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Capacity Building Program to Improve Stakeholder Resilience and Adaptation to Climate Change in Jamaica (CBCA)

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Capacity Building Program to Improve Stakeholder Resilience and Adaptation to Climate Change in Jamaica (CBCA)

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Abbreviations and acronyms

AIC	Agro-Investment Corporation
Alliance	Alliance of Bioversity International and CIAT
CARICOM	Caribbean Community
CC	Climate change
CCAFS	CGIAR Research Program on Climate Change, Agriculture and Food Security
CIAT	International Center for Tropical Agriculture (now part of the Alliance of Bioversity International and CIAT)
CMIP5	Coupled Model Intercomparison Project - Phase 5
CRA	Climate-Risk Assessment
CSA	Climate-Smart Agriculture
CSA-PF	Climate-Smart Agriculture Prioritization Framework
CSA-RA	Climate-Smart Agriculture Rapid Appraisal
CSA-TP	CSA Training Program
DEM	Digital Elevation Model
DJF	Climate Period December to February
EVADP	Essex Valley Agricultural Development Project
FAO	Food and Agriculture Organization of the United Nations
GCM	General Circulation Models
GEE	Google Earth Engine
GHG	Greenhouse Gas
GOJ	Government of Jamaica
ISRIC	International Center for Reference and Information on Soils
JJA	Climate Period June to August
LAC	Latin American and the Caribbean
LCCS	Land Cover Classification System
LULUCF	Land-Use Change and Forestry
MoAF	Ministry of Agriculture and Fisheries
NDC	Nationally Determined Contribution
NIC	National Irrigation Commission
RADA	Rural Agricultural Development Authority
RCP	Representative Concentrative Pathways
SCCADP	South St. Catherine and Clarendon Plains for Agricultural Development Project
SPADP	Southern Plains Agricultural Development Project
SRTM	Shuttle Radar Topography Mission
UNEP	United Nations Environment Programme
UWI	University of West Indies
WCRP	World Climate Research Programme
WHC	Water holding capacity

Summary

Jamaica will face future climate trends marked by increases in the intensity and frequency of climate extremes, escalating rainfall variability, and increased droughts and floods; combined with fragile ecosystems and sensitive coastal zones, the result is that Jamaica has a relatively high vulnerability to climate change. In particular, the Southern plains of Jamaica, particularly the parishes of St. Elizabeth, Clarendon, and St. Catherine, are essential for Jamaica's food security. St. Elizabeth is often referred to as the breadbasket parish. The average rainfall in the Southern plains is about 30% lower than the national average, making rainfed agriculture a risky business for farmers in the region. Irrigation projects and the smart design of efficient water management for the region are a high priority for the national agricultural sector.

Climate-Smart Agriculture (CSA), which incorporates adaptation/resilience and mitigation measures while ensuring sustainable productivity, has the potential to build synergies and limit tradeoffs in agriculture under present climate uncertainties, and reduce existing knowledge gaps and facilitate alignment between sectors and policies. CSA has the potential to deliver “triple wins” by contributing to multiple objectives: (1) sustainably increasing productivity and food security, (2) enhancing farmers’ resilience capacity (adaptation), and (3) reducing or removing greenhouse gas emissions (mitigation).

The Evidence-Based, Gender-Equitable Framework for Prioritizing Climate-Smart Agriculture Interventions has been adapted from different tools and research methods to overcome the challenge of identifying context-specific technologies and understanding better the tradeoffs and co-benefits that different combinations of portfolios could deliver for different stakeholder. The framework integrates the Climate-Smart Agriculture Rapid Appraisal (CSA-RA) tool with the CSA Prioritization Framework (CSA-PF), and Modeled Crop Climate-Risk Assessment (CRA). In collaboration with the Department of Geography & Geology at the University of the West Indies, we have included a new component of Development of Training Programs (CSA-TP) for Jamaica.

Findings include a spatial water-balance model that was applied to four parishes to simulate the principal hydrological cycle components including monthly runoff, effective precipitation, soil moisture, percolation, potential, and actual evapotranspiration. Simulations of future climate characteristics using the crop model AquaCrop show that some crops such as sweet potato and groundnut are more suitable for expected future climate conditions, while others such as onion will depend more on irrigation. Overall irrigated systems to balance the crops water demand are crucial to achieve higher yields.

