particularly well-suited for an antiviral mesh covering to exclude insects (and insect-borne viruses).

At lower elevations, higher temperatures limit the practical use of antiviral mesh because it impedes ventilation resulting in heat build-up inside the structure. Average daily temperatures above 35°C (96°F) will hamper crop performance and restrict productivity. Consequently, open-siding or shade cloth are preferred coverings to allow increased airflow for cooling. Protection from pests in these areas will rely on the use of pesticides and/or virus-resistant cultivars.

The structure's form, its orientation, materials used, unit cost, and the type of crop to be grown are additional important factors to consider in planning and construction decisions. This consideration includes recognizing that all factors are interdependent. For example, in establishing the orientation of your structure you must consider both ventilation needs and light requirements.

This module covers:

1. Structure Types
2. Ventilation
3. Structural Loads
4. Site Selection
5. Construction Materials
6. Covering Materials
7. Additional Considerations

STRUCTURE TYPES

Protected agriculture structures can be constructed in a variety of styles that range from shade houses to high tunnels to large gutter-connected houses. Small stand-alone houses typically utilize a two-roof single ridge construction and offer the advantages of a low overall initial investment and flexibility of operation. However, they are generally more expensive to construct on a square foot basis. By connecting individual units or bays at the eave or gutter a gutter-connected structure can be formed. Each bay's roof can be either a gable or an arched structure or can be sloped to form a saw-toothed roof.

Low Tunnel Structure

LOW TUNNEL STRUCTURES

Low tunnels, also known as mini-tunnels, are only 0.6–1.0 m (24-39 in) in height and cover low growing crops such as cabbage and lettuce. Mini-tunnels are created by hoops covered with a lightweight, synthetic fabric. The structures utilize floating row cover material supported by small hoops with the floating material usually secured by covering the edges with dirt. The use of mini-tunnels protects plants from pests like aphids, thrips, and leaf-feeding beetles and can also be used as a temporary sun-shade.

HIGH TUNNEL STRUCTURES

The term 'high tunnel' generally refers to a structure that is passively ventilated and no more than 9m (30ft) wide. Most high tunnels are ventilated via roll-up sidewalls and end walls that can be opened or removed. They are considered temporary structures because they can be easily dismantled for movement to a different location or in times of severe weather. High tunnels are tall enough to walk in comfortably and to grow tall, trellised crops such as tomatoes. In Jamaica, they usually include mesh screens at the ends for venting and pest control.

High Tunnel House

RIDGE VENTILATED STRUCTURES

Ridge ventilated structures, which can have a single or double ridge, have a relatively large, continuous, open roof ridge to provide ventilation. Single-ridge and double-ridge are two relevant design types. The two roof single-ridge structures are normally 9-12 m (30-40 ft) wide and 29-61 m (96-200 ft) long. Commercially available polyethylene sheets easily cover this size. These structures are naturally (passively) ventilated and are better suited to higher elevations, preferably at least 400 m (1,312 ft) above sea level. Structures of this size normally result in a roof higher than the acceptable range for gutter connected structures, which are usually mechanically (actively) ventilated, and they should be designed so that air does not have to travel more that 37 m (120 ft) to an opening to ensure minimal temperature gradients within the structure. The benefit of the double-ridge design is that it allows for heat dissipation regardless of the wind direction whereas the single ridge design is less efficient if the wind is coming from the opposite direction as the ridge opening. An additional benefit to ridge ventilated structures is the higher sidewall, which alleviates the issue of heat getting trapped in the canopy of the plants, a common problem experienced with structures having lower sidewalls.

Double-ridge structure

Two roof single-ridge structure

GREENHOUSE STRUCTURES

A greenhouse is considered a permanent structure. Greenhouse structures provide a greater level of control than high tunnel houses whether they are actively or passively ventilated. The structure also provides more control of the environment, which often translates into higher yields. However, these highly engineered structures require high levels of crop production management and are often cost prohibitive for growers in Jamaica.

Below is a table comparing the estimated construction cost of different protected agriculture structures in Jamaica.

CONSTRUCTION COST OF SELECTED PROTECTED AGRICULTURE STRUCTURES
Estimated cost of structures commonly constructed in Jamaica since 2005

DESIGN	FEATURES	AREA M^2 (FT^2)	TOTAL COST (JA $)	COST/SQ. M (JA $)
Fiddlestick High Tunnel	Fiddlewood Shade Cloth	65 (700)	40,000	615
Fiddlestick High Tunnel	Fiddlewood Shade Cloth	195 (2,100)	120,000	615
Commercial Lumber High Tunnel	Treated Lumber Shade Cloth	195 (2,100)	188,000	964

Tunnel Roof Vertical Vent	Metal Pipes Insect Screen	270 (2,900)	560,000	2089
Gable Roof Vertical Vent	Local Lumber Insect Screen	490 (5,300)	920,000	1878
Gable Roof Vertical Vent	Treated Lumber	600 (6,500)	1,200,000	2000
Gable Roof Horizontal Vent	Treated Lumber Insect Screen	670 (7,200)	1,310,000	1955
Imported Tunnel Roof Vertical Vent	Metal Pipe, Insect Screen	900 (10,000)	2,430,000	2700

VENTILATION

In general, air temperature inside the structure is comparable to the outside temperature but this does not mean that good ventilation is not important. There are two categories of ventilation in the greenhouse industry: active ventilation and passive ventilation. Active ventilation is also known as mechanical ventilation with one example being the use of exhaust fans. Another active method is fan and pad cooling, which is often employed in North America and other similar climates (and in the poultry industry in Jamaica). Passive ventilation has low energy requirements while still providing high ventilation rates with an even temperature gradient inside the structure; an example of passive ventilation is an open ended structure. Although both are effective, active ventilation is often cost prohibitive for the Jamaican market. Fortunately, Jamaica's climate lends itself to the benefits of passive cooling; therefore, it is crucial to understand some key factors of passive ventilation for successful results.

PASSIVE VENTILATION

Passive ventilation is also known as natural ventilation and is accomplished by air coming in one side of a structure and flowing out the other. In some structural designs, wind creates vacuum pressure as it blows over the roof vent causing air to be sucked out of the structure. Even if there is no wind ventilation occurs by the hot air from inside the structure rising to the top and pushing cooler air down towards the crop. This demonstrates the principal of buoyancy, commonly dubbed "hot air rises", and is the same principle as what gives lift to a hot air balloon. Buoyancy, as applied to protected agriculture structures, occurs because moist air is denser than dry air. This may not be intuitive because we think of water as very dense, but that when it is in its liquid state. Water in its vapor state is less dense than the surrounding air and therefore rises upward. For temperature regulation to take place it is important for hot, moist air to have a clear path up and out of the structure to its ultimate destination - forming clouds in the atmosphere. Though this is a relatively simple concept, two factors - structure orientation and structural design - impact the success of natural ventilation in the structure.

STRUCTURE ORIENTATION

Structure orientation is crucial to maximize the efficiency of passive ventilation. For gutter-connected multi-spans, a combination of windward side vents and continuous leeward roof vents tends to result in the most effective ventilation design. For retractable roof designs, open windward side vents are as important as the open roof area to achieve cooling.

STRUCTURE DESIGN

Though the ventilation rate is highly dependent on wind speed and direction, it is important to have an effective inlet that moves through the plant canopy on its way to an outlet. The ventilation outlet area should open leeward and be at least 30% of the total square footage of the floor area. With higher gutter heights it is more effective if the windward side is aerodynamic (opens only on the leeward side).

STRUCTURAL LOADS

Structural loads need to be taken into consideration with regards to the integrity of the structure. For example, a strong wind in St. Ann lifted a tunnel house and wrapped it around a tree. Wind and rain are not the only risks to structural integrity though. A greenhouse once collapsed because of the weight of full-grown tomato plants on the trellising system attached to the greenhouse frame.

DEAD LOADS

Loads are stresses to the structure from external or internal forces. Dead loads are gravity loads, weight acting usually in a vertical direction and that is constant throughout the structure's life. These include fixed equipment such as HAF fans. Long-term crops that are suspended from the frame, such as trellised tomatoes, are also considered dead loads.

LIVE LOADS

Live loads are temporary or short-term in nature. These include wind loads or any other environmental stress. Rainfall is also considered a live load. Live loads are measured in both volume and intensity. Wind loads can come from any direction but usually act against the sidewalls by hitting them at a perpendicular angle. 71 km/h (44 mph) wind creates a live load of 24 kgf/m^2 (5 psf) whereas 100 km/h (62 mph) wind creates a 49 kgf/ m^2 (10 psf) live load. Basic wind speeds that greenhouse structural designs are designed to withstand are 145 km/h (90 mph); high tunnel structures are generally not framed to withstand gusts of this magnitude and steps should be taken to protect the structure, such as removing the covering if this strength of wind is predicted. Structures placed perpendicularly to prevailing winds typically receive the most damage so it is important to know the prevailing wind direction for a given location when deciding on a structure’s orientation. Additionally, decreasing rib spacing from 1.5 m (5 ft) to 0.9 m (3 ft) intervals increases the amount of load that a structure can carry by 66%.

SITE SELECTION

ORIENTATION

In temperate climates, orientation is a major consideration as it is crucial to avoid shadows by other structures and to balance the amount of light available throughout the day given the heliotrophic nature of plants. However, at the latitudes of Jamaica, any orientation should be adequate and light is not a limiting factor. Special consideration should be given to protected agriculture structures that are located on hillsides so the topography does not shade the structure during sunrise or sunset.

LIGHT

Good sunlight is needed for successful growing in protected agriculture structures. A minimum of 2,000 foot candles (fc) is necessary. Full, unobstructed sunlight has an intensity of approximately 10,000 fc. An overcast day will produce an intensity of around 1,000 fc. As stated earlier, light is generally not a limiting factor in Jamaica.

SOIL

Though it may be tempting to select an unproductive field site for the protected agriculture structure, good soil quality is important. Soil should be well-drained to avoid water-logging and flooding. Tomatoes are particularly sensitive to the lack of oxygen in a waterlogged environment. Amending soil with compost, peat, or other organic materials to improve drainage and quality is suggested when utilizing a protected agriculture structure. Where access to good quality soil is not available, soil-less cultivation systems should be considered.

Metal-frame structure being constructed on elevated pad

TOPOGRAPHY

The protected agriculture structure is most productive if built on a slightly elevated earthen pad that is three feet larger than the structure in all directions. The interior pad of the high tunnel should be level with a slight slope to the exterior for drainage. The pad should be high enough to prevent excess rain water from flowing into the structure, especially if the structure is built in a low-lying area.

WATER SUPPLY

It is important to identify water availability and quality when selecting the site for the protected agriculture structure to ensure successful production. An outside irrigation source is required because crops will obviously not receive moisture from rainfall. Calculating if adequate water supply is available to support crop production is crucial. A general rule of thumb is that each plant requires two liters of water in a single application. With that in mind, a simple calculation can determine how much water is sufficient. For example, a structure that is 60 m^2 and maintaining a plant density of .37 m^2 per plant would support approximately 162 plants. 162 multiplied times 2 liters of water equals 324 liters of water at each application. This is only a rough estimate that does not address frequency of water application and different water requirements at different stages of plant growth It does, however, provide a place to start when reviewing water needs and water supply.

Using municipal water is often cost prohibitive for small holding growers; water sources commonly used in Jamaica are ponds, bores, and rainfall collection. River water is less ideal as it may contain disease-causing organisms and may require filtration to remove silt and other particulate matter that might clog irrigation systems.

Water should be professionally tested to determine the chemical composition and pathogen load before significant resources are invested in a particular water source (the Rural Physical Planning office provides this analysis). A water pH between 5.0 and 7.0 is desired as levels outside that range may hinder absorption of nutrients by the plant. A common problem in Jamaican water sources is a high level of alkalinity (a pH above 7.0), which can lead to clogged drip irrigation lines and crop growth problems related to high pH. Additional criteria for good water quality are discussed in *Module 5: Nutrient Monitoring*.

CONSTRUCTION MATERIALS

Construction materials must fit the requirements of the structure and allow for the needs of the plants to be grown in a specific environment. Note that interactions between some materials such as polyethylene and PVC pipe may be incompatible and will shorten the lifespan of materials.

Structure under construction using a metal frame in Middlesex

FRAME & FRAMING MATERIALS

The frame supports the structure and must withstand various stresses or "loads." To add strength to the frame, a number of strategies can be employed:

- Drive posts 46-61 cm (18-24 in) into the soil;
- Use heavier gauge metal pipe for the ribs;
- Add more than one purlin (horizontal cross-bracing) to the structure;
- Decrease the spacing between the hoops;
- Fasten plastic glazing tightly to the structure;

Note cross-bracing on the end-walls of this metal frame structure

In general, structures without sidewalls or with short sidewalls are stronger than structures with higher sidewalls.

POLYVINYL-CHLORIDE (PVC) PIPE

PVC is an inexpensive plastic material used for rib construction and is lightweight and easy to maneuver. However, this lowest cost material is also one of the weakest. Protected agriculture structures made from plastic hoops are vulnerable to wind uplift, and PVC expands and contracts with temperature changes.

WOOD

Lumber is often a component of end walls, hip boards, and baseboard construction in protected agriculture structures. Some indigenous wood species are long lasting, but should be used only if harvesting is permitted by the government. If wood is used for rib construction, proper specifications must be followed to avoid points of weakness (e.g., a splice mid-span). Treated lumber should be used for baseboards and any other wooden structural components that will come in contact with the soil. Importantly, however, avoid wood treated with Copper Naphatenate as it can be toxic to some plants.

METAL PIPE

Metal pipe is the strongest framing material for rib construction. Quality ranges from electrical conduit pipe on the weakest end to 4.8 cm (1.9 in) OD (outside diameter) thick steel or schedule 80 water pipe as the strongest materials used for protected agriculture construction. Schedule 40 (3/4" galvanized water pipe) is commonly used but results in a 20% weaker structure compared to using Schedule 80 pipe. A negative of using metal pipes is that metal ribs make the structure very heavy and difficult to maneuver.

Metal framing components are beginning to be manufactured on the island. This creates economic benefits in other sectors of industry in Jamaica.

Structure in Christiana constructed with wood frame and metal ribs

Pipe bender used to manufacture metal ribs in Christiana

COVERING MATERIALS

POLYETHYLENE

Greenhouse-grade polyethylene, a kind of plastic sheeting, is the most common material used for covering protected agriculture structures. "Poly" is sold by thickness in millimeters (1 mil = 1/1000 of an inch) and is rated for longevity in years. Typical covering specification for a protected agriculture structure such as a high tunnel would be a single layer of greenhouse grade 6-mil poly rated for five years. Polyethylene glazing contains additives designed to enhance durability and performance, but these also increase cost and reduce light transmission.

It is important to understand the properties of a given covering material, looking particularly at light quality and quantity, to avoid unintentional consequences of using that material. For example, Photosynthetic Active Radiation (PAR) is a measure of light quality that is utilized by the plant in photosynthesis and occurs in the 400-700 nm wavelength range. Plants would not thrive with compromised light quality that blocked out PAR. It is often the case, however, that there is too much light and the amount of light entering the structure needs to be decreased. Due to the abundant amount of sunlight, or light quantity, available in Jamaica, polyethylene covers containing green shade or opaque materials should be considered for covering protected agriculture structures. Put simply, do not block out light used in photosynthesis when shading a crop. Use of the following materials can help to reduce inside temperature without causing loss of plant yields.

ULTRA-VIOLET STABILIZING ADDITIVES

Ultra-Violet (UV) stabilizing additives block UV light to slow degradation and hardening of plastic. It also optimizes the useable light spectrum by screening out growth-restricting UV rays. Avoid purchasing construction grade plastic because it does not contain a UV-inhibitor and will only last one growing season.

PHOTO-SELECTIVE FILM

Photo-selective film absorbs or reflects a specific range of wavelengths to manipulate plant growth. For example, installing a poly with a photo-selective film that blocks 280-320 nm UV light may prevent *Botrytis cineraria*, because this light range is essential for sporulation of this disease.

SHADE CLOTH

Shade cloth is made from knitted polyethylene strands or woven polyester and is water permeable. As such shade cloth is used to reduce light intensity, temperature, and plant exposure to wind, but allows in rainwater. Shade cloth is often used in combination with plastic covering, but in some applications it is used as the sole covering for a structure. Black, white and various shades of green and brown can be used depending on the environment and the crops being grown in the structure. White shade cloth may have a greater cooling effect than black and other darker colors of shade cloth because it reflects more light. Shade cloth is purchased by percent light blocked, 20-90% are commonly available. For example, air temperatures can be reduced by four degrees Fahrenheit with 30% shade cloth.

Crop species requirements dictate what percent shade cloth should be used for a structure. If used in conjunction with polyethylene, shade cloth may be installed on the inside or outside of the protected agriculture structure. When using shade cloth inside, light is converted to heat inside the greenhouse so while plants still get less light, the internal temperature is increased. With shade cloth that is installed outside of the structure, sunlight is converted to heat before entering the greenhouse, keeping internal temperatures lower.

INSECT SCREEN

Insect screen is intended to exclude insect pests and in some cases to prevent beneficial insects from escaping the crop growing environment. The fine weave of screening may reduce air circulation, however, leading to problems with high temperatures and humidity. Therefore, planning for adequate ventilation of the crop is necessary when screening is used. While selecting insect screens, proper ventilation takes priority over insect management because poor air circulation will place the plants will under constant stress, thereby decreasing yields and quality. Insects can be managed by other means such as resistant cultivars or pesticides.

ANTI-VIRAL SCREENING

The diameter of the holes in this screening material measures 0.2181 mm^2, which will exclude Leafminers (0.6350 mm), Aphids (0.3302 mm), and White Flies (0.4572 mm). The minimum recommended altitude for utilizing anti-viral screen is 400 meters (1,312 ft) above sea level. Below this elevation anti-viral netting should not be used unless additional equipment for cooling is added.

Anti-viral screen covering a double ridge vent.

ANTI-THRIPS SCREENING

The screen hole diameter in this material is 0.0225 mm^2, which will exclude Thrips (0.1905 mm) as well as the other pests blocked by Anti-Viral Screening.

ADDITIONAL CONSIDERATIONS

ATTACHMENT TECHNIQUES

Secure attachment of the covering material is necessary to avoid tearing and excessive wear that shortens its longevity. Fastening poly between two boards such as the hip board and batten board is the least expensive method of attaching it to the structure; however, this method may be the least secure, depending on the type of screws, spacing and installation technique used. Wiggle wire, a continuously s-curving wire that is placed into the channel by "wiggling" it back and forth, nestled in an aluminum channel offers continuous force along the surface of plastic and is relatively easy to install. Many channel and clip systems are manufactured, including Poly Clip, Agrilock, and Surelock, and are available on the Jamaican market. These are the most secure and most expensive poly attachment systems; importantly though, they do not allow for quick removal in the event of a hurricane. In addition, some designs have been reported to rip the plastic at the attachment site.

Horizontal air flow fans provide air movement within the structure.

HORIZONTAL AIR FLOW FANS

The objective of utilizing horizontal airflow is to keep air moving among the plants at all times, which helps to manage overall airflow and temperature within the structure. It is accomplished by using relatively low-cost electric fans. These fans are used as tools to circulate air in both passive and actively ventilated structures and the name refers to the movement of air within the structure, as opposed to drawing fresh air in from outside. This inside air movement is important to the health and productivity of protected agriculture crops. Constant air movement is important because it maintains a more uniform environment throughout the greenhouse and it reduces or negates completely “pockets” of high or low temperatures or humidity. Air movement also: (1)

helps to keep leaf surfaces dry so that diseases are less likely to develop and (2) it supports photosynthesis by preventing air from becoming stagnant and thus hindering the formation of carbon dioxide, which is essential for photosynthesis to take place.

IRRIGATION EQUIPMENT

Irrigation equipment needs is also a consideration during planning and construction. The type of production system dictates the equipment needed. For example, a fertigation system would require an injector, water tanks, drip tape, and filters while an overhead sprinkler system would require hoses and sprinklers.

HURRICANE PREPAREDNESS

Jamaica lies within the Atlantic hurricane belt, which has a hurricane season running from June to November. Greenhouses are unable to withstand winds of such magnitude so sites should be selected with this in mind. With all but the most rigid growing structures, the best strategy for withstanding a hurricane is to enable rapid dismantling of part or all of the structure in order to save the structure and to avoid losing expensive covering materials and components.

The following factors should be considered at the time of construction design in hurricane-prone regions:

- Shade cloth, if used, should be attached so as to be easily removable and secured.
- The polyethylene glazing and any insect screen should be attached with quick attachment components, such as wiggle wire or rope, which can be rapidly removed. The less costly approach of securing poly with lath nailed to base or shoulder boards will be slow to remove and will likely result in damage to the poly.
- Allow 15-20 cm (6-8 in) of excess poly or insect screen during initial installation so that there will be sufficient material to hold onto when reapplying these materials to structures.
- Ideally, indoor storage space for poly and other coverings and seedling trays should be available to minimize debris and wind damage after they have been removed from the structure.
- Design the trellis system so it can be lowered carefully to the ground and covered with a tarp or with the plastic that has just been remove. The edges should be weighed down and
- Consider if a fuel pump and/or stand-by generator is necessary to power water pumps or other systems after the hurricane has passed and electricity is not immediately restored.

USAID/JBRP Production Bulletin #14 gives the following recommendations for hurricane preparedness:

- If the plastic and/or antiviral mesh has not been placed on the structure, wait until the hurricane is gone to do so.
- Any seedling trays kept in the greenhouse should be taken to a secure location.
- Clean and deepen the trenches around the greenhouse. All of the soil that is removed must be placed over the bottom of the antiviral mesh to secure it against the heavy winds.
- Note that is cheaper to replace the plastic than the whole structure. If the plastic is already set-up on the greenhouse, be ready to remove it if approaching winds are strong. This will reduce wind pressure under the structure.

- Make sure the water tanks are completely full. This way, they will be heavy enough to withstand strong winds.
- Before the storm be sure to apply a fungicide/bactericide to your crop. Use a systemic fungicide. This should be repeated following the storm.

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Module 2

PRODUCTION SYSTEMS

INTRODUCTION

When provided an optimum growing environment, a plant will produce the highest yield of the highest quality. It is essential to understand the factors that contribute to such an environment to provide for optimum growth and development. This knowledge assists the grower to develop an appropriate production system that maximizes plant growth and which ultimately translates into an economic advantage. In many cases creating the ideal growing environment will involve both the proper use of protective structures and an array of specialized cultural practices.

For example, at a particular location, a tomato grower may require a relatively simple structure, relying on passive ventilation and shade netting. At another location, more active ventilation may be required along with complete protection of the crop inside through the use of antiviral netting. A sound understanding of environmental factors can give a grower an economic edge, enabling him to optimize plant growth with the appropriate available resources.

This module covers:

1. The Plant Growing Environment
2. Monitoring Environmental Factors
3. Growing Mediums
4. Irrigation Systems

THE PLANT GROWING ENVIRONMENT

The environmental requirements of plants vary with species, *cultivar* (a plant variety used for cultivation), and the stage of growth. Extremes of any factor can be very damaging to a crop; moreover, even subtle variations of a given factor can impact crop quality and yield. It is also important to remember that environmental factors impact one another in visible and invisible ways; something that impacts the above ground plant parts will also have effect on the roots below ground.

For example, when the temperature rises, the moisture requirements of plants increase. When light intensity increases, the temperature rises, increasing not only the need for moisture, but also the need for minerals for plant growth. During daylight hours, a closed growing structure will trap heat and air and limit circulation, resulting in increased temperatures, humidity, and the development of an environment conducive to plant diseases.

Gentle breezes over a plant will increase the *transpiration rate* (the rate of emission of water vapor though the leaves of a plant), which in turn, will increase its need for moisture and minerals. The same breeze will also tend to reduce air and leaf temperatures and to lower the humidity in the structure.

LIGHT

Three aspects of light affect plant growth: intensity, duration, and quality. Intensity refers to the brightness of the light. Duration refers to how long daylight is available for plants to photosynthesize. This is also called the *photoperiod*. Light quality, in this case, refers to the relative abundance of particular wavelengths or ranges of wavelengths (infra-red, visible, photosynthetic active, ultraviolet). The portion of the electromagnetic spectrum that falls between 400 - 700 nm, is referred to as the spectrum of visible light. Photosynthetic Active Radiation (PAR) is light that is utilized by the plant in photosynthesis and occurs in the 400 - 700 nm wavelength range.

TEMPERATURE

Temperature can effect plant growth in a number of ways, particularly through its effects on leaves and roots. The temperature of the air, growing medium, and the water used for irrigation can directly impact the temperature of the plant. Another important aspect for crop growth is daily minimum and maximum temperatures.

Temperature is not an independent parameter; it is dependent on the light intensity and quality inside a structure temperature, which is dependent on the amount of light which comes into the structure. It is the infrared component of light which makes significant contribution to temperature. External shades over the structure’s roof may be of value to reduce the inside temperature by blocking the amount of light entering into it.

MOISTURE

WATER

Water is a major driver of plant growth. It transfers minerals from the soil or other growing medium to the plant and creates *turgor pressure*. Turgor is a force exerted outward on a plant cell wall by the water contained in the cell. This force keeps the plant rigid, and may help to keep it erect. The following aspects are important when considering moisture in relation to crop production: volume; rate of application; temperature; quality (soluble salts); and pH.

RELATIVE HUMIDITY

Monitoring relative humidity is important to maintaining plant hydration. If high relative humidity is paired with a high internal temperature, the ability of a plant to move water from its roots to its leaves is reduced, causing reduced circulation of needed minerals.

MINERALS

Minerals are the raw materials from which the plant synthesizes complex nutrients. The proper types, amounts and rates of mineral application by the grower are critical to successful cultivation.

OXYGEN

Air is essential for all aerobic organisms, including crops. In the managed environment, air movement within the protected environment requires particular attention since structures can tend to limit free air movement. Good aeration of soils and/or other growing media is of equal importance.

BIOLOGICAL FACTORS

Crops interact with other organisms, including the growers who tend them, pests that eat them, and a host of beneficial or benign organisms above or below the soil surface that may assist or hinder nutrient uptake and defense against disease. Macro-organisms can be seen with the naked eye while micro-organisms can only be seen under high magnification. Micro-organisms can fill the plants environment in astonishing numbers. For example, a gram of soil contains up to a billion microorganisms. Other factors such as soil structure and pH are also important and are covered in further detail in *Module 4: Nutrient Management.*

MONITORING ENVIRONMENTAL FACTORS

Human senses, in general, are not sensitive enough to monitor the specific levels of each environmental factor for each crop; various instruments are used to assist in this. These instruments are of limited use, however, unless baseline data for optimum culture of the crop is known, which allows the grower to decide whether and how to take corrective measures. In Jamaica where smaller growers may not be able to afford to analyze soil and water on a regular basis, pH and E.C. meters could be the two most valuable tools to monitor fertility in crops and to make informed decisions.

Minimum-maximum thermometer

All instrument measurements and observations of the environment need to be referenced against known baseline data for optimum crop production. Once data is compared, steps must be taken to bring the actual production conditions in line with those known standards. Publications and other references should be used to determine and understand the baseline information and, since new research may bring to light new information, it is important to seek up-to-date information through publications and growers associations. It is also useful for the grower to continuously conduct on-farm experiments and fully record them in order to assess the effect of the local environment on crop practices.

THERMOMETER

The most useful type of device for protected agriculture is a minimum-maximum thermometer, which records not only the current temperature, but also the lowest and highest temperatures that occurred since the last time the thermometer was reset. The grower can monitor and record temperatures for each 24-hour period if the thermometer is reset at the same time each day.

Analog hygrometer-thermometer

While air temperature is most commonly measured, soil and leaf temperatures are more important to the plant. Special thermometers are available for these measurements. When monitoring temperature, it is important to properly shade thermometers to prevent false readings due to heat load from light on the thermometer or on nearby materials, which lead to biased temperature readings.

HYGROMETER

A hygrometer measures humidity, which is the level of moisture in the air. This enables the grower to adjust ventilation or air circulation to modify humidity levels in the structure. Hygrometers can be digital or analog and are commonly paired with a thermometer on a single console or within the same instrument.

Light Meter

LIGHT METERS

Light meters are used to measure the intensity of light. Light intensity readings can help indicate when cleaning of the structure's protective surface is necessary, and determine when to apply or remove shading compound or shade cloth for best crop performance.

ANEMOMETERS

Anemometers are instruments used to measure wind velocity. While useful in some instances (like determining when to spray pesticides outdoors), they have limited use in protected structures.

MOISTURE SENSORS

Various moisture sensors are useful for protected agriculture, including rain gauges to measure rainfall. Other important gauges include tensiometers, gypsum blocks and other instruments used to measure soil moisture and to aid in determining when to water crops.

FERTILITY LEVEL METERS

pH METERS

pH meters are used to measure the level of acidity or alkalinity (pH) of the growing medium or of a fertilizer solution. Appropriate pH levels in the growing media are necessary to have nutrients available for plant uptake and absorption. It is essential to keep a pH meter properly calibrated with solutions of known pH values; these solutions can be purchased at any grow supply store.

Hand-held pH meter with known buffering solutions

ELECTRICAL CONDUCTIVITY METERS

An electrical conductivity (EC) meter measures the total amount of all fertilizer mineral salts in a solution. An EC meter is a very useful tool for measuring total soluble salt levels in water, fertilizer solutions, and *leachates* (liquids running through composting or waste piles).

MAGNIFYING LENSES

Magnifying lenses are used to observe and identify insect pests and disease symptoms.

Resource

See Appendix #1: Instrument Bulletin

GROWING MEDIUM

The growing medium provides the appropriate root environment, plant support, and means of nutrient and water delivery to the crop. While there are many systems available, soil culture is the most commonly used system in Jamaica at present. There are growers using soil-less media systems and others who are growing in soil while adding a significant quantity of amendments. Amendments are materials incorporated into the soil, like compost or manure to improve soil properties. This is especially important when utilizing marginal lands such as mined-out bauxite areas.

SOIL

For crops grown directly in soil, raised beds should be constructed and covered with plastic mulch (drip irrigation lines are also integrated into the raised bed). Soil preparation involves constructing raised beds with amendments such as chicken mature or compost. The goal is to create a well-aerated loose soil which encourages development of a healthy root system. A raised bed also avoids compaction by ensuring that people do not work or stand too close to the plants.

Tomatoes produced in grow bags filled with coir

SOIL-LESS

A variety of soil-less media are available on the Jamaican market. All have a variety of strengths and weaknesses for different crops and come at various price points. Below is an introduction to these soil-less media.

COIR

Coir is made of coconut husks milled with a hammer-mill machine into a ground coffee-like texture. Coconut coir tends to be pH neutral (7.0), which helps ensure proper ionic balances in nutrient solutions as fewer additions of pH adjusters are typically required to compensate for the pH of the growing media. Coconut coir can be purchased in either loose or dried and compressed forms. The compressed forms require hydrating prior to use. Although the hydration process may be laborious, the dried and compressed blocks are much easier to transport to the growing location. Coir is not screened to remove the fibers, which adds to its porosity and provides better aeration. The physical properties of coir include:

Loose coir is also used for post-harvest storage at the CPC packing house

1. air-filled porosity: 10-20%

2. water holding capacity: 70-80%
3. chemical properties: low EC
4. carbon to nitrogen ratio: 80:1

All essential nutrients have to be supplied on a regular and constant basis to maintain good productivity when using this medium.


Perlite

PERLITE

Perlite is a siliceous volcanic rock (aluminum silicate) that when crushed and heated expands to form white particles with numerous closed, air-filled cells. Water will adhere to the surface of perlite but will not be absorbed into the perlite aggregates. Perlite is sterile, chemically inert, has a negligible EC, and is nearly neutral with a pH value of 7.5. Perlite has a low water-holding capacity and is often added to other media to increase aeration around the root zone. Due to its very limited water holding capacity, irrigation systems have to be designed to deliver irrigation on a constant basis when using this medium. As with coir, all essential nutrients must be supplied in the irrigation water.

VERMICULITE

Vermiculite is made from mica, much like perlite. During its production, the vermiculite is heated to very high temperatures that cause it to expand and also sterilize it. Vermiculite is lightweight, sterile and able to absorb large quantities of water. It does provide some nutrients in the form of potassium and magnesium, and it will retain fertilizer. Vermiculite is often found as a component in commercially prepared media mixes, in particular those formulated for seed germination.


Vermiculite

SAND

Sand is most commonly used in media mixes to add a coarser texture needed to provide increased drainage and aeration. Sand has a low water holding capacity and contains no nutrients. Sand should be sterilized either by heat or chemically as disease causing organisms may be present in natural sand.

PEAT

Peat is an organic material grown in acidic, bog-like conditions that is harvested in a partially decomposed state. Peat has many desirable properties such as being lightweight, providing nitrogen, and having a high water holding capacity. Peat is expensive and is not commonly used exclusively; however, it is often an ingredient in commercially prepared mixes that are used in Jamaica.

PREPARED MEDIA

Prepared media is commercially mixed to specific proportions of materials such as peat, perlite, and vermiculite with optional additives such as wetting agents, slow-release fertilizer, and mycorrhizae (a root growth promoting fungus).,Pro-Mix is a trade name of one mix with different formulations that is available in Jamaica.

WATER

When growing in water, plants are positioned in troughs (often using gutters) through which a constant flow of nutrient solution keeps the lower portion of the roots wet. This is referred to as hydroponics, which includes the Nutrient Film Technique (NFT) and bag or container culture, which uses an additional substrate such as perlite. NFT systems are well suited for the production of leafy vegetables.

IRRIGATION SYSTEMS

When soil becomes too wet, it becomes *anaerobic*. This is a condition which allows for the growth of harmful fungi and molds, causes rotting of the roots and slows or stops completely the growth of root hairs responsible for the absorption of nutrients. An excess of moisture in the soil also causes the soil temperature to drop with negative implications for crop growth. Conversely, soil that has received too little moisture can have as much trouble as waterlogged soil. In overly dry soil, the root hairs die from a lack of moisture and nutrients become "locked-up" and unavailable to the plant.

Gravity-fed irrigation system

When soil moisture is kept at a constant level beneficial soil organisms thrive and create more *humus*. Humus is the end product of decomposition of organic material and is what makes the soil loose and able to hold moisture while simultaneously bonding nutrients so they are not leached away. Humus thrives in conditions which provide a thin film of moisture; when conditions are too dry the nutrients remain locked within the humus particles. When water is applied following a dry period there is a delay before the nutrients are again available to the root hairs for absorption. The healthiest growth and greatest yields occur when there is a consistent moisture level, not when there are cyclical wet and dry conditions.

Determining the amount of water to apply and when to apply it is important. *Tensiometers* (an instrument to measure soil moisture levels), gypsum blocks and other sensors can be used to determine when crops need water. When sprinklers or some types of drip systems are used, the amounts of water applied can be monitored using a large cup or other appropriate container. Grower observation is still the most common method for determining water levels, but is too subjective for truly accurate application.

Irrigation methods include hand watering, overhead sprinklers and drip irrigation. In determining the systems to be used the grower should take in to consideration the goals of production and a variety of other issues, including:

- Sprinkler and drip systems can be operated either manually or automatically with a timer;

- Drip irrigation reduces foliar diseases while overhead irrigation increases cooling effects;
- Sprinkler systems use water inefficiently due to evaporation before water reaches the plant;
- Sprinkler systems contribute to foliar disease because of the moist environment created in the foliage canopy;
- The cost of a given system; and
- The crops to be cultivated.

If soluble fertiliser will be injected through irrigation lines, consider the compatibility of the water supply, delivery system, and type of fertiliser injector. Additionally, water quality, temperature, volume, and timing are important issues to consider when selecting the appropriate irrigation method.

In protected agriculture production, the most common delivery system is drip irrigation, of which there are several versions. Drip irrigation involves a low-pressure water source attached to tubing which is placed on the ground along a row of plants. Water emitters are built into the tubing at regular intervals. In container or bag culture systems, spaghetti tubing and specialized emitters are used to irrigate crops. Drip systems are designed to provide water directly to the plant root zone in very controlled volumes. There are many advantages inherent to a drip irrigation system, including the reduction of water usage by almost 50%. In addition, the lengthy, slow trickle provided by a drip system has been shown to increase yields 84% over other methods of watering.

Proper filtration and clean water are essential to the efficient operation of low volume irrigation systems. Contaminants present in the irrigation water source will lead to clogged emitters and reduction in system efficiency. Screen filters are excellent for removing hard particulates including trash, algae, sand, and silt, though they are not sufficient for removing organic materials such as algae, mould, and slime. These non-solid materials tend to embed themselves in the screen material where they are very difficult to remove. In other cases they simply slide through the holes in the screen by temporarily deforming their shape. Several methods of flushing are common with the simplest being to flush the valve outlet at the bottom of the filter.

SCREEN FILTER MESH SIZE AND USES	
FILTRATION MESH	**RECOMMENDED USES**
40-60 mesh	**Micro-sprinkler with 40 GPH and up**
80 mesh	**Micro-sprinkler with 20-40 GPH**
120 mesh	**Micro-sprinkler with 20-40 GPH**
140-160 mesh	**Drip system & micro-sprinkler up to 10 GPH**
200 mesh	**Fogger & mister up to 4 GPH**

Module 3

PLANT PRODUCTION COMPONENTS

INTRODUCTION

It is important to understand the basic components of introductory plant production prior to addressing more technical and scientific issues related to plant health. An overall knowledge of what is essential for a successful grower will assist the Rural Agricultural Development Authority (RADA) officer in servicing the protected agriculture sub-sector. Many of the topics introduced in this module will be expanded upon in later modules.

This module covers:

1. Propagation Techniques
2. Crop and Variety Selection
3. Seed Propagation
4. Planting Care and Harvesting

PROPAGATION TECHNIQUES

There are two main types of plant propagation: asexual and sexual. Asexual techniques include vegetative, grafting, and micro-propagation; sexual propagation refers to growing plants from seed. Raising plants from seed has the potential to provide large numbers of uniform, high quality seedlings. Seed propagation is the most common method for vegetable crop production in Jamaica. For asexual production, grafting is a common practice in fruit and nut tree propagation for hard-to-propagate varieties or those which have an inadequate root stock. In Jamaica, micro-propagation, or tissue culture, is currently being used at the Christiana Potato Growers Co-operative to develop potato varieties that are most suitable for conditions in Jamaica, and planting material for Irish Potatoes.

Tissue cultures under grow lights at the Christiana Potato Growers Cooperative (CPC)

An example of asexual vegetative propagation in Jamaica is using auxiliary shoots (commonly called suckers or gormandizers) to grow tomatoes. With this method suckers can be taken from the healthiest and most vigorous plants in a tomato crop, transplanted, and they will readily root in a potting medium. This practice may have potential for savings on seed costs, but is also potentially risky as there is potential to take suckers from an apparently healthy plant that is in fact virus-infected, which will result in a new crop of infected plants.

CROP AND VARIETY SELECTION

Although most growers know what crop they are going to grow as they embark on the planning and construction of the protected agriculture structure, it is important to continuously evaluate market demand for a particular crop species. Equally important is choosing a cultivar of that species. The term *cultivar* comes from the phrase cultivated variety. Cultivar is often abbreviated "cv" and is also known as a variety or a hybrid. Growers should choose a variety of a selected species that is most appropriate for the conditions of the production system and which is appealing to the market.

Cultures are taken in a laminar flow hood in effort to maintain a sterile environment

Varieties are available, with new ones constantly in development, to provide the best possible advantage to the success of a crop. These new varieties are developed by crossing plants with desired characteristics. The advantage of cultivating hybrids is a stable, uniform crop with the uniformly extending not only to the fruit, but also to height of the plants and yield. Additionally, varieties are bred for disease resistance and to minimize or limit physiological problems such as blossom end-rot.

Whenever possible, select high quality seeds from reputable seed companies. It is of note that field production varieties are not bred for protected agriculture conditions, and it is therefore recommended that only greenhouse varieties be used for protected agriculture production. It is also important to remember that "resistance" labelling does not indicate that a crop will be completely immune to a disease or pest.

There are many benefits to planting hybrids, but one drawback to their use is that saved seed from a hybrid variety will not produce a plant "true to type" in the next growing cycle as characteristics from parent seeds could be expressed that may not be desired. This means new seeds will have to be purchased for each season, which will increase production costs.

SEED PROPAGATION

Plant uniformity starts in the germination tray. The general steps for seed propagation of all species are:

1. Calculate the number of seeds to sow for the desired crop size (taking into account that some plants will be lost to disease, pests, or will simply fail to thrive) and procure sufficient supplies;
2. Sanitise the propagation area, tools, and supplies (including new trays);
3. Mix starter solution into sterile growing media;
4. Fill trays uniformly with the selected media (this has a major impact on seedling uniformity);
5. After placing one seed per cell, cover lightly with more germination media;

6. Water the cells gently so the media do not splash out and making sure the media are thoroughly moist;
7. Place in a germination chamber and keep the chamber in cool area;
8. Check regularly so etiolation (the act of causing a plant to develop without chlorophyll by growing it without exposure to sunlight does not occur, making the seedling more susceptible to damping-off;
9. Once sprouted, immediately remove the plants from the germination chamber;
10. Place the seedlings in an area where optimum conditions can be provided, which are 1000-1500 foot candles of light and 75-85°F (24-29°C);
11. Do not let the media completely dry out between watering.

A number of inert media are available for protected agriculture seed propagation which provide good levels of moisture and oxygen while being chemically inert and free of disease pathogens. Together these properties translate into a fine-textured media. This type of medium is often a mix of two or more individual media. For example, Pro-Mix offers a germination mix of vermiculite and peat. If mixing your own media, make sure all components are sterile. Factors to consider when choosing a propagation media include: aeration, water-holding capacity, susceptibility to disease pathogens, and cost.

One way to sterilise media is through *solarization*. Soil solarization is the process of covering moist soils with clear polyethylene to trap solar radiation and raise soil temperatures to levels lethal to most pathogens and weed seeds. Solarization is most effective when applied for at least 30 days. Two layers of polyethylene, separated by fillers (i.e., PVC pipes or 2'x 4's) spaced every few feet to create an air space, increases the efficiency of solarization. Media can also be chemically sterilised; however, this is often cost prohibitive and has negative environmental impacts.

Pre-made germination chambers are commercially available; however, simply stacking trays and sealing them in black plastic bags creates the proper conditions - darkness with high humidity. The chamber should be placed in a cool place which does not receive direct sunlight.

OPTIMUM GERMINATION CONDITIONS Temperature and days to germination for selected species			
CROP	°F	°C	DAYS
Tomatoes	78	26	3-6
Lettuce	76	24	4-8
Cucumbers	76	24	3-5
Sweet Pepper	77	25	10-14

DISEASE CONTROL DURING GERMINATION AND SEEDLING STAGES

Damping-off diseases is the term for the death of small seedlings resulting from attacks by certain fungi, primarily *Pythium ultimim* and *Rhizoctonia solani*. Pathogens resulting in “damping-off” can cause serious loss of seeds, seedlings, and young plants. In addition, there are a number of fungal, viral, and bacterial diseases that are either seed-borne or can be present in the water supply. Other fungi, for example *Botrysis cineraria* and *Phytophthona spp* may also be present and interactwith *Pythium* and *Phytophophona* to produce spores that move about in water.

Damping-off occurs at various stages during seed germination and subsequent seedling growth:

1. Pre-emergence damping-off: The seed may decay or the seedling stem may rot before the seedling pushes through the surface of the media. This results in a partial or even total lack of seedling emergence.
2. Post-emergence damping-off: The seedling develops a stem that rots near the surface of the media and falls over.
3. The seedling may remain alive and standing, but the stem will become girdled and the plant stunted, eventually dying.

The environmental conditions prevailing during the germination period will affect the growth rate of both the attacking fungi and the seedling. The optimum temperature for the growth of *Pythium* and *Rhizoctonia* is between 20-30°C (68-86°F). The moisture content of the germination media are of great importance in determining the incidence of damping-off. Typical conditions associated with damping-off include over-watering and poor drainage.

TREATMENT FOR DAMPING-OFF DISEASES

Disease prevention is crucial and it is important to use sterile media and fungicide sprays in an effort to eliminate pathogens during propagation. The close control of plant growth and environmental conditions will minimize the effects of damping-off, will at least until the seedlings have passed their initial vulnerable stages of growth. If damping-off begins after seedlings are growing, it may be controlled by treating that area of the media with a fungicide mixture which includes metalaxyl (trade name: Ridomil) and thiophanate methyl (trade name: Topsin).

TRANSPLANTING

In general, it is time to transplant the seedling from the germination tray to the final growing container when the seedling has met several developmental milestones. With both tomato and sweet pepper the seedlings should be 10-15 cm (4-6 in) tall and have at least 3-4 true leaves developed prior to transplanting. Roots should be well developed, and, when removed from the germination tray, the “plug” should stay mostly intact.

In tomato culture, when using grow bags, the bags should be placed in their final location and spaced appropriately, and then the transplants should be taken to the bags. To remove the plugs, wet the germination tray completely and squeeze from the bottom to push the seedlings out without nicks, cuts or other damage that could occur to the plant or root system if pulled by the leaves. Precautions should be taken to transplant seedlings when it is not very hot, preferably on cloudy days or late afternoon so seedlings can adjust to temperature changes overnight. Make sure that the soil or the growing media are not dry. If using coir, bags should be pre-moistened as well.

PLANT SPACING

When growing crops in protected structures, it is important to use the proper planting density. For example, for best results, tomatoes need to have at least four square feet per plant. To determine how many plants can be grown in a structure, multiply the length of the structure by the width and then divide by four or five. When calculating, it is important to remember that if some of the floor space will be used for other purposes, this area must be subtracted from the total before dividing by four or five.

Using a higher plant density will cause the yield per plant to decrease; this is due primarily to plants shading each other. Overcrowding plants also tends to promote disease development since foliage does not dry as readily once wet and sprays cannot easily penetrate the thick foliage. Ideally plants should be staggered in double rows, about four feet apart on centres. The term *on centres* is used in regard to the method of measuring plant spacing, it means to measure from the main stem of one plant to the main stem of another. Within a row, tomato and sweet pepper plants should average 36-41 cm (14-16 in) between stems. For specific information on spacing other greenhouse crops see the crop-specific section in Module 9.

Trellised tomato plants at a middle stage of growth.

POLLINATION, TRELLISING, AND PRUNING

Pollination, trellising, and pruning are three labour intensive activities that increase yield and over-all quality of most crops grown in protected agriculture structures.
Pollination must be performed by the grower in a protected agriculture structure as natural pollinators such as bees are excluded. Additional steps must be taken to ensure pollen successful transfer within the structure.