Through a multi-criteria analysis with stakeholders, priority CSA practices for each key value chain (crop) per site were identified, followed by a cost-benefit analysis that revealed the financial profitability of the practices for farmers by evaluating indicators such as net present value (NPV), payback period (PP), internal rate of return (IRR), cost-benefit ratio (C/B), among others. In a final workshop with stakeholders, CSA practices indicators (food and nutritional security, adaptation, and mitigation) along with identified economic benefits, and a multi-dimensional analysis of opportunities for and barriers to the adoption of CSA practices were used to rank CSA practices across the three sites.

The final step of the Evidence-Based, Gender-Equitable Framework for Prioritizing Climate-Smart Agriculture Interventions was co-creating together with farmers the outlines for locally specific Climate Smart Agriculture (CSA) training manuals and programs.

Objectives and Scope

In collaboration between the Alliance of Bioversity International and CIAT, the Department of Geography and Geology at the University of West Indies (UWI), and relevant national stakeholders, i.e., MoAF, RADA and among others, the project was carried out to achieve the following objectives:

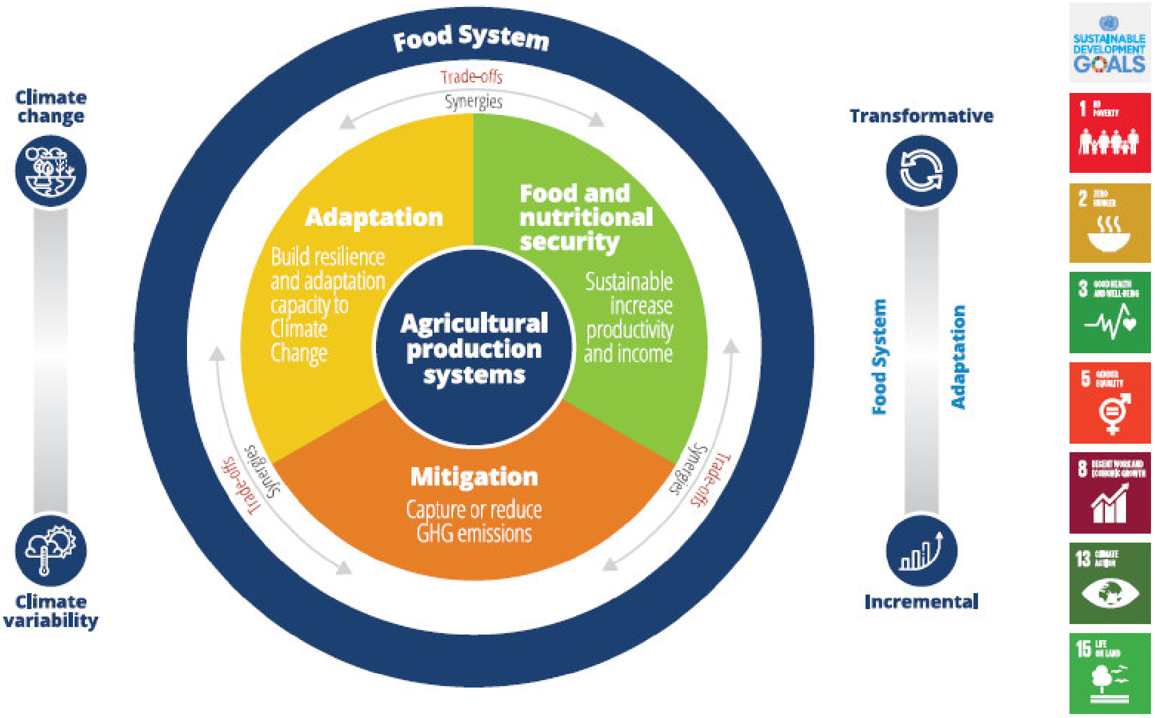
- *Phase I – Crop Modelling of Impact of Climate Change in Project Intervention Areas*
  - *Risk assessment and simulation of the impact on crops*
  - *Identification of locations specific Climate-Smart agriculture options*
  - *Prioritize Climate-Smart Agriculture options*
- *Phase II – Development of Training Program in CSA*
  - *Development of Climate-Smart Training Program*
  - *Preparation of detailed course materials*
  - *Recommendations for a Knowledge Transfer Program*