Trellising of plants supports them in order to keep the stems from lying on the ground, and to allow the plants to occupy vertical space in the protected structure rather than spread horizontally. Wooden stakes, twine, and various clips and wrappers are used to support the plants.

Trellised tomato plants further along

Pruning removes excess leaves that are not necessary for plant growth and that can cause excessive shade for surrounding plants or attract pests.

Specific pollination, trellising, and pruning techniques for tomato and sweet pepper are described in further detail in Module 9: Crop Culture.

HARVEST AND POST-HARVEST MANAGEMENT

As crops mature, another crucial aspect of a successful season must be considered: how to manage the harvest and handling of the ripe crop. Ideal harvest conditions are in the morning when cool temperatures cause the plants to transpire at a lower rate. Harvesting should be done with the utmost care to avoid bruises and nicks. Attempts should be made to keep the

Tomatoes waiting for transport to market

produce cool during transportation in order to extend shelf life. Storage life can be shortened by moisture loss and chilling injury. As an example, harvested sweet peppers should be kept at 7-10°C and 95% relative humidity. Temperatures below 7°C will result in chilling injury. Under properly managed conditions, peppers have a storage life of 3-5 weeks. Contact RADA for information on crop-specific optimum storage conditions.

STORAGE DISEASES

Post-harvest storage diseases include *Alternaria*, *Botrytis* and *Phytophora* rots. These fungal rots can be controlled by quickly cooling harvested fruit and by avoiding bruising and injury during harvesting. Additional techniques include hot water dips and post-harvest application of antimicrobials. Contact RADA for additional, up-to-date information on harvest and post-harvest management, including lists of registered fungicides for vegetable crops.

Module 4

NUTRIENT MANAGEMENT

INTRODUCTION

Agriculture is a science and its subjects are not static. Producers must rely on keen observation and daily interaction with the plants to ensure a healthy harvest. Nutrient management requires knowledge of the requirements of specific crops and the source(s) of fertiliser that will most effectively meet those requirements. It is also essential to understand fertiliser delivery systems and the methods by which you will mix fertiliser.

This module covers:

1. Plant Nutrient Requirements
2. Fertiliser Sources
3. Fertiliser Application Types
4. Methods of Mixing Fertilisers

PLANT NUTRIENT REQUIREMENTS

METABOLISM

The complex process which leads to plant growth is referred to as *metabolism*. The grower must possess a fundamental understanding that plants are living entities and as such, interact with their environment to sustain life. Plants manufacture their own food through the process of *photosynthesis*, the capturing of energy present in light waves, the consumption of carbon dioxide, and the conversion of water into a simple sugar. This sugar is further metabolised into other carbohydrates, fats, proteins and other foods; however, this synthesis occurs only if certain minerals, along with proper environmental conditions, are present.

Minerals are absorbed while in a water-based solution, usually through the roots, and are translocated to the parts of the plant where they are incorporated during growth. Minerals occur naturally in soils in varying amounts. Intensive agricultural production can deplete these naturally-occurring minerals and if production is to be sustained they must be replaced in the soil. Since the components of many artificial media are inert and contain no soluble minerals, necessary minerals are initially provided by the grower through the introduction of fertilisers of various kinds – chemical and/or organic - which the plants are then able to utilize.

Energy the plant uses for the growth process comes from the various foods the plant has synthesised. This energy is released from the food products through a process called *respiration*. In an appropriate environment, the metabolic cycle of energy capture (photosynthesis), food synthesis, and energy release (respiration) occur, thus enabling life, growth and reproduction. Since many animals, including humans, cannot survive without plants in their diet, they are ultimately dependent on the successful metabolic cycle of plants.

From seed to maturity, plants require different amounts for mineral nutrients for optimal growth. Growth stages such as vegetative, bud initiation and fruit set are all a result of distinctive metabolic processes that require different amounts of mineral nutrients, Therefore, recommended fertilisation rates to meet mineral requirements vary not only by plant species, but also by the stage of development of the plant.

MINERAL REQUIREMENTS

Thirteen minerals have been identified as essential to plant growth. These are classified in several ways but the essential understanding is that different species use them in different quantities, and that these requirements are further influenced by the environmental conditions in which the plants are grown. Some studies have suggested that other minerals may impact plant growth, but these have not been validated at the grower level. The nutrients required for plant growth are as follows:

- Macro-nutrients:
    - nitrogen (N)
    - phosphorus (P)
    - potassium (K)
    - calcium (Ca)
    - magnesium (Mg)
- Micro-nutrients:
    - sulfur (S)
    - boron (B)
    - copper (Cu)
    - iron (Fe)
    - chlorine (Cl)
    - manganese (Mn)
    - molybdenum (Mo)
    - zinc (Zn)

FERTILISER SOURCES

CHEMICAL FERTILISER

Minerals are used by plants in different quantities; nitrogen, phosphorus and potassium are used in the largest amounts and are usually referred to as primary, macro-nutrients or macro-elements. The most often applied fertilisers contain one, two, or all three of these macro-elements (in different proportions) in their composition. The label on the fertiliser bag lists them in the order N, P, K along with the percentages of each present in the makeup of the fertiliser. For example, a fertiliser listed as 10-5-15 is 10% N, 5% P (actually P_2O_5) and 15% K (actually K_2O). The remaining 70% of the fertiliser is inert carrier material. Controlled release solid fertiliser formulations allow for the release of soluble fertilisers over a period of time.

Other fertiliser minerals are applied in certain conditions, but in lesser quantities. Calcium, magnesium, and sulphur are part of a group of them known as secondary macro-elements. Some minerals are used by plants in very small amounts and are referred to as micro-nutrients or trace elements. The micro-nutrients group is made up of boron, chlorine, copper, iron, manganese, molybdenum and zinc. The elements carbon, hydrogen, and oxygen are also required for plant growth but are available from air and water in the quantities needed for plant growth. For this reason they are not included in pre-packaged fertilisers. Carbon, however, when applied as organic matter to soil, can make a positive contribution to plant growth.

Regardless of which mineral is required for growth, each one mentioned above, in its appropriate proportion, is absolutely necessary for plants to survive and thrive.

ORGANIC FERTILISER

Compost can be comprised of any organic material which has decomposed under managed conditions which cause or allow for the compost pile to heat up to a temperature at which weed seeds and many pathogenic organisms are killed. Minerals from the composted material are then more readily available when mixed into or on top of the soil. Properly made compost also contains beneficial microorganisms.

Fresh, organic sources of minerals are usually applied over a period of months or years. Prior to planting the crop, natural organic materials, including manure, must decompose in the soil or be composted in order to release minerals. Compost is usually applied to crops growing in soil rather than artificial media. Organic sources tend not to have consistent levels of minerals from batch to batch and manures from different livestock or poultry can vary in mineral content as well, mostly due to the feeding methods used for the animals.

FERTILISER APPLICATION TYPES

PRE-PLANT

Both organic and chemical fertiliser can be applied to the growth medium prior to planting the crop. This "pre-plant" method requires that the fertiliser be worked into the soil. This will trigger the decomposition process for organic matter or, if using chemical fertiliser, will allow the dry chemical to dissolve in the soil solution. Rarely are liquid fertilisers applied pre-plant.

FOLIAR FEEDING

Plant leaves and stems absorb water and nutrients, and exchange oxygen and carbon dioxide through small pore-like openings called *stomata*. Foliar feeding, spraying an appropriately diluted fertiliser solution over the foliage of the crop, takes advantage of this natural phenomenon. It is an efficient way to apply fertiliser to plants because the fertiliser is absorbed directly by the plant canopy rather than absorbed by the roots and later translocated to the leaves. Foliar feeding is an especially useful technique to quickly correct deficiencies (such as a magnesium deficiency) or to introduce nutrients that do not translocate inside the plant (such as phosphorus and iron). A note of caution: it is easy to overfeed using this method, especially in the case of multiple applications in a short timeframe.

FERTIGATION

Fertigation involves applying fertiliser dissolved in irrigation water at each watering. This method can be used with crops grown in soil beds or in artificial media growing systems. Fertigation provides an accurate method to deliver nutrients while providing labour savings and consistency in distribution. A properly managed system will eliminate waste and reduce run-off, thereby diminishing adverse environmental impacts.

METHODS OF MIXING FERTILISERS

There are two primary means of mixing fertilisers, bulk tank and injector. Both have their strengths and weaknesses, which should be taken into account before deciding on the preferred method for a given environment.

BULK TANK

The bulk tank system consists simply of a tank (generally plastic or concrete), the size of which depends on the square footage of the structure. The larger the tank, the less frequently it will have to be filled; however, if the tank is too large, you will toned to wait until it is empty to mix a new batch of fertiliser if a change in fertility requirement requires corrective action. There are solubility limits (Table 1) as to the amount of fertiliser salt that will dissolve in water. It is important to understand these levels and dissolve the fertiliser completely, otherwise it will settle to the bottom of the tank and the plants will not receive the intended dose. In some cases, in order to fully dissolve the fertiliser, it may be necessary to mix the solution with a circulating pump, mechanical mixer or to use hot water to promote dissolution.

TABLE 1: NUTRIENT COMPOSITION AND SOLUBILITY LIMITS OF FERTILISERS
Solubility limits of selected fertiliser salts in 379 L (100 gal) of cold water

FERTILISER	ELEMENTAL COMPOSITION						SOLUBILITY
	% N	% P	% K	%S	%Ca	% Mg	g/litre*
Calcium nitrate	15.5				19.0		1500
Potassium nitrate	13.8		44.5				450
Ammonium nitrate	34.0						710
Urea	46.0						570
Phosphoric acid		75.0**					
Magnesium sulphate				13.0		9.7	810
Potassium sulphate			50.0	14.4			110
Ammonium sulphate	21.0			24.0			750
Potassium chloride		60.0					
Mono-ammonium phosphate	12.0	61.0					290
Diammonium phosphate	16.0	48.0					430
Monopotassium phosphate		52.0	34.0				290
Calcium chloride					36.0		

*Solubility at 30°C (86°F)
**Percent may vary

It is important to ensure the proper proportion of fertiliser to water when mixing a solution. There is essentially one formula for all fertiliser; however, if you are using an injector system, you must consider the injector ratio. With a bulk tank system, there is no injector or injection ratio, so that factor can be excluded.

***Bulk System Formula**:* ppm = (% fertiliser) x (lb. added to tank) x (16 oz per lb.) x (.75) x (100 / gal. of bulk tank)

Bulk System Example: If using a bulk tank system with 15 pounds of 8-5-16 fertiliser mix and the bulk tank holds 600 gallons of fertiliser, 10 pounds of potassium nitrate (13.75% N) should be added to ensure the plants get plenty of nitrogen. To determine the amount of nitrogen the plants are receiving, the following ratio should be utilized:

With a bulk tank system, leave out the ratio factor ppm from 8-5-16 = (8) x (15) x (16) x (.75) x (100/600) = 240 ppm N ppm from KNO_3 = (13.75) x (10) x (16) x (.75) x (100/600) = 275 ppm N Total ppm N = 240 + 275 = 515 (which is too high for tomatoes, around 200 ppm is the upper limit)

INJECTOR


Fertilizer Injector

A fertiliser injector, also referred to as a proportioner, is a device that mixes precise volumes of concentrated fertiliser solution and water together. A knob or dial on the injector can be turned to increase or decrease the ratio of fertiliser solution going from the concentrated tank to the injector, where it is diluted by water being delivered into the irrigation system. The concentrate is held in small containers of 38-189 L (10-50 gal). The advantage of an adjustable rate injector is that the same fertiliser concentrate can be applied at different concentrations to plants at different stages of growth.

Chemical interaction must be taken into consideration when dealing with high concentrations. For example, at high concentrations calcium combined with phosphate or sulphate forms a precipitate that not only makes the nutrients unavailable to the plant but also clogs injectors. Two heads and two concentration tanks are needed - one for the calcium nitrate (tank A) and the other for all other nutrients (tank B) – to avoid this problem. Additionally, a third head is recommended to inject acid (phosphoric, sulphuric, or nitric) if the pH of the water is above.6.8.

Injector System Formula: ppm = (% fertiliser) x (lb. added to tank) x (16 oz per lb.) x (.75) x (100 / gal of concentrate) x (1 / ratio of injector).

Injector System Example: Place 25 pounds of a 15-11-29 fertiliser mix in a 30-gallon concentrate tank and then use a 1:100 injector. How much nitrogen are your plants getting? Since you have an injector system, be sure to use the injector ratio. ppm = (15) x (25) x (16) x (.75) x (100/30) x (1/100) ppm = 150 ppm nitrogen

Electrical conductivity (EC) is a measure of the ability of a solution to conduct electricity. The more concentrated the fertiliser solution, the more electricity it will conduct and the higher the reading will be. EC is measured in micro Siemens per centimetre (µS/cm) that is equivalent to micro-mhos per centimetre (µmho/cm).

Module 5

NUTRIENT MONITORING

INTRODUCTION

Nutrient monitoring is especially important in a protected agriculture environment to ensure plant health and the success of a crop. Understanding plant nutrition is crucial to successful cultivation and managing plant nutrition is a skill that can be developed to result in increased yields and quality of produce. Nutrient monitoring does depend heavily on grower observation, but also utilizes water, soil, and tissue analysis, which are available through government agencies.

This module covers:

1. Water Quality
2. Soil Tests
3. Tissue Analysis
4. Grower Observations
5. Nutrient Disorders

WATER QUALITY

Water quality is a key factor in the production of greenhouse crops. Before any crop production plans are made for a specific site, the quality of available water should be determined. A laboratory analysis can be used to determine water quality. In Jamaica, the Rural Physical Planning Division (RPPD) of the Ministry of Agriculture, Scientific Research Council (S.R.C.) and some commercial laboratories conduct water analyses on a fee-for-service basis. Following the initial testing, it is important to monitor quality standards on a frequent basis to avoid potential problems. Discussed below are quality factors as well as use guidelines which may be used to determine the effect water will have on plant growth.

COMPONENTS OF WATER QUALITY

The chemical properties which are measured to determine water quality are defined by a complex mixture of nutrients that have specific impact on crops. Water quality factors that are given the most focus from a grower’s standpoint are soluble salts, sodium and chloride concentration, hardness, pH, and alkalinity. Water with high soluble salts (also known as saline water) or with high levels of certain minerals may not be suitable for crop irrigation unless corrective measures are taken.

SOLUBLE SALT MEASUREMENT

When using fertigation, soluble salts can be measured with an electrical conductivity (EC) meter to determine the total concentration of soluble salts of the solution, which can then be compared to optimum soluble salt level information. This information can then be converted to parts per million (ppm) for use in other measurements. The meter does not measure the individual minerals, only the total combination of them in the solution, which is registered as salt concentration. Therefore, the grower must prepare the solutions with appropriate proportions for the crop being grown. As individual minerals are used by the crop or impacted by other factors, the total soluble salts reading will decline. This method is particularly useful with crops grown in artificial media, which require more accurate fertilization management than crops grown in soil.

SODIUM (Na)

Sodium is a *cation* (a positively charged ion) occurring in most irrigation water. Sodium is often responsible for salinity problems when linked to chloride (Cl) and sulphide (SO_4). Sodium concentration is expressed in terms of Sodium Absorption Rates (SAR). High sodium levels are of concern because they contribute to salinity problems that interfere with plant nutrient availability - especially the availability of magnesium and calcium.

CHLORIDE (Cl)

Chloride is an *anion* (a negatively charged ion) of the element chlorine found in irrigation water. Elevated levels of chloride can be toxic to a plant. Chloride determinations are used to establish the relationship to the total acidity as well as to indicate possible toxicities to sensitive crops.

HARDNESS

Water with a high concentration of calcium and magnesium is termed “hard.” The problem with hard water is that magnesium and calcium can combine with bicarbonate and form insoluble salts. Once these salts form they can impact the pH of the growing media (not the water pH- as insoluble salts they are no longer in the water solution). Also, these salts reduce the amount of sodium available to the plant.

pH

PH is a measurement of the concentration of hydrogen ions (H+) and has no direct impact on plant growth. However, it does affect the form/availability of nutrient elements in irrigation water, fertiliser solutions and growing media. The pH of irrigation water should usually be within the range of 5.2-6.8. This level enhances the solubility of most micronutrients and avoids a steady increase in the pH of the growing media that can sometimes occur. This pH range also optimises the solubility of nutrients in concentrated fertiliser stock solutions.

ALKALINITY

Alkalinity is not the same as *alkaline*. Alkaline refers to a pH level greater than 7; alkalinity is a measurement of water’s capacity to resist changes in pH, the power to neutralize acids. This is sometimes referred to as *buffering capacity.* Another way to think about alkalinity is if an acid were added to water, the pH of the water would decrease. If the water had high alkalinity, the decrease in pH would be much slower than if the water had low alkalinity.

What determines if water has high or low alkalinity is the amount of carbonates, bicarbonates and hydroxyl ions. The greater the measurement of these compounds is, the greater the alkalinity of the water. Generally speaking, water is considered to be of high alkalinity if it has more than 100 ppm of calcium carbonate. At that point, a grower should consider using an acid-based fertiliser such as ammonium nitrate (rather than a calcium-based fertiliser). Water with high alkalinity is a concern to growers using container production because it will gradually increase the pH of the media (not the water pH) over time. This means more acid will need to be injected into the water to counteract high pH in the media.

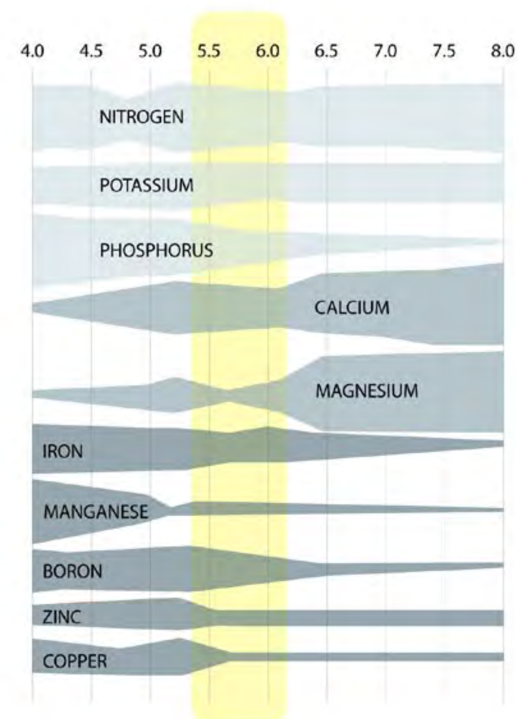
WATER QUALITY STANDARDS					
	EC (millmho)	SOLUABLE SALTS (ppm)	SODIUM CONTENT (% Na)	SAR	pH
EXCELLENT	0.25	175	20	3	6.5
GOOD	0.25-0.75	175-525	20-40	3-5	6.5-6.8
PERMISSIBLE	0.75-2.0	525-1400	40-60	5-10	6.8-7.0
DOUBTFUL	2.0-3.0	1400-2100	60-80	10-15	7.0-8.0
UNSUITABLE	3.0	2100	80	15	8.0

SOIL TESTS

If the crop is to be grown in soil, as opposed to an artificial media, a laboratory soil test should be undertaken to determine its fertility level. Recommendations for a fertilisation program should then be developed based on the existing soil fertility levels and with regard to the crop to be grown. At a minimum, natural or amended soil should be tested prior to each crop planting. In Jamaica, the Scientific Research Council (S.R.C.) provides soil analysis services.

TISSUE ANALYSES

It is possible that although soil fertility levels are adequate, the plants do not uptake the necessary minerals. Though soil tests can determine the fertility level of soils, they do not indicate the uptake rates and levels of minerals in the plants themselves. Tissue analysis gives a "snapshot" of the state of the plant tissue at the time the test is taken and is recommended to determine the nutrient levels in the crop. For this test, an actively growing part of the plant is removed and tested for nutrient levels. All the minerals in the plant part are identified and compared to baseline data. The resulting report will outline any reparative steps that might need to be taken to improve growth. In Jamaica, the Rural Physical Planning Division (RPPD) also provides tissue analysis services for a fee.



Nutrient Availability and pH of Substrate

GROWER OBSERVATIONS

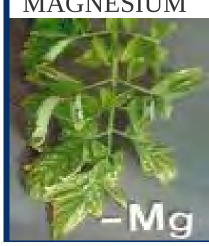
The keys to successful management of plant nutrition are an awareness of standards, attention to details, and constant observation of the plants and growing systems. The crop should be observed daily to note any changes in growth or appearance, which could indicate larger problems. It is important to keep consistent and accurate records of these observations to be able to note changes in the crop over time.

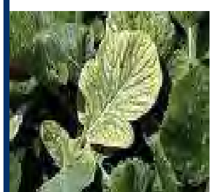
NUTRIENT DISORDERS

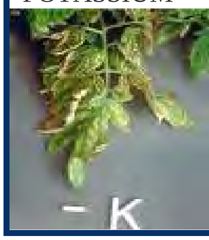
It is imperative to understand the baseline mineral needs of the crop and to manage the fertilization strategy to meet those needs. Minor levels of mineral imbalance will impede plant growth, but significant imbalances can lead to more serious problems and place stress on the plants, which can increase susceptibility to insect and disease damage.

pH levels can be influenced by the components of the growing media, fertiliser, irrigation water quality/condition, and by weather factors. The pH of the growing media can also have a serious impact on mineral imbalance. The substrate pH should be checked prior to planting a crop and a weekly testing routine should be established post-planting. The pH must stay within the range identified for that crop as any variation will result in the unavailability of certain minerals to the plants, even though they may be present in the growing media.

Deficiencies or excesses of certain minerals can produce visible symptoms, which can help identify to the imbalance (see Common Nutrient Disorders Table below). While visual scouting can alert the grower that a problem is developing, several problems often occur simultaneously (i.e., mineral deficiency, pest infestation, etc.) which can lead to an inaccurate interpretation of the root issue. It is much safer to rely on the appropriate tests for an accurate reading of symptoms.

COMMON NUTRIENT DISORDERS		
	DEFICIENT	EXCESS
COPPER 	Stunted growth, distorted younger leaves, growing tip dies.	Induces iron deficiency.
CALCIUM 	The tips of the shoots and roots turn brown and die. Causes blossom end rot in tomatoes and tip burn in lettuce.	Causes either magnesium or potassium deficiency symptoms.
MAGNESIUM 	Yellowing of older leaves between veins. Severe deficiency produces death of older leaves and *chlorosis* (paling or yellowing of leaves from insufficient chlorophyll) of the entire plant.	No specific symptoms

SULFUR 	Light yellowing most pronounced in the younger leaves. Very similar to nitrogen deficiency. Roots longer that usual, stems become woody.	Premature leaf death.
IRON 	Yellowing, inter-veinal chlorosis of younger leaves.	No symptoms.
MANGANESE 	Stunted growth, inter-veinal chlorosis of younger leaves.	Older leaves develop small brown spots surrounded by a yellow chlorotic zone
BORON 	Growing points become abnormal, becoming stunted and dying. Leaves and stems become brittle.	Leaf tips become yellow, then scorched and eventually leaf falls off.
ZINC 	Inter-veinal chlorosis of young leaves, plant growth stunted leaves die and fall off.	No common symptoms.
PHOSPHORUS 	Slow growing, stunted and dark green plants. Older leaves may show purple coloration - occurs in older leaves first.	Causes iron and/or zinc deficiency.

NITROGEN 	Plants are slow growing, weak and stunted. Leaf colour light green to yellow seen on older leaves first. Plants mature early, reducing yield.	Plants are dark green, soft, succulent foliage. Fruit and seed crops may fail to yield.
POTASSIUM 	Scorch along margins of older leaves.	Causes magnesium deficiency.

Module 6
INTEGRATED PEST MANAGEMENT

INTRODUCTION

Many diseases and insects can attack crops grown in protected agriculture structures, which can severely affect production and quality. It is important to accurately scout for and identify these pests and know how to effectively, economically, and responsibly control them. One approach is the use of Integrated Pest Management (IPM), which is the use of multiple tactics including biological, cultural and chemical methods, to suppress pest population. This approach differs from a single attack method such as repeated insecticide use. An integrated approach uses preventative measures to avoid likely insects and diseases while routine crop monitoring and record keeping allows for early detection. In general IPM aims to use biological control when possible, and insecticides only when needed. This strategy can reduce pesticide use while improving pest control.

This module covers:

1. Types of Pests
2. Management Strategies and Methods
3. Pest and Disease Profiles
4. Fungus Diseases
5. Bacterial Diseases
6. Virus Diseases

TYPES OF PESTS

INSECTS AND MITES

Insect pests cause crop damage by feeding on the plants and can also be vectors of viruses and other detrimental diseases detrimental. Some of the harmful insects which affect crops grown in protected agricultural structures include mites, white flies, aphids, thrips, moth larvae, and the tomato fruit worm. Not all insects and mites are damaging to crops, however. Some feed on the harmful insects and are considered beneficial to the crop. Beneficial insects include ladybugs and lacewings, which feed on soft-bodied insects such as aphids. Predatory mites feed on thrips, and other mites are extensively used for biological control in North American greenhouses. Some of these may be available in Jamaica for control of specific pests.

Wherever insect pests are found, there are native predatory insects that feed on them. For example, parasitic wasps, *Encarsia formosa*, attack the greenhouse whitefly, but do not attack the sweet potato whitefly. Accurate pest identification before introducing *Encarsia* wasps to control whiteflies is therefore essential. Pest populations can increase rapidly and can outpace their predators, in which case alternative strategies such as pesticides must be used.

PATHOGENIC BACTERIA, FUNGI AND VIRUSES

Plants affected by bacteria, fungi, and viruses can exhibit symptoms on roots, stems, leaves, and fruit. With experience, the grower can narrow down the possible causal agent. Accurate identification of specific diseases can be complicated by the similarity of symptoms exhibited by various diseases. While definitive identification is available through laboratory tests, this can be inconvenient and cost prohibitive.

Key fungal diseases include Botrytis molds, powdery mildew, downy mildew, early blight, and pythium root rots. Certain bacteria cause serious diseases such as bacterial spot, bacterial wilt, and pith necrosis. Common viruses include tomato yellow leaf curl virus (gerry curl), tobacco mosaic virus, and tomato spotted wilt virus. Resistant varieties of many crops are bred to target specific disease; selecting the appropriate variety is an example of a preventative measure central to the IPM strategy.

PHYSIOLOGICAL PROBLEMS

Sometimes plants exhibit symptoms that cannot be easily connected to a specific pathogen. The cause of the symptoms might be traced to stressful plant environment interaction or to a cultural practice. An example of this is blossom end-rot, which occurs commonly on tomato and pepper plants. The identifying symptom is a dry, brown, sunken area on the distal end (the end opposite the stem) of the fruit. The cause of this is an insufficient amount of calcium being translocated to that part of the fruit, resulting in a failure of normal fruit development. The cause is not due to unavailability of calcium in the root substrate (soil/medium), but to a dramatic fluctuation of moisture content of the substrate. In fact, calcium may be present in more than adequate quantities and additional applications of calcium are generally not necessary. Rather, the solution to the problem is to ensure that irrigation is consistently applied to keep moisture levels in the soil at appropriate levels.

Sunscald is another physiological problem that can affect the fruits of tomato, pepper, and other crops. Fruit, still on the plant, unshaded and exposed to intense sunlight and heat can sunburn. This fruit develops a distinct leathery discolouration of the epidermis and underlying tissue. The problem must be anticipated and care should be taken when pruning to leave sufficient side stems and foliage to provide adequate shading for the fruit. Artificial shade can also help to alleviate the problem.

OTHER PESTS

Plant parasitic nematodes can cause serious problems with the roots of plants. Nematodes are the most numerous multi-cellular organisms on earth with over 20,000 individual species identified, the vast majority of which are not plant parasitic but are an important component of the soil food web. When plant parasitic nematodes attack plant roots, they impede the plant’s ability to take up water and nutrients. Research in Florida has shown that nematode attack also predisposes the plants to infection by fungal or bacterial pathogens and that they may transmit viral diseases.

Cultural or chemical methods, or a combination of both, are used to manage nematode populations. For soil culture, chemical treatments are used. All are hazardous and must be used strictly according to the label directions. A cultural method most often used is growing the plants in containers or bags of artificial media and fertigating via a drip system. Properly managed, this approach can minimise the nematode problem. If it develops within the contained media, the medium and plants growing in them can be easily removed to prevent spreading. If the problem increases, the media can be replaced and the container sterilised, causing the growing environment to again be free of nematodes. Media replacement and sterilization should be done after several seasons anyway.

MANAGEMENT STRATEGIES AND METHODS

CULTURAL PRACTICES

Since most growing conditions that favor plant growth also favor the growth of insects and diseases a balance must be struck to achieve healthy plant growth and the reduction of pests and disease. Pest incidence is found to be higher when plants are under stress. For this reason, growers should understand and apply recommended practices to maintain an optimum growing environment while regularly and often monitoring the crop.

RESISTANT CULTIVARS

Resistant cultivars (also known as variety or hybrid) of a certain crop, can minimise or eliminate the impact of specific pests; however, they may be geographically specific, as the local pest complex may include other species or variants for which the new cultivar is not resistant. Growers should grow trial plots of new resistant cultivars prior to adopting them on a large scale. Before deciding to switch to a certain cultivar, though, it is important to remember that while some cultivars may be resistant to the specific pests on site, the cultivar may not suit the tastes of the target market. Additionally, resistance means an attempt to prevent a disease and does not guarantee complete control. This is a subject area in which new developments are frequent. The grower should maintain regular contact with Rural Agricultural Development Authority (RADA) officers, grower co-operatives, and seed suppliers to stay up-to-date on new varieties as they become available. It is advised that prior to adopting a new cultivar on a large scale, growers should plant a trial patch if possible.

USE RESISTANT CULTIVARS

This is an area in which new scientific developments are frequent. Resistant cultivars can minimize or eliminate the impact of specific pests; however, they may be geographically specific, as the local pest complex may include other species or variants for which the new cultivar is not resistant. The use of resistant varieties greatly increases harvest success as they are developed for pest resistance as well as local climatic and environmental conditions. By extension, use of the best available seed sources will also ensure a good start to plants. The grower should maintain regular contact with extension agencies, grower cooperatives, seed suppliers, and use the internet to stay up to date on new developments. It is important to remember as well that while some cultivars may be resistant to the specific pests on site, the actual production of the cultivar may not suit the target market of the operation of the farm. It is always best that the grower research the tastes of the target market before beginning production of a new crop.

SANITATION

A critical component in managing pests and disease is “keeping things clean” inside and outside the structure, including the workers, supplies, and plant material itself. The goal is to eliminate spaces in the production area that would be prime environments for pests and disease to thrive.

Crucial to maintaining a clean growing environment is the prompt remove of trash, weeds, pruned leaves, and over-ripe fruit from the structure.

A hand washing station inside the greenhouse structure

A hand washing station should be available to workers who will be in direct contact with plants and supplies. As the Tobacco Mosaic Virus and other soil-borne disease can be tracked into the structure on shoes, a sanitising foot bath should be placed at each entry point. A simple reservoir filled with a commercial surface disinfectant or a 10% chlorine bleach solution enough to cover the edge of the sole of a shoe is sufficient. Keep in mind that chlorine bleach loses half of its sanitising strength every two hours due to evaporation. At a minimum the solution, whether purchased commercially or using diluted bleach, should be changed daily.

Dirt floors and walkways are difficult to sanitise and can be a breeding place for pest and disease. Adequate drainage is necessary to avoid standing water which can lead to further pest and disease implications. Ideally, a disinfectant (again commercially available or a 10% bleach solution) should be used on all supplies, tools, and walkways.

It is recommended to use insect-free transplants and to avoid bringing other plants into the greenhouse once you plant the intended crop. This also applies to exchanges of plants from other growers. If new plants must be brought in, quarantine them for several days to be sure that they are pest and disease free.

A foot bath filled with disinfectant should be placed at each entry to the structure.

Algae growth should also be kept to a minimum. Not only does an alga serve as a food source for pests, it also can clog emitters and irrigation lines and prevent sufficient wetting on the growing media surface. Not surprisingly, algae flourishes in protected agriculture environments, but proper water and fertilization management can keep growth to a minimum. Allowing the surface of the media to dry between watering sessions will also help to slow growth.

Weeds compete with crop plants for light, water, nutrients and can also harbour or serve as alternate hosts for insects and diseases, which can then migrate to crop plants. Some weeds commonly found among Jamaican crops include Bermuda grass, yellow and purple nutsedge, and white top. Weed control should extend to the adjacent exterior areas of a protected agriculture structure during cropping and non-cropping cycles.

EXCLUSION

One method of preventing plant problems is by minimising access of pathogens to the growing area. Exclusion, keeping insects from entering the protected agriculture structure, is a key part of insect management in Jamaica. Two common methods used in Jamaica are using an airlock entry and insect screening. Air-lock entryways to the structure helps control insect pests from entering through the door as workers enter and exit the structure. For very small insect pests, like thirps, anti-thrips screening is available; however, this will reduce airflow and decrease ventilation potential. Screen all ventilation inlets and outlets, such as a ridge vent and repair holes or tears immediately and clean screens to maintain airflow.

Airlock entry to a greenhouse structure

CROP BARRIERS AND TRAP PLANTS

Crop barriers and trap crops are used to attract pests away from other crops. For example, corn can be planted around a field to serve as a crop barrier to protect the field from insect infestation; it is an especially good crop barrier for scotch bonnet peppers. The use of trap crops and crop barriers is effective within controlled environment systems as well as open field cultivation.

SCOUTING

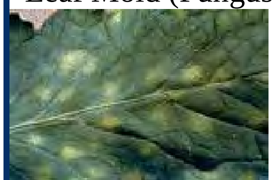
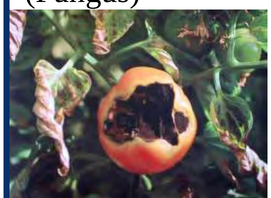
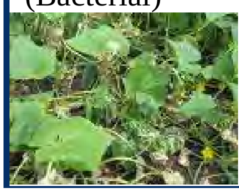
Regular, daily inspection of the crop plants and premises by the grower or assigned employee using a standardised inspection procedure will provide information about developing problems. This information must be documented in writing and immediately evaluated, and the appropriate action should be taken to limit negative impact. Pay attention to plant symptoms, evidence of insect or other pests on plants and any changes in the plant growing structure or premises.

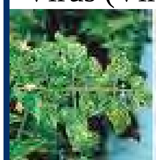
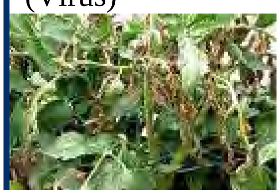
Sticky card traps are uniformly positioned for scouting and recordkeeping

Another key insect monitoring method is the use of yellow sticky traps to measure the presence of white flies, aphids and other important insect pests of the managed environment. Sticky traps are available commercially and are typically bright yellow to attract insect pest. Other colours are also manufactured to attract specific pests. In general, bright yellow is the most effective.

These traps can also be fabricated using boards or cards painted bright yellow and covered with motor oil or another sticky substance. The consistent size and effectiveness of a standard trap is essential for accurate record-keeping. The number of insects trapped each day should be recorded on a tracking sheet and compared to threshold levels, which, when met, indicate when corrective action needs to be taken.

DISEASE MONITORING

DISEASE MONITORING		
Key Disease	**How to Control Disease**	**Where to Look**
Botrytis Gray Mold (Fungus) 	• Keep humidity below 90%. • Avoid overhead watering. • Inspect leaves and remove faded flowers. • Improve air circulation.	Look for light-tan or gray spots on infected leaves. These areas become covered by a brown or gray fuzzy mass of fungus growth and the leaf collapses and withers. Other sites of infection include dying flowers and the calyx area of fruit.
Leaf Mold (Fungus) 	• Use disease resistant varieties of seeds. • Leaf mold can be kept under control if there is good air ventilation and air circulation. • Keep humidity below 90%.	Look for pale-green or yellowish areas with irregular margins on upper leaf surfaces. Beneath the yellow spots areas of olive green velvet growth are visible. Infected leaves become yellow-brown and drop prematurely.
Early Blight (Fungus) 	• Practice crop rotation. • Remove and destruct all crops from previous crops. • Practice staking, mulching, and timely application of fungicides (if necessary). • Use disease tolerant varieties of seeds.	Look for characteristic circular brown leaf spots up to 2 inches in diameter. Spots contain dark rings with a common centre, giving a target-board appearance. Symptoms appear on leaves, stems, and fruit.
Powdery Mildew (Fungus) 	• Provide good air circulation. • Avoid spraying excess fertilizers. • Include adequate spacing between plants and rows. • All production areas should be thoroughly cleaned and plant debris removed between crops and production cycles. This includes removing all weeds in and around the greenhouse.	Look for white patches of fine, powdery growth on the upper sides of leaflets. Patches are up to 2 inches in diameter and generally appear on the oldest foliage. Severe cases weaken the plants and lead to lower yields.
Bacterial Wilt (Bacterial) 	• Control cucumber beetles, as they transmit the bacteria. • Remove all infected vines - wilted vines can not be saved. • Control weeds in and around greenhouse as they can easily help transmit bacteria	Symptoms of the disease first appear on a single leaf which suddenly wilts and becomes dull green.

Pith Necrosis (Bacterial) 	• Pith Necrosis may be controlled by avoiding excessive nitrogen levels. • Keep humidity levels low.	On the lower stems, look for brown, sunken, necrotic (dead) stem cankers. Length-wise cuts through cankers reveal hollow stems, a symptom of the disease.
Tomato Mosaic Virus (Virus)  	• Choose resistant varieties. • Spreads through touch and some types of tobacco. Be careful and make sure your hands and clothes are clean. • Use fresh soil after each crop as it can be transferred through the soil. • Carefully clean all plant growing equipment and all greenhouse structures that come into contact with plants.	Look for plant stunting and leaves developing mild to severe yellow-green spots, crinkles, ridges, strings, or curls. Stems may develop streaks of dead plant tissue. Generally, fruit shows no symptoms, although severe strains may cause internal browning, pitting, or severe mottling. When you suspect the disease is present, you need to get an accurate diagnosis and remove diseased plants promptly.
Tomato Spotted Wilt (Virus) 	• Tomato spotted wilt is one of only a few viruses transmitted by thrips and is by far the most dangerous. Eliminate weeds from inside the greenhouse and the adjacent exterior areas. • Greenhouse workers should avoid wearing yellow or blue clothing to deter the spread of thrips.	Look for small, dark brown leaf spots in the upper portion of the plant, which may be arranged in a "ring-spot" pattern. Also look for dark streaking in petioles and stems, stunted growth terminals, and brown or black lesions on distorted fruit

BENEFICIAL INSECTS

Predatory insects, mites, nematodes, and parasitiods which feed on pests can be purchased, encouraged and/or conserved. While this approach can be effective in insect pest control, availability and cost constraints are a limiting factor at this time in Jamaica. At present there is limited production of insect pest predators in Jamaica and, due to their fragile nature, transportation can be risky. Another control technique involving non-threatening insects is the use of insect pheromones to trap or disrupt pest populations. An example of this from Jamaica is the use of the sweet potato weevil females to attract males to a water trap, where they are then drowned.

BENEFICIAL BACTERIUM

The use of cultures of bacterial toxins from bacteria such as *Bacillus thuringiensis* (Bt) to control caterpillars is another form of biological control. Bacterial toxins are applied on crop plants with a spray which, when ingested by the pests, kills them. They are selective in action and are harmless to humans and most other non-target organisms.

TRAP CROPS

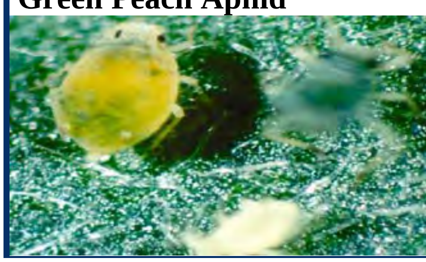
The trap crop strategy involves identifying a type of plant which provides greater attraction to the pest than the cash crop does. The trap crop is planted some distance away from the cash crop but near enough to attract the pests. The pests can then be controlled on the trap crop without causing damage or leaving chemical residues on the cash crop.

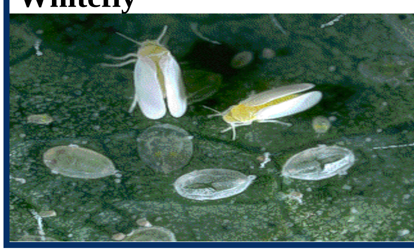
An example from the US is the perimeter planting of a trap crop of Blue Hubbard squash around a cucumber crop to manage spotted cucumber beetles. The Hubbard perimeter is sprayed with insecticide when the beetles arrive. The beetles are contained at the perimeter, thus ceasing the need to spray the cash crop for this pest. Trap cropping is most effective and economical when a specific insect is a regular, serious seasonal pest.

CHEMICAL CONTROL

The use of chemical sprays should not be the first choice for control of pests in protected agriculture structures but rather among the last options. When it is determined that other methods are not effective and chemical pesticide spraying must be done, the grower should abide by the RADA list of approved pesticides for specific crops grown under specific conditions. This is imperative to ensure compliance with food safety, worker safety, and environmental impact. All directions for use on pesticide labels must be accurately followed.

PEST AND DISEASE PROFILES

PEST MONITORING		
Key Pest	**How to Monitor**	**Where to Look**
Melon Aphid 	Rely on plant inspection, not sticky cards. Early in the crop, before flowering, scout weekly. Look for small, 1/16" long aphids with dark cornicles or "tailpipes." Melon aphids are less likely to form winged adults than green peach aphids.	Inspect incoming plant material on underside of leaves and stems. Melon Aphids are more likely to be found along the plant stem than on the growing tip.
Green Peach Aphid 	Monitor weekly. Rely on plant inspection, not sticky cards. Winged adults are only found on cards when aphid colonies on weeds and crops become overcrowded.	Look on tips of new growth for 1/14" long green to pinkish aphids. Look for signs of aphid activity: shed white skins, honeydew, and/or the presence of ants. Inspect and remove weeds.

Western Flower Thrip 	Rely on sticky card counts for population trends and to evaluate treatments.	Inspect incoming plant material for adults and larvae by tapping tender new growth and flowers over a white sheet of paper. If thrips are suspected, keep plants isolated for 4-5 days to detect emerging eggs and pupae. Inspect and control weeds outside of the greenhouse in early spring. Check in and around the flowers.
Nematode 	Perform weekly plant inspections. Visible symptoms (root knots) will appear 6 weeks after first infestation.	Look for swellings (knots) on the roots. These could be localized. Look for weeds during the pre-planting phase.
Caterpillar 	Perform weekly plant inspections.	Look for leaf damage and frass (feces). Inspect fruit.
Whitefly 	Rely on plant inspection to detect immature stages, (especially on young plants) and use sticky card counts to monitor adults.	Older larvae are found on the lowermost leaves. Egg-laying adults are found on the uppermost leaves. Inspect and remove weeds.

APHIDS

Green peach aphid, *Myzus persicae*; Potato aphid *Macrosiphum euphorbia;* Melon aphid, *Aphis gossypii*

There are several different species of aphid. All of them suck plant juices, causing leaves to curl and turn yellow. Aphids (also referred to as plant lice) are small, soft-bodied insects that differ in colour from light green or yellow to pink, red, or black. Some species inject toxic saliva or disease-causing organisms into the plant during feeding. Heavy aphid infestations may cause a failure of bloom set in some vegetable crops. Aphids excrete large amounts of sticky undigested plant sap, known as honeydew, which can support the growth of sooty mould fungus. Although sooty mould fungus does not attack the plant directly, heavy amounts of honeydew and sooty mould can discolour fruit and interfere with photosynthesis.

BIOLOGY

Most aphid species reproduce without mating and give birth to live aphid nymphs rather than laying eggs. Under the best conditions, the nymphs, which are usually all females, can reach maturity and begin bearing young of their own within seven days. Due to this high reproductive rate, heavy infestations can develop quickly. Mature females may be winged or wingless depending on environmental conditions, and infestations are easily spread through the wind-assisted flight of winged females. Although aphids usually have a fairly narrow host range, many species occur on a number of vegetable plants as well as on certain common weeds.

Outdoors, aphids are preyed upon and parasitised by many beneficial insects, such as ladybugs, and this naturally occurring biological control normally keeps aphid populations in check. Outbreaks occur when aphid populations get ahead of biological controls or when this control is disrupted by insecticide treatments targeted toward other pests. Aphid infestations often begin in isolated areas within the greenhouse and prompt spot treatments can eliminate these infestations before they spread. Several biological control agents are available for use against aphids in greenhouses, including generalist predators such as lacewings, lady beetles and several species of parasitic wasps.

MANAGEMENT

Exclusion and sanitation are important in avoiding aphid infestations. Proper screening of ventilation fans and maintaining a "bug tight" greenhouse will prevent entry of wind-borne females. Do not allow weeds and other plants to grow in the greenhouse during non-crop periods and maintain control of broadleaf weeds around the outside edges of the greenhouse to further limit infestation risk. Also, do not allow other plants to be brought into the greenhouse when a crop is in production.

INSECTICIDES FOR APHID CONTROL

An aphid infestation is a challenge to control with chemicals in protected agriculture structures. They are resistant to many insecticides and have a high reproductive rate. Due to this resistance research is being done on other methods of control, much of it focused on the effects of releasing the aphid's natural enemies into the structure. In Jamaica, unfortunately, this practice is currently limited by supply and shipping issues. Some insecticides that are registered for aphid control include Azadirachtin ,Malathion, and pyrethrims. Malathion is an extremely toxic contact insecticide. Less toxic insecticide methods include *Beauvaria bassiana*, insecticidal soaps, horticultural oil, and natural pyrethrums. The biopesticide *Beauvaria bassiana* is a fungal disease that infects aphids.

WHITEFLIES

Silverleaf whitefly, *Bemesia argentifolii;* Greenhouse whitefly*, Trialeurodes vaporariorum*

Despite their name, whiteflies are not true flies but rather are closely related to aphids. Adults are about 1/16 inch long and have four wings covered with a white, powdery material. They rest with their wings folded tent-like over their backs and are weak fliers. Immature whiteflies are very different from adults. Except for the newly hatched crawlers, immature flies are immobile and resemble tiny, oval scales attached to the underside of leaves. Whiteflies cause damage by sucking sap from plants and producing honeydew, which supports the growth of sooty mould. These insects can build up large populations in protected greenhouse environments and are capable of causing severe crop loss.

There are several different species of whiteflies but the two most common species in greenhouse tomatoes are the greenhouse whitefly and the silverleaf whitefly. Of these, the silverleaf whitefly is the bigger threat and is the more difficult to control. Silverleaf whiteflies can transmit several serious tomato viral diseases and they also cause a problem known as irregular ripening. This is thought to be physiologically induced, meaning that it is not caused by a disease itself but is an indirect result of the whitefly infestation. It is important to know which species of whitefly you are dealing with before implementing treatments. Proper species identification is especially important when using biological controls because many biological control agents only work on a certain species. The parasitic wasp *Encarsia formosa* is especially effective against greenhouse whiteflies, but other parasites are more effective against silverleaf whiteflies.

BIOLOGY

Female whiteflies lay about 150 eggs at a time, usually attached to the undersides of leaves. In greenhouses, eggs hatch in 4-7 days and tiny, white, oval crawlers emerge. These move a short distance, insert their mouth-parts into the plant tissue, produce a protective scale-like covering, and do not move for the rest of their nymphal development. Nymphs go through three instars and a pupa stage before reaching adulthood. The winged adults emerge through a slit in the pupae covering after 25 to 30 days. Adults may live up to 30 days.

MANAGEMENT

Yellow sticky cards placed in the upper plant canopy are useful for monitoring whitefly populations. Exclusion and sanitation are the keys to whitefly management. You can also buy and release certain predators and parasites into the greenhouse system to manage whiteflies. To be effective, though, biological controls must be well planned and put in place when whitefly populations are low.

It is important to know which species of whitefly you are targeting with bio-control efforts. For example, *Encarsia formosa* can provide good control of greenhouse whiteflies, but Eretmocerus wasps more effectively control silverleaf whiteflies. There are also some predatory insects, such as the tiny lady beetle *Delphastus pusillus* that attack whiteflies. Bio-pesticides, such as *Beauveria bassiana* fungus, are also useful in controlling whiteflies. Although biological controls can be initiated when the whitefly population is small, good exclusion practices are still important. If other pests are present, the grower may have to apply insecticide that would disrupt the biological control program. Properly screened greenhouses also keep expensive biological agents from escaping after their release.

INSECTICIDES FOR WHITEFLY CONTROL

Azadirachtin, *Beauvaria bassiana*, buprofezin, imidacloprid, paraffinic oil, potassium salts of fatty acids, pyrethrins, pyriproxyfen {acetamiprid}, spiromesifen are useful insecticides for whitefly control.

Effective control of whiteflies depends on controlling the immature stages. Azadirachtin is a botanical insect growth regulator useful against whiteflies. It controls the larvae and has a short pre-harvest interval (PHI). Buprofezin (Talus) and pyriproxyfen (Distance) are insect growth regulators that are very useful against whiteflies. Imidacloprid and acetamiprid are useful systemic insecticides that control larvae as well as adults. Imidacloprid (as Provado) has a very short PHI when applied as a foliar spray. Imidacloprid (as Admire) may also be applied one time per crop as a media drench, with a 0-day PHI. Paraffinic oil and potassium salts of fatty acids provide contact control of adults and crawlers. Pyrethrins will provide short-term control of adults but these products will not control immature whiteflies.

Regular scouting and undertaking control efforts when whiteflies are first detected is crucial. Whiteflies are difficult to control with insecticides because the eggs and non-feeding pupae are not controlled by either contact or systemic treatments. The actively feeding nymphs are hard to control with contact insecticides. There are several insecticides that kill exposed adult whiteflies, but effective control of whiteflies depends on controlling the immature stages. Fortunately, greenhouse growers now have access to several systemic or insect growth regulator products that are effective against whiteflies. The growth regulators buprofezin (Talus) and pyriproxyfen (Distance) and the systemic insecticide imidacloprid (Admire) are especially useful whitefly control tools. When applying foliar sprays for whiteflies, it is best to spray when the temperature is 70 to 80 °F. Because whiteflies can quickly develop resistance to insecticides they are exposed to repeatedly, pay close attention to information on labels about resistance management and alternate insecticide use.

THRIPS

Western flower thrips, *Frankliniella occidentalis*; Tobacco thrips *Frankliniella fusca*; Onion thrips *Thrips tabac*.

Thrips are tiny insects, less than 1/16 inch in length, that feed on plant leaves, blooms, and fruit with “punch and lap” mouth-parts. There are several different species of thrips but western flower thrips, onion thrips, and tobacco thrips are the most common in Jamaica. Although they do not often occur in greenhouse tomatoes in large enough numbers to cause serious injury, thrips are important pests to learn about because they can vector tomato spotted wilt virus (TSWV). Thrips can also scar and distort fruit by feeding on it at a young stage.

BIOLOGY

Thrips reproduce on a large number of crops and weeds, many of which serve as hosts of TSWV. The eggs, which are inserted into plant tissue, hatch into elongated, spindle-shaped larvae. They begin feeding on the undersides of leaves by puncturing cells with their ice pick-like mandible and lapping up the outflowing plant fluid. The larvae feed in this fashion for 8 to 12 days before moving to the ground, finding a protected location, and entering the pupa stage, which lasts 3 to 7 days.

Adult thrips, which have fringed wings, return to host plants to feed in the same manner as the larvae and to deposit eggs. Although they are small and relatively weak fliers, adult thrips are easily windblown and can migrate long distances. Adult flower thrips often gather in blooms where they feed on pollen. Immature thrips become infected with TSWV when feeding on infected plants. Migrating adults remain infected for the rest of their lives and spread the virus to other hosts.

MANAGEMENT

Because thrips can vector TSWV, exclusion and sanitation are the best methods of control. A very fine mesh screening to needed to exclude the pests due to their small size. Screening and other exclusion practices will also prevent entry of other greenhouse insect pests. Blue or yellow sticky cards are useful monitoring tools; blue cards are most attractive to thrips, but yellow cards attract a wider range of pests, including thrips.

Be careful to avoid bringing thrips or TSWV-infested plants into the greenhouse. It is also important to control and prevent the growth of broadleaf weeds around the greenhouse because these weeds can serve as hosts for both thrips and TSWV. When insecticide treatment is needed, contact insecticides such as spinosad or Malathion can provide effective control. Other control options such as *Beauveria bassiana* may be more compatible in greenhouses where biological control is used. Several species of predatory mites prey on immature thrips.

INSECTICIDES FOR THRIPS CONTROL

Azadirachtin, *Beauvaria bassiana*, chlorfenapyr, Malathion, paraffinic oil, potassium salts of fatty acids, pyrethrins, spinosad are useful for controlling a thrip infestation. Although spinosad is mainly used to control caterpillar pests, it is also one of the best products for thrips control. Malathion, paraffinic oil, potassium salts of fatty acids and pyrethrins provide contact control of thrips. Azadirachtin is a botanically derived insect growth regulator. *Beauvaria bassiana* is a bio-pesticide mainly used to control whiteflies, but it also provides some control of thrips.

LEAFMINERS

Vegetable leafminer, *Liriomyza sativae;* Serpentine leafminer, *Liriomyza trifolii.*

Leafminers feed on a variety of weeds and vegetable crops, including tomatoes. In the outdoors, naturally occurring parasites and predators often keep leafminer populations in check; however, leafminers can be significant pests in greenhouses where the naturally occurring parasites and predators are excluded. The leafminers most commonly encountered around greenhouse tomatoes are vegetable leafminers, *Liriomyza sativae*, and serpentine leafminers, *Liriomyza trifolii*. Adults of both species are small flies about 1/12 of an inch long that are black with yellow markings. Their overall appearance is similar to that of fruit flies.

These pests never attack the fruit directly. Damage is caused by the larvae, which mine in the leaves, causing winding or blotch-shaped mines that reduce leaf area and interfere with translocation of minerals and nutrients within the leaf. Although light infestations (one to two mines per leaf) have little negative effect, heavy infestations can decrease the functional leaf area and overall productivity of the plant. Heavy infestations are usually found in the lower portion of the plant, fortunately reducing negative impact on the yield in comparison to an attack on the newer, higher leaves.

BIOLOGY

Egg laying is concentrated in the middle and lower parts of the plant as leafminers prefer to deposit their eggs in mature leaves. The female flies insert their eggs into the leaf tissue individually, laying several hundred eggs over a lifetime. The eggs hatch in about 3 days and the small larvae begin feeding between the upper and lower leaf surfaces, creating narrow, winding mines. As larvae grow, the width of the mines increases and mines often become blotch-shaped. Depending on temperature and other environmental conditions, the leafmining stage lasts 5 - 12 days. Larvae then emerge from the leaf to form yellowish-orange, oval-shaped pupae, which usually roll off the foliage onto the ground. A new generation is produced about every 23 days, but there is usually great overlap of generations in greenhouse infestations.

MANAGEMENT

Pruning lower leaves is a standard production practice that helps control diseases as well as leafminers. For success, pruned leaves must be promptly removed from the greenhouse environment. Plastic sheets placed over the surface of the growing medium can prevent pupae from falling in the growing media and cause them to roll into the aisle where they can be more easily removed with sweeping or vacuuming. In addition, *Diglyphus isaea* and *Dacnusa siberica* are two species of parasitic wasps commonly used for biological control of leafminers.

INSECTICIDES FOR LEAFMINER CONTROL

Azadirachtin, pyrethrins, and spinosad are useful in controlling leafminers. Although spinosad is mainly used to control caterpillar pests, it also is effective against leafminers. Malathion and pyrethrins are used to control adult leafminers. Because they are protected inside the leaf, larval leafminers can be difficult to control. Leafminers often quickly develop resistance to insecticides after repeated exposure.

SPIDER MITES

Two-spotted spider mite, *Tetranychus urticae*

Spider mites are not insects but tiny, eight-legged pests that feed on the undersides of leaves. Species include the Two-spotted spider mite, *Tetranychus urticae.* Although spider mites are visible to the naked eye, it takes a 10X or higher power hand lens to see these pests well. Damage is caused by both adults and larvae, which feed on the undersides of the leaves, removing sap and causing the leaves to become discoloured. Where populations are heavy, they can cause leaves to drop off of the plant.

Spider mite species range in colour from light green to red. Two-spotted spider mites are probably the most common species in Jamaica and are also one of the most difficult to control. Spider mites are most likely to reach damaging population levels under hot, dry conditions; initial signs of infestation include leaves that look *stippled*, or dotted. Close examination of the undersides of leaves with a hand lens will reveal all stages of mites and eggs.

When infestations are heavy, a fine webbing of silk will often be present and mites may be found on the upper surface of the leaves. Infestations often begin in isolated spots within the greenhouse and prompt application of spot treatments will usually prevent spread to the remainder of the house. Although they are wingless, mites can easily migrate throughout the house on workers performing normal maintenance operations. Mites can also be brought into the greenhouse on the clothing of workers or on new plants.

BIOLOGY

Eggs are deposited on the undersides of leaves where they hatch into six-legged larvae. These begin feeding on leaf tissue and soon molt into eight-legged nymphs. The nymphs then develop into sexually mature adults. The rate of development is strongly influenced by temperature and other environmental conditions; under optimum conditions, two-spotted spider mites can complete a generation in as little as 5 to 7 days. Adult females may live 1 to 2 weeks and deposit up to 100 eggs per female.

MANAGEMENT

Because populations of spider mites can develop on many species of plants, good sanitation practices are crucial to avoiding infestations. Care should be taken to control broadleaf weeds around the outside of the structure and not to let weeds grow inside the house. Several species of predatory mites, such as *Phytoseiulus persimilis*, are available for use in biological control programs.

TOMATO RUSSET MITES

The Latin name for this pest is *aculops lycopersici*. Tomato russet mites are much smaller than spider mites and can only be seen easily under a microscope or through a strong hand lens. Adults are about 0.2 mm long and are yellow, cigar-shaped creatures with two pairs of legs located near the larger end of the body were the head is. These mites belong to the family known as *eriophyidae* and differ greatly from spider mites. Since these mites are quite difficult to see with the naked eye, the damage they cause is often mistaken for disease or nutritional deficiency.

As their name implies, injury symptoms are leaf and stem *russeting*, or bronzing and leaf curling. The leaf curling is due to the large numbers of tiny mites feeding on the leaves. Tomato russet mites can survive and reproduce throughout the country in greenhouse-grown tomatoes; they are particularly aggressive in field grown tomatoes in the southern areas of the country where warm conditions allow continuous survival of favourable hosts.

BIOLOGY

Tomato russet mites are wingless. They spread by wind movement and are carried on clothing, birds, or insects. They have a relatively narrow range of host plants, occurring on solanaceous crops such as tomato, eggplant and peppers as well as on solanaceous weeds like nightshade and jimson weed. Eggs are deposited on the surfaces of leaves and stems where they hatch into tiny nymphs that immediately begin feeding and quickly grow to adults. They can complete a generation in as little as 7 days.

MANAGEMENT

Sanitation is the key to avoiding infestations of tomato russet mites. Do not allow weeds to grow in greenhouses between crops as these can serve as hosts. Likewise, maintain good control of weeds in the area immediately surrounding the greenhouse and do not allow potential host plants to be brought into the greenhouse when a crop is being grown.

MITICIDES FOR TOMATO RUSSET MITE CONTROL

Chlorofenapyr Sulphur is one of the products traditionally recommended for chemical control of tomato russet mites, but more specific miticides, such as Vertimec, provide better control.

FUNGUS DISEASES

BOTRYTIS GRAY MOLD *(Botrytis cinerea)*

Botrytis Gray Mold is probably the most common and troublesome disease to attack greenhouse tomatoes. This is because botrytis-resistant tomato varieties are not available and the fungus is present in all greenhouses. Infection by the gray mold fungus occurs when the relative humidity is 90 percent or higher. All plant parts can be invaded. Plants are generally more vulnerable during fruit bearing.

KEY SYMPTOM

Look for light tan or gray spots on infected leaves. These areas become covered by a brown or gray fuzzy mass of fungus growth and the leaf eventually collapses and withers. Other sites of infection include dying flowers and the calyx area of fruit. From the calyx, infection proceeds into fruit, which quickly becomes water-soaked and soft. Under a hand lens you can see spore-bearing structures that look like bunches of grapes on the infected tissue. Since the causal fungus does not actively attack healthy tissue, stem invasion occurs through branch stubs resulting from pruning or other injured sites along the stem. The tan cankers that form along the stem may be large and often cause early plant death. Under humid conditions, distinct masses of fungus growth form on canker surfaces.

LEAF MOLD *(Fulvia fulva)*

Leaf Mold was a common and severe problem in the early 1970's because resistant varietals were not available. Today, most modern varieties have complete resistance to all races of the leaf mold fungus. Varieties with incomplete resistance are often affected by leaf mold under humid conditions. A grower must scout these varieties frequently for early symptoms of this disease. This disease is favoured by the same conditions that encourage gray mold development. Infection occurs when relative humidity remains at 90% or higher for several hours. Leaf Mold symptoms begin on lower, older leaves and progress to younger foliage over time.

KEY SYMPTOM

Look for pale green or yellowish areas with irregular margins on upper leaf surfaces. Beneath the yellow spots, areas of olive green velvet growth are visible. Infected leaves become yellow-brown and drop prematurely with defoliation ultimately progressing up the plant as the infestation worsens.

EARLY BLIGHT *(Alternaria solani)*

Early Blight sometimes causes problems in greenhouse tomatoes. Symptoms appear on leaves, stems, and fruit.

KEY SYMPTOM

Look for characteristic circular brown leaf spots up to 2 inches in diameter. Spots contain dark rings with a common centre, giving a target-board appearance.

POWDERY MILDEW *(Erysiphye sp.)*

Powdery mildew is a fungal disease that does not present a widespread problem in greenhouse tomatoes.

KEY SYMPTOM

Powdery mildew is identified by white patches of fine, powdery growth on the upper sides of leaflets. Patches are up to 2 inches in diameter and generally appear on the oldest foliage. Severe cases weaken the plants and lead to lower yields.

BACTERIAL DISEASES

BACTERIAL WILT (*Pseudomonas solanacearum*)
Plants affected by these bacteria will rapidly wilt and die without yellowing or showing leaf necrosis. When a wilted plant is cut near the soil line, the inside of the stem looks dark and water-soaked, though, these symptoms are not always easy to detect.

KEY SYMPTOM
The grower should examine a cross-section of the lower stem for sap that could be squeezed out were the stem to be pressed. In late stages, the stem may become hollow.

PITH NECROSIS (*Pseudomonas corrugata*)
Pith Necrosis is sometimes referred to as bacterial hollow stem. Affected plants often wilt and show a slight yellowing of lower foliage.

KEY SYMPTOM
On the lower stems, look for brown, sunken, necrotic (dead) stem cankers. Length-wise cuts through cankers will reveal hollow stems, a symptom of the disease.

VIRUS DISEASES

TOMATO MOSAIC VIRUS (ToMV)
ToMV was a major threat to protected cultivation until the introduction of resistant varieties of tomato in the early 1980s. Today, most modern varieties are resistant to ToMV, a strain of Tobacco Mosaic Virus (TMV), and this disease is no longer a serious menace to production. Those growers who use vulnerable varieties need to become familiar with ToMV in case the disease attacks and plant removal becomes necessary. ToMV diagnosis may be difficult; symptoms depend on variety, age of plant at time of infection, and environmental conditions.

When infected, plants become stunted and leaves may develop mild to severe yellow-green spots, crinkles, ridges, strings, or curls. Stems may develop streaks of dead plant tissue. Generally, fruit shows no symptoms, although severe strains may cause internal browning, pitting, or severe mottling. With such a wide array of possible symptoms, there are no key symptoms to scout. ToMV spreads easily through pruning, fruit harvesting, and other routine activities, and when the disease is suspected, it is imperative that the grower get an accurate diagnosis and remove diseased plants promptly.

TOMATO SPOTTED WILT VIRUS (TSWV)
TSWV can be a widespread problem in greenhouse tomatoes. Like ToMV, diagnosis of TSWV in greenhouse tomatoes can be difficult as symptoms can be many and varied. TSWV symptoms can also be confused with those caused by other viral, fungal or bacterial pathogens, or nutritional disorders. Scouting for and controlling thrips populations is important to prevent the spread of TSWV. Many weedy plants can harbour the virus, thus it is important to keep a weed-free perimeter around the greenhouse. Test kits are available to check for the presence of TSWV in tomatoes.

KEY SYMPTOM

If you suspect TSWV, look for small, dark brown leaf spots in the upper portion of the plant, which may be arranged in a "ring-spot" pattern. Also look for dark streaking in petioles and stems, stunted growth terminals, and brown or black lesions on distorted fruit. Remove suspect plants immediately.

The preceding Pest and Disease Profiles are adapted from Greenhouse Tomatoes Pest Management in Mississippi, a Mississippi State University Extension Publication #1861, Blake Layton and David Ingram.

Resource

See Appendix #2: Pest and Disease Management inside the Greenhouse (Crop Bulletin #5)

Module 7

BUSINESS MANAGEMENT

INTRODUCTION

The concept of good business management can be summed up as having a solid plan to reach a reasonable goal and the resources and knowledge to act on that plan. In this case, successfully producing a crop and selling it to the market for a profit is the goal. Business management can be considered to have five basic components: planning, organizing, leading, coordinating, and controlling. In this module, the widely recognized tool for plannin*g* - a business plan - will be presented. Types of record keeping that aid in organization and coordination across different aspects of a business will be distinguished. This type of coordination will lead to easier control of the decisions a business should take to manage an operation that is profitable. Also included is an introduction to credit options in Jamaica, current market information, and external web resources that provide detailed information, advice, and templates for business management documents such as business plans, record keeping, and financial applications.

For the Rural Agricultural Development Authority (RADA) extension officer, it is necessary to have a wide range of knowledge when assisting protected agriculture growers. Just as the environment and agriculture are inextricably linked, economics has significant effect on the success of small holding growers. Assisting growers who are using protected agriculture to turn a profit is an important part of helping to avoid environmentally damaging practices of agriculture around Jamaica. The RADA marketing division can play a key role in assisting extension officers with business related issues that the grower may experience.

This module covers:

1. Business Plans
2. Credit
3. Types of Records
4. Market Information
5. Resources

BUSINESS PLANS

A business plan is a written document that summarizes the operational and financial goals of a business – in this case a farm using protected agriculture techniques. Ideally, the business plan will contain detailed plans and budgets that act as a roadmap, showing how the objectives are to be realized. The plan describes the nature of the business, marketing strategy, and financial background of the farm. While a business plan is commonly thought of as a crucial tool for banks, stockholders and investors to determine the status and future of a venture, it is also a beneficial tool for the owner of a business. The process of preparing a business plan can reveal strengths and weaknesses of an operation and allow for analysis of a business in a methodical and strategic way. Although there are variations to the format of a business plan, the basic components are generally the same.

COMPONENTS OF A BUSINESS PLAN

EXECUTIVE SUMMARY

The executive summary is considered the most important part of the plan because it communicates the size and scope of your business and how it will fulfill a need in the market. The summary should get the reader's attention and be easy to read, generally less than two pages long. It is most effective to write this section last when you have already worked out the details of the plan and can better summarize them.

BUSINESS SECTION

The business section usually starts with a short description of the sub-sector in which the business operates, relevant current trends, and why the business planner has decided to pursue the given line of business or the activity for which the plan is being developed, if applicable. This section includes details about products and services, in this case crops to be grown and the market to which they will be marketed, business management, business organization, legal structure, and an operational plan.

An operational plan describes the day-to-day activities of employees (including job descriptions) in the business. For example, who is in charge of irrigation, who troubleshoots nutritional disorders, who scouts for pests, who maintains market contact, and who pays the bills.

MARKETING SECTION

The goal of the marketing section is to outline the strategy the business owner uses to sell the product and, ultimately, to make a profit. In order to make this outline complete, it is necessary to cover such topics as: current trends in the sub-sector, target market, uniqueness and market demand of your product, competition, and advertising. The section is also expected to identify barriers to entering the market and what plan, if any, there is to surmount them. For example, transportation barriers including access to roads and refrigerated trucks to maintain produce quality in the post-harvest stage should be addressed.

It is appropriate to present personal observations, and crucial to provide secondary sources of information. Personal, primary sources reveal the understanding of the sub-sector as a whole and how a grower fits into the market. Secondary sources provide objective data and include published information found in technical sheets from the government agencies, newspapers, trade journals, industry association proceedings and vendor records.

FINANCIAL SECTION

The financial section communicates how to finance ("pay-for") the overall vision of the business venture. If accurately done, it becomes a reasonable estimate of how and how quickly the operation will turn a profit. Details about the amount of capital needed and whether personal funds or outside financing will assist in project start-up are crucial. If applying for a loan, clearly state the amount needed, how it will be used, and how it will make your business more profitable (which is how the loan will be repaid).

All statements in the financial section should be supported by standardized business documents and worksheets such as personal financial statement, annual income projections, a break-even analysis, a balance sheet, and cash flow statements. Similar to the business plan, these documents are required by investors and stakeholders, but are also immensely beneficial to the owner. The process of creating them often reveals areas of financial weakness in the business.

CREDIT

It is the responsibility of the loan recipient to foster and maintain a good relationship with his or her creditors. Lenders must be provided with accurate and current personal and business financial statements as well as other materials as requested. The process of applying for a loan can be significantly eased by providing the lender with balance sheets, income statements and cash statements for your business in addition to business and marketing plans, as discussed in the last section. These plans give your lender a better feel for your operation, where it is headed, and how well you have planned your business for challenges that could occur in the future.

In Jamaica, there are several credit options. Traditional loans, which typically require collateral and a down payment, generally offer competitive interest rates. Credit availability has been enhanced through a Scotia Bank-initiated, single digit interest rate fund, available through the People's Cooperative Banking System and the Development Bank of Jamaica. Commercial banks and other lending institutions offer loans at higher rates. For example, in April 2008 traditional loan terms hovered around 7.8% annual percentage rate (APR) for JA $100,000 to JA $5,000,000. Other loan structures require no collateral or down payment; however, the terms of the loan are different than a more traditional loan. For example, interest may be calculated with a monthly percentage rate instead of an annual rate, meaning that a 3% monthly rate can become a very expensive 36% annual rate if the loan is not paid off quickly. Other financing options include loans offered directly from a company providing services or supplies. An example of this would be a drip irrigation company which provides the financing for consultation and supplies.

TYPES OF RECORDS

Record keeping requires time and effort but is crucial to operating and growing a successful business, be it a small holding farm with one employee or a large agro-processing start-up that will employ 20 people. Systematic record keeping tracks progress and allows the recorder to learn from mistakes. It is important to recognize that records are important in all aspects of your operation, not just financial areas. Production records, for example, can track the performance of different cultivars to take the guess work out of ordering seed for the next crop cycle.

INVENTORY RECORDS

An inventory should be kept of all stock items such as fertilizers, tools, buildings and machinery for insurance and loan purposes. Inventory records make ordering supplies fast, efficient and accurate.

FINANCIAL RECORDS

Financial records are crucial to a profitable operation and provide an assessment of the profitability of the growing operation. They should include all transactions (in coming and out going) that occur in the course of business. Some examples of important financial records are a balance sheet and income statement. A balance sheet determines the financial state of the farm at a given point in time. An income statement demonstrates the financial in-flow and out-flow, or income and expenses, of the business over a determined period of time.

PRODUCTION RECORDS

These documents provide information on quantity of produce harvested and sold, fertilizer applied, comparisons between past yields, and other information necessary for specific crops, cultivars and conditions. These records are particularly useful overtime to track long term trends in productivity.

LABOR RECORDS

Labor records provide information pertaining to a farm's paid workers. This includes, but is not limited to, wages, hours worked on specific tasks and type of work. Objective information regarding specific tasks a worker performs also allows for fair expectations of productivity.

CROP RECORDS

These documents provide information pertaining to general plant health and the environment including:

- daily minimum and maximum temperatures;
- relative humidity measurements of plant growth and development;
- pH and EC of growing media;
- general root health and other crop specific observations;
- insect scouting totals; and
- counts from monitored plants.

MARKET INFORMATION OF PROTECTED AGRICULTURE CROPS

The case has been widely made that purchasing managers in Jamaica prefer protected agriculture-produced crops. The information provided in this section of the module outlines the main findings from the USAID-funded JA FARMS project Market Survey.

The Market Survey was targeted at prominent agro-processors, bulk produce buyers (restaurants, grocers, resorts), and small producers to determine their supply chain needs and to identify potential new markets for the expanding sub-sector of protected agriculture growers in Jamaica. The breakdown of participating industries is illustrated in the chart below.

How would you describe the sector to which your firm belongs?	
ANSWER OPTIONS	RESPONSE PERCENT
Restaurant	28.60%
Hotel/Resort	28.60%
Grocery/Supermarket	23.80%
Grower/Producer/Processor	38.10%
Other (please specify)	Airline caterer

Key Findings:
The respondent firms are well aware of, and well connected to, the island's local growers. The majority of firms – across all produce-buying industries – want to buy locally and already source a significant percentage of their produce domestically. Most of the firms interviewed for this survey indicated that their consumers preferred to eat local produce, and that the flavor found in local produce far exceeds that of imported produce, even as there continues to be a role for the import market in supplying items not indigenous to Jamaica and in managing interruptions in supply. The two exceptions to this rule were an importer and a foreign-owned grocery store, who both expressed deep frustration with the local produce market's lack of consistent supply and in some cases, poor quality.

This question asks firms how many small growers are already supplying them:

What percentage of your current suppliers would be considered domestic, small (fewer than 50 employees), micro or cooperative enterprises?	
ANSWER OPTIONS	RESPONSE PERCENT
0-25%	11.80%
25-50%	29.40%
51-75%	11.80%
51-75%	11.80%
76-100%	47.10%

Despite the interest of most firms to buy locally, several obstacles exist which must be overcome before the sector will be able to deliver the consistency of supply and the quality of the produce that the market as a whole requires. These obstacles center around disruption caused by storms, the weak farming practices of many small growers, limited access to technology, and the limited access to capital many small growers require to run a reliable farming operation.

Firms are already spending substantial sums of money on produce, a portion of which could be sourced from greenhouses. The firms that responded to this question jointly spent forty one million JD last year on cabbage alone, sixty three percent of which was sourced domestically. Seventy one million JD was spent on callaloo, of which virtually all was sourced domestically. Thirty six million JD was spent on scallion, of which ninety seven percent was sourced domestically.

The following were the items on the produce list ranked by expenditure in the left column (excluding Other categories).

How much money does your firm spend purchasing each product annually?		
RANK	ANSWER OPTIONS	RESPONSE PERCENT
1	Callaloo	$72,685,288
2	Cabbage	$41,639,000
3	Escalion	$38,165,241
4	Tomato	$19,500,000
5	Lettuce – Iceberg	$15,492,000
6	Sweet Pepper	$2,950,000
7	Cantaloupe	$2,805,000
8	Cucumbers	$1,756,000
9	Broccoli	$1,530,000
10	Cauliflower	$1,176,000
11	Squash	$1,090,000
12	Zucchini	$560,000
13	Lettuce – Romaine	$540,000
14	Snow Peas	$250,000
	Other 1	$2,468,881
	Other 2	$1,068,192
	Other 3	$5,890,180

These additional items are also in high demand:

1. Carrot
2. Scotch bonnet pepper
3. Ginger
4. Thyme
5. Onion
6. Sorrel
7. Pumpkin
8. Irish potato
9. Melon
10. Pigeon peas
11. Mushrooms
12. Herbs

*Also listed were many fruits that cannot be grown in greenhouses.

While many purchasers currently do not use greenhouse growers to supply their businesses, they do believe that there is room for a successful greenhouse sub-sector in Jamaica and would be interested in building relationships with high-quality growers in the future. While a number of firms were excited at the thought of a burgeoning greenhouse sub-sector, noting that it would increase the quality and the volume of produce, many firms expressed concern that greenhouse produce would be too expensive in an already expensive marketplace. Firms also cited concerns that while greenhouses may improve the quality of the produce, they would not address the equally vexing problem of consistency of supply and would take business away from the smallest and poorest of the growers.

In what ways have you considered expanding your supply chain?	
ANSWER OPTIONS	RESPONSE PERCENT
Hiring local famers and cooperatives.	84.60%
Building relationships with domestic greenhouse	69.20%
Building relationships with major importing companies.	61.50%
Developing self-managed farms.	53.80%
Other (please specify)	76.90%

Most participants responded that local small producers provide the best overall value for their goods, despite significant challenges with consistency of supply and quality. Though frustrations, including negotiating a fair price and *praedial larceny* (theft of things attached to the land or a farm), plague the industry, most participants still felt that local growers provided the best overall value for their produce.

This next question sought to find out which suppliers provide the best overall value (price, quality, consistency of supply).

In what ways have you considered expanding your supply chain?			
ANSWER OPTIONS	DOMESTIC SMALL PRODUCER	DOMESTIC GREENHOUSE GROWER	IMPORTED USA
Cabbage	8	2	2
Lettuce - Iceberg	6	4	2
Lettuce - Romaine	3	1	5
Sweet Pepper	6	2	5
Tomato	4	6	3
Squash	2	0	6

Zucchini	4	1	3
Callaloo	10	2	2
Broccoli	3	0	7
Cauliflower	2	0	5
Cucumbers	7	0	2
Snow Peas	3	1	3
Cantaloupe	6	0	3
Scallion	11	2	2
Other 1	7	1	0
Other 2	4	1	0
Other 3	4	1	0

More information regarding the market survey can be obtained through the RADA Marketing division by requesting the JA FARMS Market Survey for Protected Agriculture crops.

RESOURCES

The following websites provide online assistance and templates for creating a simple business plan:

www.score.org
SCORE is a non-profit association dedicated to educating entrepreneurs nationwide. SCORE is a resource partner with the United States Small Business Administration.

www.sba.gov
United States Small Business Resources includes resources such as planners and form templates

www.entrepreneur.com
Entrepreneur.com includes articles, advice, and resources for small business owners

Module 8

ECOLOGICAL CONSERVATION

INTRODUCTION

The following section describes the natural history of the island of Jamaica and its associated ecosystems, and the relationship between biodiversity conservation and sustainable agriculture. The long-term changes in the environment due to agriculture are examined against the need for a shift in thinking towards sustainable and protected agricultural practices to offset centuries of negative environmental impact and the increasing threat of climate change. Food security and an ever more harsh and competitive global market also drive the need for production systems that are able to increase production while withstanding the uncertainty of weather patterns and avoiding excessive negative impact on the surrounding environment.

This module covers:

1. History
2. Basic Ecology
3. Agriculture and Biodiversity Conservation
4. Water
5. Air Quality
6. Soil Erosion
7. Reduction in Chemical Use
8. References

HISTORY

Agriculture has been an activity identified with Jamaica since the island became a Spanish colony in the sixteenth century. After the English took control of Jamaica from the Spanish in 1655, there began a period of widespread agricultural expansion which included growing sugar cane on flat coastal and inland areas, raising cattle in dry areas, cultivating cocoa in hilly areas and producing coffee in mountainous areas, in particular the Blue Mountains. Estate slaves practiced subsistence agriculture behind colonial states; this was the source of some open field cultivation techniques still used in Jamaica today. At the time of emancipation, environmental degradation due to agriculture was reasonably contained even though soils in some repeatedly cultivated areas were already showing signs of nutrient depletion.

The nineteenth and early twentieth centuries saw a rapid increase in the number of small holding growers operating in Jamaica; by the 1950s there were just over 173,000 farms of less than 10 acres in size on the island. The number of farms of similar size, including landless farmers, stood at 220,000 in 2007. This rapid increase in labor intensive cultivation led to pronounced and often negative environmental impacts. The promotion of agriculture, particularly for domestic food production, and, by extension, the incentives given to small growers to encourage increased farm production, accelerated the impact of agriculture on the environment. The detrimental impact of roughly 300 years of uncontrolled agricultural cultivation has been noted by growers and naturalists alike who have grown progressively more concerned about the future of Jamaican biodiversity. In response, initiatives to protect forests, woodlands, and wildlife were designed and implemented in rural Jamaica in the last quarter century. The designation of game and forest reserves and the launch of a number of major conservation programs and projects have been overseen by the Jamaican government to address the growing danger to the island's biodiversity from farming/agricultural land use. These programs include:

- the *Land Authorities Programmes* in Yallahs and Christiana, under the Land Authorities Act of 1952;
- the *Farm Development Scheme*;
- the *Integrated Rural Development Project*;
- the *Jamaica Watershed Management, Forestry and Irrigation Project*;
- the *Hillside Agriculture Development Project*;
- the *Morant Yallahs Agriculture Development Project*; and
- the *Eastern Jamaica Agriculture Support Project*.

In addition to the areas designated under local legislation as protected, several wetlands have ben declared "Wetlands of International Importance" under the *Ramsar Convention*. These projects have had various objectives but share the common goals of increased food protection, improved standards of living in rural areas, soil conservation, reduced deforestation and increased tree cover.

In Jamaica, both the *National Biodiversity Strategy* and the resulting *Action Plan* recognize that unsustainable agriculture is a major challenge to biodiversity on the island. Respectively, they propose and outline the implementation of steps to address this major challenge. Improper agricultural practices, such as slash and burn, inappropriate crops and the introduction of exotic species, which lead to soil erosion, forest incursion and high water consumption, are all included in the documents as issues to be addressed now and moving forward.

BASIC ECOLOGY

The science of ecology studies the distribution and abundance of living organisms and the interactions between these and the environment. The environment of an organism includes physical properties, which can be described as the sum of local *abiotic* (non-living) factors, such as sunlight, the climate, and geology, and *biotic* (living) factors, or other organisms that share the same habitat.

Biological diversity, or biodiversity, is defined as the variability among living organisms from all environments, to include terrestrial, marine, and other aquatic ecosystems and the ecological processes of which they are part. Thus, biodiversity includes the variety of genera, species, and habitat types within a given environment.

An ecosystem is a functional unit of an environment that consists of all plants, animals and micro-organisms interacting. The interaction of these organisms with each other and with the abiotic elements of the environment comprises the ecosystem. In Jamaica, typical land-based ecosystems include montane forests, limestone forests (wet or dry), coastal scrub, thorn thickets, mangroves, swamps, rocky shorelines, and beaches; sea grass beds and coral reefs are typical marine-based (salt water) ecosystems and rivers are aquatic (fresh water) ecosystems. The ecosystems described above are natural ecosystems, meaning that they have developed and thrive without human input. Farms are recognized as a kind of ecosystem as well and are called agro-ecosystems. An agro-ecosystem is an ecological and socio-economic system comprised of domesticated plants and/or animals that produce food or other agricultural products under human guidance.

Within ecosystems, there are communities. A community is a collection of plants or animals that share a distinctive combination of biological characteristics. Within communities, there are habitats. A habitat is the natural environment in which a plant or animal lives, or the physical conditions by which they are surrounded and on which they depend to survive. Habitats are often characterized by their climate or physical conditions, and can be natural or human-controlled.

Flora refers to all plant life on the planet, regardless of the medium in which it occurs; *fauna* refers to all animal life, from whales to amebas. Both flora and fauna are subdivided into species. A species is a single, distinct class of living organisms with unique and distinguishable features. Among other characteristics, members of each species are capable of interbreeding among themselves, but not with other species.

The term *endemic* refers to a plant or an animal found only in a particular geographic location. *Endemicity* is the percentage of endemic flora and fauna in a given location and is a measure of the uniqueness of the biodiversity in that area.

AGRICULTURE AND BIODIVERSITY CONSERVATION

ECOLOGY CONSERVATION

As noted in the introduction, there have been various programs established by the Jamaican government to address ecological conservation, both in natural systems and in agricultural systems. Jamaica has been aware of the endangered status of watersheds and the lands in the elevated regions of the island from as early as the late 1800s.

It is important to increase our understanding of how ecological systems work and to find ways to apply ecological principles in the design of managed systems. Agricultural practices during the second half of the last century demonstrated how the lack of ecological understanding can be highly detrimental to the natural environment and, ultimately, have negative economic implications for the sector as a whole. Specifically, intensive and highly mechanized agricultural practices have threatened or damaged the soil, bodies of water, and wildlife. Over time, these negative effects have had an impact on agriculture itself, including pesticide resistance in crops and genetic mutation. To alleviate these problems, it has become necessary to facilitate a change in the way that growers view the land and to develop and implement ecologically based agricultural practices. Fundamental to this shift is the view of farms as ecosystems, known as agro-ecosystems.

PRESERVING BIODIVERSITY

The biodiversity present within an ecosystem has an essential, though not always notable, role in regulating the chemistry of the atmosphere, pollinating crops and controlling the course of the water supply. As well, biodiversity is directly involved in the recycling of nutrients and maintaining the fertility of soil. The total value of the 'services' provided by biodiversity to the ecosystem in which it thrives would amount to trillions of dollars per annum. Data collected outside of Jamaica indicates that the honey bee pollination is estimated to provide the equivalent of between US$10 and US$18 billion worth of pollination performed by humans.

Current thinking in biodiversity preservation focuses on reducing the rate of degradation of natural and agricultural ecosystems. A sustainable agricultural system protects the integrity of natural systems so that natural resources are continually regenerated. An agricultural system is not sustainable unless it supports the decrease of environmental degradation. To this end, sustainable agricultural systems should aim to maintain or improve their surrounding environments in ways such as managing groundwater and surface water quality and regenerating healthy agricultural soils.

AGRICULTURE CAN SUPPORT BIODIVERSITY

Biodiversity conservation/protection within a sustainable agriculture framework requires strategies to be developed and implemented on many levels. These strategies should include farming using protected agriculture systems, partnering with non-governmental organizations involved in conservation or other entities that work to preserve local interests, and establishing an open dialogue with policy makers and institutions responsible for ecological oversight. Partnerships to protect local biodiversity can involve growers' associations that are formed to protect the natural resource base of their area, organizations with delegated authority to monitor the resources of a protected area, or even with individual communities to create demonstration sites where training can be held.

The link between agriculture and biodiversity is complex and clear identification of threats as well as a carefully articulated conservation strategy are required to address the relationship on all levels. It is often said that agricultural intensification contributes to biodiversity conservation by reducing the need to exploit natural areas; however, experience shows that intensification can have both positive and negative impacts on biodiversity. The link between agricultural activities and conservation should be clearly identified and result in appropriate monitoring mechanisms being put in place to measure all impacts.

Sustainable agricultural activities that are clearly and directly linked to the conservation of biologically significant areas may be considered biodiversity conservation activities, even if those areas are not formally recognized as biologically significant. Protected agriculture structures, such as greenhouses, have been identified as positive intervention method to mitigate threats to biodiversity in and around biologically significant areas. They offer an alternative to clearing land for cultivation on steep slopes and can limit further incursion into natural areas in relatively flat lands.

The Jamaican Ministry of Agriculture, in particular the Rural Agriculture Development Authority and the USAID-funded JA FARMS and REACT projects, have promoted the use of protected agriculture technology for intensive production of high-value vegetable crops for the last several years. As a result, growers utilizing protected agriculture structures have experienced a significant increase in yields, length of season, and resilience to climate and pests. The increase in yields has translated directly into less land area required to generate the same household income.

BIODIVERSITY CAN SUPPORT AGRICULTURE

Biodiversity has played a vital role in enabling agriculture to develop into its current productive state. Genetic variation has allowed plant breeders to select desirable plant characteristics and manipulate plant DNA. Maintaining genetic diversity will be a significant factor in the stability and future development of agriculture. Additionally, modern biotechnology is likely to pave the way for cultivation of new crops and alternative crop strains needed for food security and industrial development.

The maintenance of biodiversity also benefits the maintenance of commercial agriculture practices. An example of this is the biological control of pests, which functions effectively due to the structure of ecosystems and the predator/prey relationship. Such controls have allowed for a reduction in the use of pesticides, benefitting the ecosystem surrounding the agricultural system.

Biodiversity and agricultural development can co-exist peaceably through land management policies and practices that consider the protection of wildlife. Such policies specifically aim to:

1. Protect and maintain existing wildlife features and habitats, which are important for biodiversity;
2. Enhance the wildlife value of farmland, which is of low biodiversity at present;
3. Take advantage of opportunities to establish new, permanent areas of conservation value, especially when identifying alternative uses for idle or mined out lands.

Conversely, biodiversity conservation policies can advocate and support agricultural practices that protect biodiversity and the environment. Such policies include aim to:

- Recognize and strengthen those regional and local farming and land management practices that enhance the national diversity of flora and fauna, habitats, landscapes, historical features and character; and which will help to strengthen links between land use and local community identity;
- Improve livestock management to minimize pollution from wastes and establishing stocking densities which are related more closely to the environmental carrying capacity of the land;
- Improve crop management to reduce the need for fertilizers and pesticides;
- Encourage the use of traditional, long established livestock breeds and crop varieties, which are adapted to the climate and topography of each region;
- Recognize the importance of those traditional skills and practices used by those who manage land and upon which many valued habitats depend;
- Introduce greater diversity on the farm, for example through the encouragement of reversion of arable land to pastoral use in appropriate areas and the wider use of rotations in arable farming;
- Maintain hedges, where possible and appropriate to the area concerned; and/or
- Withdraw from productive agriculture altogether in selected areas and allowing natural succession to take its course.

ENVIRONMENTAL MANAGEMENT AND SUSTAINABLE AGRICULTURE

Environmental management is not, as the phrase could suggest, the management of the environment as such but rather the management of human interaction with and impact upon the environment. A central concept of environmental management is the measure of *carrying capacity*. Carrying capacity refers to the maximum number of individuals a particular resource can sustain. Environmental management is therefore important not only the conservation of the environment the environment's sake, but also for humankind's sake. It involves the management of all components of the bio-physical environment, both biotic and abiotic.

Sustainable agriculture is one method to keep humans living within the carrying capacity of their local environment. Sustainable agricultural production practices involve a variety of approaches that take into account topography, soil characteristics, climate, pests, local availability of inputs and the individual grower's goals. Despite the site-specific and individual nature of sustainable agriculture, several general principles are followed by growers to select appropriate management practices for their local environment:

1. Selection of species and varieties that are well suited to the site and to conditions on the farm or in the protected agriculture system;
2. Consideration of factors such as soil type and depth, previous crop history, and location (e.g. climate, topography) before planting, when site selection is an option;
3. Diversification of crops (including livestock) and cultural practices to enhance the biological and economic stability of the farm;
4. Management of the soil to enhance and protect soil quality;
5. Efficient and ecologically sensitive use of inputs; and
6. Consideration of growers' goals and lifestyle choices.

Diversified farms, or those growing several different crops, are usually more economically and ecologically resilient. While monoculture farming has advantages in terms of efficiency and ease of management, the loss of the crop in any one year can put the farm out of business and/or seriously disrupt the stability of a community dependent on that crop. By growing a variety of crops, growers spread economic risk across several investments and are less susceptible to the radical price fluctuations associated with changes in supply and demand. Diversification using protected agriculture within a larger farming system can help growers to reduce exposure to extreme weather and thereby reduce the risk of associated losses.

Transition to new ways of performing a long practiced activity can be challenging. Incentives in may be necessary to coax some people into new practices and attitudes. Making the transition to sustainable agriculture is an ongoing process and will require a series of small, realistic steps that can be undertaken in several areas. There several general areas where a grower can start to make this transition: Water, Air Quality, Soil Erosion, and Reduction in Chemical Usage.

WATER

Water conservation is crucial to sustained ecological well-being for all ecosystems; the implementation of water conservation policies that both limit waste and chemical run-off is a significant way that growers can limit negative impact on the environment. The most immediate problems related to water quality involve salinization and contamination of ground and surface waters by pesticides, nitrates and other chemical compounds.

In Jamaica, the relatively recent establishment of water user groups, water user associations and individual irrigation systems under the amended Irrigation Act is a reflection of the new approach to involving growers in the management of natural resources. Many practices associated with protected agriculture, ranging from simple row covers and mulching to more sophisticated systems such as greenhouses and advanced controlled environment agriculture, help to reduce water loss and water consumption. Drip irrigation when added to these systems further improves water efficiency. Hydroponic systems in which plants are grown in a nutrient solution with or without the use of an artificial medium can promote water efficiency, especially if the system is closed so that the nutrient solution is recovered and reused.

With respect to water consumption, growers can immediately reduce negative environmental impact by:

- Improving water conservation and storage measures;
- Using reduced-volume irrigation systems; and
- Managing crops to reduce water loss and chemical run-off.

AIR QUALITY

Air quality also needs to be addressed as many agricultural activities have a direct effect on it. Smoke from agricultural burning, dust from tillage, traffic and harvest, pesticide drift from spraying, and nitrous oxide emissions from the use of nitrogen fertilizer are all released into the air around a farm and effect more than just the growers involved as the wind carries the pollutants across the island. Options in open field systems to improve air quality include incorporating crop residue into the soil, using appropriate levels of tillage, and planting wind breaks, cover crops or strips of native perennial grasses to reduce dust. Protected agriculture systems mitigate many of these effects; the enclosed system reduces pesticide drift into the outside environment, prevents pests from attacking plants thereby reducing the overall need for pesticides, and produces minimal dust from farm machines or tillage.

SOIL EROSION

Soil erosion continues to be a serious threat to the food security of the island. The Jamaican land mass is characterized by steep slopes with more than 50% of the island over 1600m above sea level and sloped in excess of 20^{o}. This is a prime case for severe land erosion. The situation is further aggravated by susceptible soils and high intensity rainfall. A large population of small growers using natural resources on the upper slopes exerts further pressure on the already fragile system.

Numerous practices have been developed to keep soil in place, which include:

- reducing or eliminating tillage;
- managing irrigation to reduce runoff;
- erecting physical barriers;
- terracing; and
- keeping the soil covered with plants or mulch.

REDUCTION OF CHEMICAL USE

A highly debated issue in sustainable agriculture is the use of chemical pesticides. Integrated Pest Management (IPM) and protected agriculture systems are strategies to address threats to agricultural crops, which utilize varied but complementary methods in an ecologically sensitive manner. IPM is the coordinated use of available pest control methods and ecological information to prevent unacceptable levels of crop damage at a reasonable cost and with the least possible hazard to people, property, and the environment. Refer to Module 6 for details of management strategies of IPM.

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MODULE 9

CROP CULTURE

INTRODUCTION

When growing crops in a protected agriculture structure it is important to understand the basics of the plant in order to make the necessary adjustments that will lead to success. Outlined below is information about several of the most common greenhouse-grown crops in Jamaica. Crops covered in this module include: tomato, sweet pepper, cucumber and lettuce; the topics listed below are covered for each crop.

This module covers:

9. Tomato
10. Sweet Pepper
11. Lettuce
12. Cucumber

TOMATO (*Lycoperson esculentum Mill*)

The tomato is a member of the *Solanceae* family, which includes a number of other important food crops, such as the Irish potato, peppers, and eggplants. In Jamaica, tomato is one of the most commonly produced vegetables in protected agriculture structures. If the proper cultural practices are followed, one tomato plant can remain productive for nine months to one year.

GROWTH HABITS

Categories of tomato growth habits range from indeterminate types, characterized by a vining growth, to semi-determinate or determinate types that have a more compact growth habit. Indeterminate types are commonly cultivated in greenhouses where they are well-suited to trellising and training for continuous production over a long period of time. An example of this type of growth habit includes the *Alboran* variety which is commonly grown in protected agriculture structures in Jamaica. Based upon their regular growth and flowering habits, indeterminate types can yield fruit consistently over a growing season. Comparatively, semi-determinate types generally build to a large initial yield that can be followed by an extended period of moderate yield.

FRUIT TYPES & GENETIC CONSIDERATIONS

Tomato is a variable crop, producing a broad range of fruit types. Common fruit types of tomato include small grape, cherry, saladette, plum, standard, and beefsteak. As with many other crops, tomato cultivars may either be hybrid or non-hybrid (open pollinated). Tomato crops are naturally self-pollinating; an open pollinated seed typically breeds true-to-type. Heirloom is a term to describe one category of non-hybrid tomatoes. Rather than it being necessary to buy seed from a commercial seed supplier, a grower could save seed from a heirloom plant with confidence that it would produce true-to-type fruit in the next production cycle. The term *heirloom tomato* originated from the practice of growers passing down seeds from generation to generation. Heirlooms cover the gamut of fruit types in regards to size and other characteristics; the types include those which are hollow (often prepared stuffed) and which may have large non-uniform fruit comprising a diversity of colours ranging from white through yellow, orange, the standard red and to a deep burgundy referred to as black

Many modern tomato cultivars are hybrids, being produced by the controlled crossing of two parent lines to encourage specific, positive traits. Hybrids tend to be uniform, high yielding, and typically resistant to multiple diseases, but they do not breed true-to-type. Seeds saved from hybrids will produce a variable crop of mixed genotypes, segregating from the many attributes found in the parent hybrid.

A number of specific traits are present in some tomato cultivars, including:

- **Hot-set genes:** these prevent fruit abortion at higher temperatures than normal cultivars;
- **Long shelf life:** this characteristic naturally slows the ripening process at the red stage, maintaining a firm fruit for some time longer than for cultivars that do not possess this trait;
- **Uniform ripening:** this trait eliminates the tendency for tomatoes to produce green shoulders, particularly under high temperature conditions;
- **High Lycopene:** recently released on the market, this cultivar has high levels of the anti-oxidant lycopene. This may mark the beginning efforts by breeders to cater to consumer interests in enhanced health benefits from their fresh fruit and vegetables.

DISEASE RESISTANCE

Genetically disease resistant tomatoes are of great value to the reduction in the use of pesticides. For this reason tomato breeding programs work hard to identify resistance to key diseases. Several cultivars are manifestly resistant or tolerant to diseases and pests, including *Verticillium Wilt*, *Fusarim Wilt* races 1, 2 and, to a lesser extent, 3, *Root Knot Nematodes* and viruses such as *Tobacco Mosaic* (see table below). Cultivars resistant to Tomato Yellow Leaf Curl (Gerry Curl), such as Tropical Delight, are now becoming available in Jamaica.

There are still many significant diseases, particularly the foliar bacterial and fungal diseases, such as Septoria Leaf Spot and Early Blight, for which there is little or no resistance in tomato. Diseases such as these can rapidly devastate field grown tomato crops in rainy seasons and are virtually eliminated by growing tomatoes under the protection of a covered structure.

COMMON TOMATO VARIETIES GROWN IN JAMAICA

VARIETY	SOURCE	FRUIT SIZE (GRAM)	GREEN-BACK	VIRUS RESISTANT	FUNGI RESISTANT	NEMATODE RESISTANT	COMMENTS
Cocktail Type							
Picolino	De Ruiter			No	No	No	
Flavorino	De Ruiter			No	No	No	
Standard Type							
Alboran	Rijk Zwaan	140-160	Yes	ToMV	CF:-, Fol:0,1,For, Sbl, Va	No	

Beefsteak Type							
Beverly	Rijk Zwaan	160-180	Yes	ToMV, TSWV	Fol:0,1 For, Mi, Va, Cf:-, Sbl	No	
Ivone		220-240	No	ToMV	F1, F2, FCCR Leaf Mold Verticullium Wilt, Race1	No	Clusters should be pruned to 4-5 fruits, smooth skin
Geronimo	De Ruiter	240	No	ToMV	FCCR, Ff1-5, Fol:1, For, On, Va, Vd/Si, Powdery Mildew, Verticillium Albo-atrum, Verticillium Dahlie, silvering	No	Large beefsteak, vigorous plant with generative habit, high yield, not sensitive to cracking, good flavor and color
Tyranus	Seminis		No	Gemini (Geri Curl)	F1, F2	Yes	Firm fruit, good shelf life, heat tolerant
Blitz	De Ruiter	198-255	No		No	No	

F1= Fusarium Race 1, F2= Fusarium Race 2, FCCR=Fusarium Crown and Root Rot, ToMV= Tobacco Mosaic Virus, TSWV= Tomato Spotted Vilt Virus

ENVIRONMENTAL REQUIREMENTS

TEMPERATURE

Mature tomato plants thrive when daytime temperatures are between 80˚F and 85˚F and when night time temperatures are between 62˚F and 72˚F. Tomato fruit sets can cease when day temperatures exceed 95˚F and when night temperatures do not fall below 75˚F. Temperatures below 55˚F also inhibit fruit sets resulting in deformed (cat faced) fruit.

LIGHT

As well, high light intensity at temperatures over 90˚F can be damaging to the crop. Indeed, during the hottest season, the crop benefits only 50% from shade.

FERTILISER AND WATER REQUIREMENTS

Requirements for fertiliser and water vary with the stage of growth and perhaps by cultivar. Requirements for the former are determined by the amount of nutrients that the crop removes from the soil or growing media. A ton (2000 lb.) of fresh tomato fruit and vines contains about 6 lb. of N (Nitrogen), 0.8 lb. of P (Phosphorus) and 9.4 lb. of K (Potassium). Tomato requirements for potassium increase markedly after fruiting begins, and thus, nutrient formulations may vary, depending on the stage of crop growth. In a soil-based culture, nutrients come from both the soil and from added fertiliser, whereas in media-based growing systems, the grower provides for all of the plant's mineral requirements through fertigation.

In soil-based systems, application rates of fertiliser should be based on soil tests and recommendations, according to the nature and properties of local soils. Typically, pH adjustments and all of the phosphorus required by the crop are applied prior to planting along with one-third to one-half of the nitrogen and potassium requirements. The remainder of the nitrogen and potassium are applied during the crop growing cycle using a fertiliser injector system. Requirements for nitrogen and potassium increase as the tomato plant develops. The table below illustrates the increasing need of nutrients as the crop grows.

SAMPLE N AND K FERTILISATION PROGRAM FOR TOMATOES IN SOIL CULTURE				
DAYS AFTER PLANTING	DAILY N	WEEKLY N	DAILY K_2O	WEEKLY K_2O
	lb/acre			
Pre-plant	50		100	
0 – 21	0.5	3.5	1.0	7.0
22 – 49	0.7	4.9	1.4	9.8
50 – 70	1.0	7.0	2.0	14.0
71 – 91	1.1	7.7	2.2	15.4
92 – 112	1.0	7.0	2.0	14.0

Source: *Minnesota high tunnel manual for commercial growers*. University of Minnesota, USA.

In non-soil media-based systems all minerals are provided to the crop by the irrigation water in precise formulations that may be purchased as pre-mixes or formulated from soluble fertiliser salts. Total concentrations of salts vary throughout the crop cycle and the concentration of phosphorous is increased to meet demands for this nutrient during fruit production.

In organic in-ground systems, nutrients are typically added through the incorporation of compost. It is common, though not necessary, to add all of the required nutrients ahead of the crop. Excess compost is typically added based on the expectation that only a certain proportion (50%) will become available to the crop during the production season.

Water requirements vary with the size of the plant, but can be in excess of 2 qt per plant per day for a large plant during hot weather. Tomatoes are highly susceptible to flooding and will suffer if roots are submerged for even a few hours, particularly in hot weather. Therefore, overwatering should be avoided.

The table below illustrates the fertiliser needs of tomato plants cultivated in non-soil media.

SAMPLE FERTILISER PROGRAM FOR TOMATOES IN COIR CULTURE				
	Transplant to 2nd cluster (ppm)	3rd to 5th cluster (ppm)	6th cluster to harvest of 2nd cluster (ppm)	Harvest of 3rd cluster to termination (ppm)
Nitrogen	210.0	210.0	182.0	168.0
Phosphorus	62.0	62.0	46.5	46.5
Sulphur	192.0	192.0	160.0	128.0
Potassium	292.5	351.0	370.8	292.5
Calcium	481.2	421.1	320.8	389.0
Magnesium	97.2	97.2	72.9	72.9

Iron	2.8	2.8	2.8	2.8
Copper	0.2	0.2	0.2	0.2
Manganese	0.8	0.8	0.8	0.8
Zinc	0.3	0.3	0.3	0.3
Boron	0.7	0.7	0.7	0.7
Molybdenum	0.05	0.05	0.05	0.05
Iron	2.8	2.8	2.8	2.8

Source: *Minnesota high tunnel manual for commercial growers*. University of Minnesota, USA.

PROPAGATION

Tomatoes are mostly grown from seed, which is germinated to produce transplants, typically in a propagation house separate from the main production structure. In the propagation structure, seedlings should be carefully tended and monitored in order to produce high quality, compact transplants. It is advisable to germinate seeds in an artificial medium or specially formulated soil mix to ensure adequate drainage and aeration. The tomato transplant should be stocky (as opposed to leggy) and is ready for transplant when it reaches 4 to 6 inches tall - typically 4 to 6 weeks after seed sowing. The cost of greenhouse tomato seed can be very high so each plant should be carefully nurtured to ensure success and to reduce waste.

GROWING SYSTEMS AND CULTURAL PRACTICES

In protected agricultural systems, tomatoes may be grown in-ground or in media. When grown in-ground, plastic mulches are typically used to control weeds and conserve water. These may vary in colour, having aluminised or white surfaces which tend to reflect light and result in cooler soil temperatures. There is evidence that these types of material also serve to disorient whiteflies. In hydroponic systems, pots or bags containing the crop may be set out on the soil surface or on a white weed barrier used to cover the entire floor of the growing structure.

Growers examine trellised tomato plants at an early stage of growth

In the protected structure, plants are spaced in rows that allow for workers to pass easily during harvest and when tending the crop. When a trellising and training is done, use twin rows on beds spaced 1.5 m (5 ft) from the centre of one row to the next. Within row spacing, there may be up to 38 cm (15 in) between plants and an offset arrangement of plants in the twin rows. This results in a growing space of about 0.28-0.33 sq. m (3.0-3.5 sq. ft) per plant. The preferred cultural practice for greenhouse tomatoes is to train them to one or two main stems, trellising them up a string hung from a supporting wire over the bed.

The training is done either through the removal (pruning) of suckers and the clipping of the vine to the string, or by wrapping the vine around the string. For indeterminate tomatoes, extra string is wrapped on a bobbin or tomato hook hung from the overhead wire. As the vine grows and the crop is harvested, the string is unwound from the bobbin, the vine is lowered to the ground, and the twine bobbin is shifted down the trellis wire, allowing the tomato to continue growing at a manageable height. By the end of a crop, vines may be many feet long, trailing along the bed.

POLLINATION

Tomatoes require pollination to set fruit. Poor pollination may result in flower abortion or in non-uniform fruit. In outdoor systems, insects and wind ensure pollination, but in a protected agriculture system, manual pollination should be done every other day. It is possible to accomplish this using a vibrator, leaf blower, mist blower, or gently shaking the stems. The ideal conditions for pollination to occur are when pollen release is highest, around 10 AM, the relative humidity is between 60-70%, and the temperature is within 21-27°C (70-80°F).

CLUSTER PRUNING

Tomatoes produce flowers in clusters of up to 10 flowers. If each of these is allowed to set fruit, fruit size will be variable. To limit this variability clusters are frequently pruned to 3 to 5 fruits when the first fruits have set and are still small in size (no larger than a Jamaican dollar coin). Shape is compromised by excessive numbers of fruit in a cluster, leading to a reduction in quality due to the poor shape and also because the small, later-setting fruits are prone to blotchy ripening. In order to maintain good quality fruit size and shape, the cluster must be thinned, usually from three to four fruits per plant.

Cluster pruning should be done about once per week. This allows several fruits in a cluster to set, so that a choice can be made regarding which to remove and which to leave. The objective should be to thin the cluster to a group of fruits that are most uniform in size and developmental stage. Cracked fruits and misshapen fruits should be removed no matter the size. When cluster thinning, workers must take care not to rub or scratch fruits. Abrasions caused early in fruit development result in large scars at harvest; therefore, care should always been taken when working around or handling the crops.

LEAF PRUNING

Leaf pruning is done to remove old leaves from the lower part of the plant so as to improve air movement under the plant and to make the growing plants easier to manage. As fruit is harvested, leaves are removed from the lower clusters. Sharp shears are used to make a clean cut about a half-inch from the main stem. This stub will eventually dry up and abscise from the main stem. Pruned leaves and other debris should be removed from the structure and composted or disposed of in some way to avoid creating an unsanitary environment in which pests and disease thrive.

While tomatoes do not require a great deal of leaf area to support active fruit production, excessive pruning can result in depletion of the photosynthetic capacity of the growing tomato crop and may also result in the sun burning the fruit, particularly if shade cloth is not used.

DISEASES, PESTS, AND PHYSIOLOGICAL DISORDERS

Tomato Yellow Leaf Curl Disease (Gerry Curl) is a whitefly transmitted viral disease that has recently become significant in the Caribbean region. Where available, planting disease resistant varieties is a preferred approach to disease management. Although few tomato cultivars have resistance to this disease, more are becoming available, including Tropical Glory, a semi-determinate resistant cultivar. Where resistant cultivars are not available, whitefly exclusion from protected structures is the preferred method of control; this, however, presents an ongoing challenge in hot climates, since the required fine mesh screens cut down on air movement, making temperature control difficult. Additional threats arise from plant parasitic nematode populations which can be very high in tomato production soils. Resistant cultivars, if available, are the preferred approach to management.

Botrytis is a common greenhouse fungal disease which develops under humid conditions and when air circulation is poor. The main approach to controlling this disease is to remove diseased tissue from the greenhouse and to make sure good sanitation is maintained and that plants are managed to optimise air movement.

Foliar fungal diseases such as Septoria Leaf Spot do not usually present a problem under protected structures. This is because rain shelters prevent splashing and help maintain foliage in a dry state, preventing the development and spread of this and other foliar fungal and bacterial diseases.

Blossom End Rot is an important physiological disorder that can affect tomatoes. While it is the result of a calcium deficiency in the plant, it is most typically controlled through regular irrigation. Fertiliser imbalances can potentially contribute to this problem.

Sunscald can be serious in unshaded tomatoes and result in the loss of marketable yield. The best approach to sunscald is to provide shading to decrease light intensity and control heat in the protected structure.

Zippering and cat-facing are descriptive of fruit deformities that typically result from cool temperatures. A thrips infestation can also result in zippering or russeting of the fruit surfaces. Ripening disorders, such as *green shoulder*, *hard core*, and *gray wall* can happen when high temperatures occur during fruit development. *Fruit cracking* occurs when significant watering follows a prolonged period of dryness and affects some varieties of tomatoes.

Resource

See Appendix #3: Growing Greenhouse Tomatoes (Crop Bulletin #1)

SWEET PEPPER *(Capsicum annuum)*

The pepper is a member of the *Solanaceae* family, the same family as the tomato, potato, and eggplant. While there are a number of cultivated species of peppers, in Jamaica the pepper most commonly grown in protected structures is *Capsicum annuum,* known commonly as the sweet or bell pepper.

GROWTH HABITS

When grown in the field, sweet bell peppers are typically not pruned. In protected agriculture structures, they are more likely to be grown using a trellising system in order to maximise production per unit area.

FRUIT TYPES & GENETIC CONSIDERATIONS

There is a large range of pepper types. Knowledge of and demand for speciality types are increasing in many areas as consumers become familiar with the different varieties. Currently in Jamaica, protected agriculture structures are primarily used for the production of sweet bell peppers, particularly red, yellow or orange coloured fruit that usually secures a high market price in the hotel trade. Local markets, on the other hand, often demand the more affordable, smaller, green fruit.

Genetic considerations for peppers are similar to those of tomatoes. The crop tends to be self-pollinating, although open-pollinated cultivars do exist. Though the crop will self-pollinate and produce fruit, it does benefit from mechanical or bee pollination. Humidity does not inhibit pepper pollination. Many modern pepper cultivars are hybrids, meaning that seeds originating from these cannot be saved or bred to be true to their parent type.

TEMPERATURE REQUIREMENTS

Sweet bell peppers grow best in the range of 21-24°C (70-75°F). Below 18°C (64°F) and above 27°C (81°F), growth will decrease. Peppers can tolerate daytime temperatures of over 30°C (86°F) if night temperatures fall to the 21-24°C (70-75°F) range.

FERTILISER AND WATER REQUIREMENTS

Sweet bell peppers have higher general requirements for fertilizer than tomatoes. A ton (2000 lb.) of fresh pepper plants will contain 12.4 lb. N, 1.2 lb. P and 12.4 lb. K. As with tomatoes, requirements for potassium and nitrogen increase with plant growth and fruiting.

In soil-based systems, rates of fertilizer application should be based on soil tests plus recommendations made by individuals with knowledge of the nature and properties of the local soil types. Phosphorus applications and pH adjustments should be made prior to planting, and one-half to two-thirds of the nitrogen and potassium may be applied through fertigation during crop growth.

In hydroponic systems, the concentrations and proportions of nutrients in the solution provided to the plants is varied during the growth cycle, starting low and increasing in concentration as the crop grows. The University of Florida recommends irrigating up to 10 times/day providing 1.3 oz per plant per irrigation event; as plants mature, irrigation should occur up to 40 times/day at 2.5 oz per plant per irrigation event.

PROPAGATION

Like tomatoes, peppers are seed propagated; however, peppers are not amenable to vegetative propagation in the way that tomatoes are because they do not produce “suckers.” Seedlings are transplanted when they have 4-5 true leaves, usually occurring up to 4-6 weeks after seeding.

GROWING SYSTEMS AND CULTURAL PRACTICES

Peppers are grown in-ground or in media (pots, bags or nutrient film technique (NFT)). Typically, peppers are grown in single or double rows in beds 5’ on centre, with 22” between offset rows of plants, and 18” between plants in those rows. Trellising and support systems for peppers typically involve training to two stems. Studies have shown that similar yields and fruit sizes can also be obtained using the “Spanish” system, where plants are not pruned, but rather held in place with a support system of poles and horizontal twines.

DISEASES, PESTS, AND PHYSIOLOGICAL DISORDERS

Mites, thrips, whiteflies, aphids and some lepidopterans can attack peppers. Peppers are very sensitive to the use of horticultural oils so care should be exercised if these are used for pest control. Under high temperatures, peppers may develop colour spots that turn yellow as the fruit matures, causing a blemish. Cracking and russetting of peppers can also occur, as can blossom end-rot. Some of these issues can be controlled through adequate watering and selection of cultivars that are less prone to these problems.

COMMON SWEET PEPPER VARIETIES GROWN IN JAMAICA					
VARIETY	SOURCE	FRUIT COLOR	FRUIT SIZE (GRAM)	DISEASE RESISTANT	COMMENTS
Lorca	DeRuiter	Red	230	TM2	Vigorous, excellent deep red color, sets easily
Lullaby	DeRuiter	Yellow	220	TM3	
Paramo	DeRuiter	Orange	220	TM2	Vigorous, broadly adaptable, long cropping period, good against sunscald and blossom end rot, sensitive to cracking under high temperatures, sets easily, very sweet fruit
Allaolin	Seminis	Yellow		Bacterial Spot Races 1,2,3	
Early Sunsation	Seminis	Yellow		Bacterial Spot Races 1,2,3; Potato Virus Yellow; some strains of TMV	
King Henry	Seminis	Red		Bacterial Spot Races 1,2,3	High yield, developed for the hot humid conditions of the tropics, firm, blocky fruit
Lexington	Seminis	Red,		Bacterial Spot Races 1,2,3; TMV	Vigorous, blocky dark green fruit
Revelation	Seminis	Green to Red		Bacterial Spot Races 1,2,3; PeMV; PVY; Tobamo Po	Heavy fruit set, dark green, large blocky shape, excellent uniformity and size, .76-.91 m (2.5-3.0 Ft) tall, heat tolerant

Resource

See Appendix # 4: Growing Greenhouse Sweet Peppers (Crop Bulletin # 2)

LETTUCE *(Lactuca sativa L)*

Lettuce is a member of the *Asteraceae* family also known as the *Compositae* family. *Asteraceae* is commonly referred to as the daisy family and includes other food crops such as artichokes and endive. Lettuce is an excellent crop for growth in protected agriculture structures because of the rapid growth cycle. The controlled environment protects the leaves from environmental hazards and insect pests, greatly increasing yield and quality. Lettuce may be harvested at the full head stage or may be grown for baby salad greens.

GROWTH HABITS

There are four different categories of lettuce: head, upright, leaf, and butterhead. Head lettuces have light green leaves forming a tight, firm “head.” Upright lettuce forms plants that can be 10” tall comprised of tightly folded leaves. Leaf lettuce does not form any type of head, rather remains open. Butterhead has loosely folded leaves creating a relatively smaller head.

TYPES & GENETIC CONSIDERATIONS

Head lettuce, also known as crisp head, includes one of the most common varieties, iceberg. The outer leaves of upright lettuces tend to be darker green than the inner leaves, a common example being Romaine. Leaf lettuce, often referred to as loose-leaf, includes such varieties as Oakleaf, Black Seeded Simpson, and Ruby. Often leaf lettuce is marketed as a mix and called mesclun. Common types of butterhead lettuce include Bibb, Boston, and Buttercrunch. Head lettuce is the preferred type of lettuce in the Jamaican market.

Lettuce is a naturally self-pollinating crop. While breeding programs have developed many new lettuce cultivars, few if any are hybrid, meaning that the saved seed will breed true to type. Some lettuce cultivars are more heat tolerant, i.e. not bolting or becoming bitter when grown under hot conditions. These should be evaluated for suitability of production under hot conditions in Jamaica.

DISEASE RESISTANCE

Considerable breeding efforts are concentrated on generating new disease resistant cultivars, including species resistant to downy mildew, bottom rot and some virus diseases.

TEMPERATURE REQUIREMENTS

Generally lettuce thrives in relatively cool conditions with lower light intensity than other vegetable crops. Optimum temperatures are generally listed at 60-70F. Varieties can be selected that are heat tolerant up to temperatures as high as 85F.

FERTILISER AND WATER REQUIREMENTS

Lettuce is a short-season crop, with loose leaf types reaching harvestable size in as little as four weeks after planting. Head lettuce cultivars require just 2 weeks longer. Despite its short season, lettuce responds well to adequate soil fertility and should not be limited in water. For in-ground cultivation, fertilizer recommendations should be based on the needs of the crop and on a soil analysis interpreted with knowledge of local soils. All nutrients may be applied pre-plant or in split applications with supplemental feeding of nitrogen and potassium through fertigation.

A fertigation formula for successfully growing hydroponic lettuce is as follows: N 200 ppm, P 50 ppm, K 300 ppm, Ca 200 ppm, Mg 65 ppm, Fe 3.0 ppm, Mn 1.0 ppm, Zn 0.2 ppm, B 0.3 ppm, Cu 0.1 ppm, Mo 0.05 ppm and S $<$ 100 ppm. The exact proportions listed are required. Amounts added to a solution should be adjusted based on the results of a water test to ensure they are met.

Nitrogen for lettuce production should be predominantly in the nitrate form, with no more than 15% in the ammonium form.

PROPAGATION

Some lettuce seeds require light for germination and should be planted only very shallowly. Additionally, lettuce can become dormant if high temperatures occur during germination. Growers often seed in the late afternoon or early evening and maintain seeds in a moist and cool environment during the evening hours. Seeds will germinate within 24 hours given appropriate temperature conditions. Lettuce can be direct seeded and thinned or can be grown from transplants.

GROWING SYSTEMS AND CULTURAL PRACTICES

Lettuce grows well in in-ground and hydroponics systems. In hot environments, the use of white plastic mulch and/or bags and irrigation components can help keep temperatures cool and also aid in growth. In protected structures, shade cloth may be used to keep crop and soil temperatures relatively cool.

DISEASES, PESTS AND OTHER DISORDERS

Tip burn is a physiological disorder of lettuce that occurs when temperatures are high. Some cultivars are more susceptible than others to this problem.

Resource

See Appendix #5: Growing Greenhouse Lettuce (Crop Bulletin #3)

CUCUMBER *(Cucumis sativus L)*

The cucumber is a member of the *Cucurbitaceae* family, which includes a number of other important food crops including pumpkins, squash, melons and chocho (chayote). Although not in large scale production in Jamaica, growers are finding and emerging market as a supplier for restaurants and hotels.

GROWTH HABITS

Cucumbers are vine crops and, while there is variation in growth habit within the species, types grown in protected structures mostly have the tendency to produce multiple, rapidly growing vines. These will tend to produce lateral branches, resulting in a dense mat of foliage if not pruned or trellised.

FRUIT TYPES & GENETIC CONSIDERATIONS

Cucumber fruit types cover a considerable range, from those indigenous to various parts of the world to those bred for specific uses, such as pickling and slicing. Cucumbers vary in skin colour, shape, size, skin thickness and degree of shininess. Different markets demand specific types of cucumbers and the local market demand should be understood prior to deciding on the varieties to grow.

With separate male and female flowers, cucumbers are primarily a cross-pollinated crop. Traditional cultivars tended to be open-pollinated while modern types are hybrids. The normal tendency of cucumbers and other cucurbits is to initially produce male flowers, followed by the production of female flowers. The female flower produces the fruit. Some cucumber genotypes are highly *gynoeceous* (meaning they have a tendency to produce female flowers from the beginning of flowering). Also, many greenhouse cultivars tend to be *parthenocarpic* (can produce fruit without pollination). Major greenhouse cultivars are gynoeceous <u>and</u> parthenocarpic. For example, the Beit Alpha variety of cucumber is both parthenocarpic and gynoeceous, but has the tendency to produce multiple fruit at each node. This is in contrast to standard types that produce only one flower and one fruit at each node. Parthenocarpic cucumbers will set seed if pollinated and may become distorted and bitter; hence, structures where they are grown are often screened to exclude pollinators.

TEMPERATURE REQUIREMENTS

The optimum growth temperature for cucumber culture varies by type. Heat tolerant types are most suitable for tropical climates. The Dutch type grows between 18-32°C (65-90°F) and the Beit Alpha type grows from 10-38°C (50-100°F).

FERTILISER

Cucumber as a species is a heavy feeder, growing very rapidly and requiring relatively large amounts of fertilization. In hydroponic systems, the following formula is recommended for cucumber: N 100 ppm after transplant, shifting to 180 ppm at first harvest, P 50 ppm, K 150 ppm, Ca 135 ppm, Mg 50 ppm, S 65 ppm, Fe 3 ppm, Cu 0.2 ppm, Mn 0.8 ppm, Zn 0.3 ppm, B 0.7 ppm, Mo 0.06 ppm. pH should be between 5.5 and 6.5 and EC between 1.5 and 2.5.

PROPAGATION

Cucumber seeds germinate within 2 -3 days of planting when the temperature is at a constant 29°C (84°F). Once germinated, lower temperatures are preferred for optimal seedling growth – around 25°C (77°F). Transplants should not be allowed to become water or nutrient stressed and should be transplanted at the 3-4 leaf stage.

GROWING SYSTEMS AND CULTURAL PRACTICES

Cucumbers can be grown in-ground or hydroponically in media or bag systems. They may be planted in double rows in beds 5' apart or in single rows. In a double row system, the distance between plants is ideally 2' apart with offset rows. In single row plantings, the distance between plants ideally would be 18". Cucumber plants are trained to a single leader and trellised to a string to which they may be wrapped around and/or clipped. In order to encourage vegetative growth, initial fruits are typically pruned off up to the 8th node. After that, with Dutch greenhouse type cultivars, a fruit is allowed to set every other node. The leader may be tipped at the top of the trellis and two laterals allowed to grow back down to the ground in a vertical cordon system.

Cucumbers may also be grown in a v-cordon system, in which alternate plants are trained to grow at an incline in opposite directions. The Beit Alpha type is trained to a single leader and lower fruit is removed to the 6th or 8th node. With this type, laterals are allowed to develop as they produce fruit, but are pruned to the second node. Cucumbers benefit from careful sanitation, with removal of all debris from the protected structure being crucial. Screening will help keep out pollinators and will also exclude insect pests.

DISEASES, PESTS AND OTHER DISORDERS

Pests and diseases can have negative impacts on the cucumber crop in a protected agriculture structure. The most common pests include aphids, whiteflies, thrips, mites and Lepidoptera. Additionally, root rots caused by Fusarium and Pythium can be a problem in hydroponic systems. Biological control agents are increasingly available for use as root inoculates, and more information about their efficacy for the control of problems in managed environment agriculture specific to Jamaica will certainly be forthcoming as use increases. For in-ground culture rotations, 2-year rotations may be desirable.

Resource

See Appendix #6: Growing Greenhouse Cucumbers (Crop Bulletin #4)

Module 10

TECHNOLOGY TRANSFER

INTRODUCTION

When planning any training session, three key things must be taken into consideration: what does the audience already know, how best can I teach what the audience members don't know, and how can I measure what was learned. This module will introduce methods by which a trainer may answer all of these questions and plan a high-impact, high-retention training series.

This module covers:

1. Training Needs Analysis
2. Trainings Resources and Methods
3. Evaluation of Trainings

TRAINING NEEDS ANALYSIS

Sometimes certain information or concepts must be taught prior to others due to their immediate applicability to a given situation or the need to establish basic or foundational techniques before introducing more complex ones. Such priorities can be determined by a training needs analysis. One model to use in determining the needs of a given region or target audience is to conduct a needs analysis to target the most pertinent information to the participants. Targeted messages can then be more successfully delivered, especially in the grower participatory subjects. For example, advances in ventilation techniques would not be as pertinent to growers at relatively high elevations, but might be necessary in other locations due to increased ventilation needs.

Ideally, the needs assessment would include:

- existing and potential use of protected agriculture structures;
- protected agriculture systems;
- main commodities;
- central issues of production; and
- negative impacts

For example, a central issue of water availability impacts on-farm management capacity (as shown in Table 1). A detailed needs analysis could serve as a modified Agro-Ecosystem Assessment (AESA). An AESA is an extensive assessment of all stakeholders that evaluates the performance of improved management strategies (herbicide application, tilling, water use, etc.) and sets benchmarks to see if they work. While a training needs analysis would not represent a full AESA, it would serve as a starting point to justify the need for an AESA. A needs analysis provides baseline information to quantify needed improvements, identify what is working and what is not, and provides tangible evidence to report to funding agencies.

TABLE 1: EXAMPLES OF CENTRAL ISSUES TO COVER IN A NEEDS ASSESSMENT

CENTRAL ISSUE	TOPICS TO ADDRESS

Soil Degradation	Low Soil Fertility, Low Soil Organic Matter, Erosion
Soil Fertility	Decreased Yields
Water Quality	Acidification, Alkalinity
Water Availability	On-Farm Water Management Capacity
Lack of PA Technologies	Inappropriate Structure for Required/Proposed Function
Structure Ventilation	Pests, Disease, Heat Build-up
Hurricane Preparedness	Crop Damage, Structure Damage, Flooding
Irrigation Management	Salinity, Nutrient Leaching
Fertigation	Tank Mixing, Injector Controls
Integrated Pest Management	Exclusion Techniques, Chemical Control, Pests & Diseases
Nutrient Management	Diagnosis, Corrective Actions
Compost	Carbon Limitations, Proper Tools
Market Development	Identification, Branding
Record-keeping	Framework, Justification
Biodiversity	Identifying Zone, Threats

TRAINING RESOURCES AND METHODS

REFERENCE MANUAL

One of the more important tools to have when conducting a training course is a well-developed and validated reference manual, which should be provided to both trainers and trainees (growers) for use during the course and for the future. Several reference manuals exist in addition to *Protected Agriculture in Jamaica*, all serving unique purposes. These manuals include but are not limited to:

1. *Managed Environment Agriculture;*
2. *Production Manual 04: Greenhouse Production;*
3. *Fundamentals of Greenhouse Agriculture- A Teachers Manual; and*
4. *The High Tunnel House Construction Manual.*

OTHER MATERIALS

Depending on the type of training being undertaken, a variety of other reference materials may be appropriate. As with the reference manual, it is important to understand the audience and to tailor the format and information to meet its needs. Examples of training materials include, but are not limited to:

POWERPOINT PRESENTATIONS

These are most useful in a workshop or seminar setting. When designing a PowerPoint, each slide should highlight only one point or idea. A mistake many presenters or trainers make is to include too much information on each slide or to read directly from the slide. This belies the point of the technology, which is to present key points in an easily digestible visual manner. It is also useful to include photographs, diagrams or other graphics to better support the topics.

BROCHURES

Brochures are a good way of getting specific information across in a concise manner that is available for reference following a training session. Ideally, they should be no more than a few pages long and should address a unique and specific topic. Again, presenting the information in easily digestible doses is best, and using graphics or photographs is a good way to illustrate a specific or technical idea.

LECTURE NOTES/OUTLINES

When providing a straight lecture, it is useful to provide participants with an outline of the information to be presented so they can follow along. Key concepts or ideas to take away from the session should also be included in this material.

DIAGRAMS AND FLIP-CHARTS

Even in on-farm participatory training sessions, some points are best taught through illustrations and other visual aids. Diagrams and illustrations of specific and/or technical ideas should be reserved to a single sheet as much as possible.

KNOW YOUR AUDIENCE

When approaching any training session, be it directed towards practical users or a group of trainers, it is crucial to understand the target audience and to structure the training and materials in such a way that is most appropriate to its average skill level as well as the cultural context in which you are presenting the material. For example, when presenting to a group with limited literacy, it is best to take a primarily hands-on, practical application approach and to keep written materials to a minimum though some sort of reference manual would probably be appropriate. For a training of trainers course in which specific technical knowledge is the end result, a combination of classroom and practical training would likely be more appropriate.

GROWER PARTICIPATORY METHODS

Participatory learning methods are recognized in all sectors of adult education. Benefits to using them include a deeper understanding of technical skills and an understanding as to why something is done a certain way. In grower participatory methods of training, the training ideally takes place on a grower’s site or at a selected greenhouse cluster in a convenient location for consistent attendance by the trainees. The intention of a participatory training is to foster hands-on and practical engagement between trainers and trainees when approaching the target material. The group dynamics of on-site participatory methods lend themselves to spontaneous or non-formal discussions between growers and trainers, and serve to expand the learning experience for all involved. This is often a time when growers can share their first-hand experiences, including successes and failures in their experimentations and innovations, allowing them to build on each other’s knowledge.

Due to the hands-on nature of the training, this method requires less written explanation of the proposed techniques. The trainees are able to witness and participate in tasks throughout the training, grounding the newly acquired knowledge in reality. However, this method takes more time and resources in planning and implementation as well as additional capital for demonstration supplies. To encourage participation and ownership of the training, one option would be for the grower who offers the site to receive any built structures or tangible product *gratis*.

TRADITIONAL METHODS

For some topics and audiences traditional workshop methods are more appropriate; yet, they can and should still incorporate the principals of participatory methods. Traditional methods include workshops or seminars dedicated to a specific topic and on-going courses that take place on a regular basis and cover a wider range of topics. By inviting growers to classroom workshops, all the participants reap the benefits of the group dynamic and interaction. In this way, RADA officers can more effectively address their needs. When possible, PowerPoint and other presentation materials included in traditional delivery method (such as diagrams and worksheets) are useful in presenting information in an easily accessible manner.

Whatever type of training is selected as most appropriate for a specific group, a reference manual outlining important topics and including specific reference information (i.e. fertilizer calculations, soil, water and tissue analysis, etc.) should be provided (Table 2). Throughout the training, participants should always be encouraged to ask questions for clarification. As well, open, relevant discussion should be encouraged, but controlled by the trainer; limiting discussion ensures that the trainer can deliver all the information in the allotted time.

TABLE 2: TRAINING METHODS FOR PA TECHNOLOGY TRANSFER TOPICS

UTILIZING TRADITIONAL METHODS	UTILIZING PARTICIPATORY METHOD
PA Structure- Form follows Function	PA Structure Planning Considerations
Fertiliser Calculations	PA Structure Construction
Water Analysis Interpretations	Nutritional Monitoring
Soil Analysis Interpretations	Tank Mixing & Injector Basics
Tissue Analysis Interpretations	Crop and Variety Selection
Principals of IPM	Seed Propagation and Transplant
Developing a Business Plan & Credit Options	Pruning, Trellising, Pollination
Market Analysis & Branding	Harvesting and Post-Harvest
Record-keeping & Costs of Production	Compost & Soil
Principals of Ecological Conservation	Hurricane Preparedness

EVALUATION OF TRAININGS

KNOWLEDGE, SKILL, ATTITUDE, ASPIRATIONS ASSESSMENT

The Knowledge, Skill, Attitude, Aspirations (KSAA) methodology provides an assessment tool to measure changes in participants' theoretical and practical knowledge resulting from a specific training course. For the purpose of teaching protected agricultural techniques, Knowledge and Skills define the specific ideas and techniques to be taught; Attitude addresses the level of success to be expected considering the motivation of the audience; and Aspirations identifies what is needed to expand the Knowledge and Skills of the audience beyond the scope of the training itself.

To utilize the KSAA method, a simple questionnaire should be designed and passed out to the training participants to be completed at the conclusion of each training session. This questionnaire will help to assess participant understanding and retention of the subject matter. To simplify the analysis of the questionnaire results, a Likert Scale (Table 3) is utilized to assess changes in attitude stemming from the course. Students are asked to respond to statements regarding the session on a scale from strongly disagree to strongly agree. In addition to gathering data about stated objectives, this tool allows the trainer to average scores across all related subjects to gauge the overall shift in attitudes about a given topic. Additionally, multiple choice and open-ended questions should be included on the questionnaire to provide anecdotal data and to illicit feedback for planning of future sessions. Examples of open-ended questions include: What did you find most helpful? What is an issue that could have been explained in further detail? From what you have learned today, what can you apply immediately?

TABLE 3: SAMPLE KSAA QUESTIONNAIRE
Example of a Likert scale to administer after a training session on fertilizer calculations

	STRONGLY DISAGREE	SOMEWHAT DISAGREE	NEITHER AGREE NOR DISAGREE	SOMEWHAT AGREE	STRONGLY AGREE
I learned something new at this session.					
From the information presented today I can apply something immediately.					
From the information presented today I can apply something in the long-term.					
I have a better understanding between the difference ppm and % active ingredient.					
I feel confident I could complete a fertilizer calculation.					

FARM PRACTICE INSPECTION

On-site farm training does not lend itself as easily to questionnaire-based data collection. One method that is useful in a farm setting is to make a baseline assessment of the technology being transferred. In subsequent visits, the trainer can observe the staying power of the technology and even the level of success in implementing the technology at other growers' sites nearby. Ideally, a form should be developed that provides a checklist of items for review so that this information is collected uniformly across a variety of sites. Representative data for this broad level of assessment would include data such as "60% of the growers in the region adopted nutrient monitoring in the one year after the information was disseminated." For accuracy, this type of observational assessment should be undertaken over a significant span of time, even up to1-2 years if necessary and reasonable.

Another type of assessment useful for practical training is a logistics assessment which records participant involvement in training sessions. Results of such an assessment might include "a total of 75 growers and RADA officers attended seven workshops". This type of assessment tool generates information regarding specific indicators across a potentially wide geographic area. It also provides a basis for understanding the interest level for a specific type of technology transfer. Through analysis, it enables trainers to better understand how to expand the reach of the trainings.

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RESOURCES

CONTACT INFORMATION

REGIONAL AGENCIES

Caribbean Agribusiness Association (CABA)
Hope Gardens
P.O. Box 349, Kingston 6
876-970-33105
www.cabaregional.org

Caribbean Agriculture Research and Development Institute (CARDI)
P.O. Box 113 Mona
Kingston 7
876-927-1231
876-977-1222
Fax 876-927-2099
www.cardi.org

Inter-American Institute for Cooperation on Agriculture (IICA)
www.agroinfo.org/caribbean/iicacarc/

Jamaica Greenhouse Growers Association (JGHGA)
RADA Building
Caledonia Road
Mandeville
Jgga01@gmail.com

Jamaica Business Recovery Program (JBRP)
www.jbrp.org

Ministry of Agriculture
Hope Gardens
Kingston 6
876-927-1731
www.moa.jm

Rural Agricultural Development Authority (RADA)
www.rada.gov.jm/

SUPPLIERS IN JAMAICA

Jamaica Drip Irrigation Ltd.
876-962-9610

AgroGrace Ltd.
www.agrograce.com
876-765-9259

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WEBSITES

GENERAL INFORMATION

High Tunnels
www.hightunnels.org

American Society for Plasticulture
www.plasticulture.org/

Appropriate Technology Transfer for Rural Areas
www.attra.org/

Cornell University & Regional Farm and Food Project
www.uvm.edu/sustainableagriculture/hightunnels.html

Noble Foundation
www.noble.org/

Rutgers University
www.aesop.rutgers.edu/~horteng/

Penn State University
www.plasticulture.cas.psu.edu/H-tunnels.htm

Washington State University
www.hortla.wsu.edu/links/plasticulture.html

DISEASE & INSECT MANAGEMENT INFORMATION
Cornell University (Ithaca, New York, USA)
www.vegetablemdonline.ppath.cornell.edu/NewsArticles/HighTunn/htm

GENERAL & STRUCTURE SUPPLIERS
CropKing, Inc. (Seville, Ohio, USA)
www.cropking.com/

FarmTek (Dyersville, Iowa, USA)
www.farmtek.com/

Grow-It Greenhouse (West Haven, Connecticut, USA)
www.growitgreenhouses.com/

Haygrove Tunnels (Elizabethtown, Pennsylvania, USA)
www.haygrove.co.uk

International Greenhouse Company (Georgetown, Illinois, USA)
www.igcusa.com

Jaderloon (Irmo, South Carolina, USA
www.jaderloon.com

Keeler Glasgow (Hartford, Michigan, USA)
www.keeler-glasgow.com

Ludy Greenhouses (New Madison, Ohio, USA)
www.ludy.com/

Paul Boers Ltd. (Vineland Station, Ontario, Canada)
www.paulboers.com/

Plastitech (Saint-Remi, Quebec, Canada)
www.plastitech.com/

Poly-Tex Inc. (Castlerock, Minnesota, USA)
www.poly-tex.com

Quiedan Company (Salinas, California, USA)
www.quiedan.com/

Rimol Greenhouse Systems (Hookesett, New Hampshire, USA)
www.rimol.com

Speedling Inc. (Sun City, Florida, USA)
www.speedling.com

Stuppy Greenhouse Mfg (Kansas City, Missouri, USA)
www.stuppy.com

Tunnel Tech (LaSalette, Ontario Canada)
www.tunneltech.ca

Turner Greenhouses (Goldsboro, North Carolina, USA)
www.turnergreenhouses.com

XS Smith (Eatontown, New Jersey, USA)
www.xssmith.com

Agra Tech, Inc
www.agra-tech.com/

KEN-BAR, Inc.
www.ken-bar.com/

PAK Unlimited, Inc
www.pakunlimited.com

DRIP IRRIGATION SUPPLIERS
DripWorks
www.dripworksusa.com/

Hummert International
www.hummert.com/

Irrigation-Mart, Inc.

www.irrigation-mart.com/

Netafim USA
www.netafim-usa.com/

Spring Brook Irrigation
www.springbrookirrigation.com/

T-Systems Intl.
www.t-tape.com/

SEED SUPPLIERS

Abbott & Cobb Inc.
www.acseed.com/

AgriSales Inc.
www.agrisales.com/

Burpee Seeds
www.burpees.com/

Chesmore Seeds
www.chesmore.com

DeRuiter Seeds
www.deruiterusa.com

Fedco Seeds
www.fedcoseeds.com/

Harris Seed
www.harrisseeds.com/

Johnny's Selected Seeds
www.johnnyseeds.com/

Seeds From Italy
www.growitalian.com/

Seed Movement
www.seedmovement.com/

Seed Savers Exchange
www.seedsavers.org/

SeedWay
www.seedway.com/

Siegers Seed Company
www.siegers.com/

Stokes Seeds Inc.
www.stokeseeds.com/

Tomato Grower's Supply
www.tomatogrowers.com/

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