The outcome of this project supports ongoing SPADP and EVADP projects. It will go in line with the National Agricultural Sector plan 2020 – 2030. Thus, selected CSA portfolios and training program contributes the countries' goal:

> "A dynamic transformation of the Jamaican agricultural sector through a sustained, research-oriented, technological, market-driven and private sector-led revolution, which revitalizes rural communities, create strong linkages with other sectors and emphatically repositions the sector in the national economy to focus on the production of high-value commodities and contribute to national food security" (GOJ. 2010, p1).

Framework for climate-Smart Agriculture Interventions

Climate-Smart Agriculture (CSA), which incorporates adaptation/resilience and mitigation measures while ensuring sustainable productivity, has the potential to build synergies and limit tradeoffs in agriculture under present climate uncertainties, and reduce existing knowledge gaps and facilitate alignment between sectors and policies (Lipper et al. 2014), (Figure 1). Effective and long-lasting management and adoption of the different climate change adaptation strategies also remain highly complicated because of localized and context-specific responses, which vary from region to region. Prioritizing Climate-Smart options in a structured process is vital before developing farmers' capacities and knowledge to make climate-smart choices in their agricultural production crucial. However, it requires an in-depth understanding of the local socio-economic contexts' suitability of practices in different agro-ecologies (Mwongera et al. 2017).



CSA has the potential to deliver “triple wins” by contributing to multiple objectives: (1) sustainably increasing productivity and food security, (2) enhancing farmers’ resilience capacity (adaptation), and (3) reducing or removing greenhouse gas emissions (mitigation). The context-specific nature of CSA points to the need to ground efforts to promote CSA in holistic food system analysis, integrating landscape, ecosystem, and value chain approach. Incentives to adopt CSA practices usually are influenced by a combination of economic, sociocultural, environmental, and political considerations, meaning that governance arrangements, institutional structures, and financing mechanisms must be well aligned to ensure that desired outcomes can be achieved efficiently, taking into account the goals of multiple stakeholders.

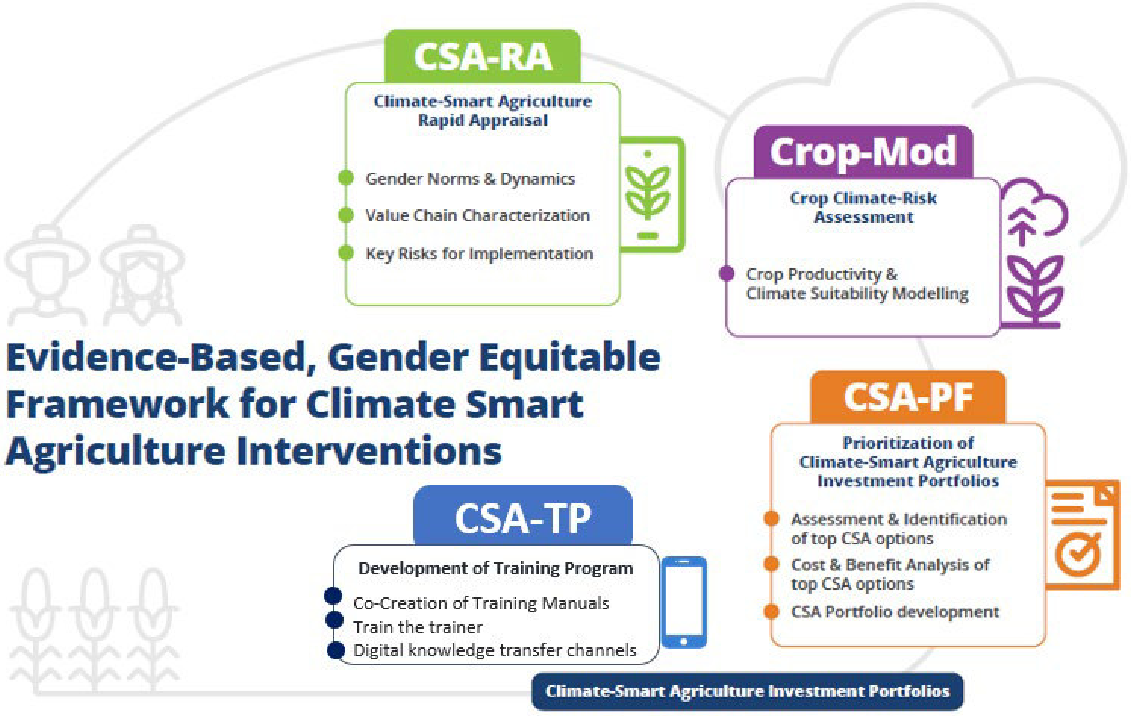
The Climate Change, Agriculture and Food Security Program (CCAFS) has designed a framework (Corner-Dolloff 2014), and process for prioritization of crops and CSA investments in sustainable agricultural interventions in different agro-ecological systems in the world, by:

☐ Co-implement a framework that provides a systematic process for targeting investment towards best-bet CSA options to boost the sustainability of the food system in the face of climate change.

☐ Identify existing and promising CSA practices and assess the tradeoffs and synergies between practices using CSA-related indicators, the costs and benefits of adopting the practices, and their possible opportunities and barriers to adoption.

- Contribute to optimized sub-national and national planning, promoting a participatory process for the development of potential CSA investment portfolios adapted to small-scale farmers' context.

The CSA-PF methodology and previous experiences in various countries can be further explored in the CSA guide web site and the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) web site. The Evidence-Based, Gender Equitable Framework for Prioritizing Climate-Smart Agriculture Interventions (Figure 2) has been adapted from different tools and implemented for the first time in the Caribbean in Guyana (Navarrete-Frias et al. 2021). The framework integrates the Climate-Smart Agriculture Rapid Appraisal (CSA-RA) tool with the CSA Prioritization Framework (CSA-PF), and modeled Crop Climate-Risk Assessment (CRA). For the current project, we included a capacity development component and Development of CSA Training Program (CSA-TP) to the framework.



Climate-Smart Agriculture Practices in Jamaica

A further step of working towards the implementation of CSA in Jamaica was done through a collaborative effort between the Food and Agriculture Organization of the United Nations (FAO) and the Rural Agricultural Development Authority (RADA), developing a manual for Jamaican extension officers (Bigi and Protz 2014). The Manual for Extension provides much specific information that can be used as fundamentals for developing CSA portfolios in Jamaica, like a detailed characterization of soil types per parish, key factors causing erosion, watershed diagnostics, and detailed descriptions of how to implement specific CSA practices.

A. RISK ASSESSMENT OF IMPACT FROM CLIMATE CHANGE ON JAMAICA'S CROP GROWN IN ST. ELIZABETH, CLARENDON, AND ST. CATHERINE

This section will provide a detailed climate risk assessment in the following three areas: Parnassus in Clarendon, Amity Hall in St Catherine, and Essex Valley in Manchester/St Elizabeth. These areas are important for food security in the country but face low water availability which places agricultural production at risk. The feasibility of irrigation projects largely depends on future water availability and the smart design of efficient water management for the region. Thus, the implementation of a water balance can provide helpful information and insights.

Output from crop production is influenced by geographical and agro-ecological characteristics, such as climate, topography, soil type, and land cover. Crop modelling using a baseline climate and future projections is a crucial method for identifying the best use of available land resources and to achieve a sustainable production resilient to climate change and climate variability.

The Climate Rationale for Jamaica's Southern Agricultural Plains

A climate rationale provides the scientific underpinning for evidence-based climate decision making. The process of developing a climate rationale includes analyzing the overall climate risks, assessing climate vulnerabilities, reviewing adaptation needs, identify main barriers and non-climatic drivers of change, and evaluate mitigation needs and barriers for implementing mitigation activities.

Summary

- The Southern Plains are Jamaica's breadbasket, but they are highly exposed to drought and heat conditions, irregular rainfalls, and extreme events like hurricanes.
- Future scenarios from the regional synthesis of observed trends and projected changes in climatic impact show increase in temperature and relative evaporation, the projections show high confidence of decrease in mean precipitation, and medium confidence of increase in agricultural drought
- The lack of access to water for farming is one of the main constraints in the region, improved water management for irrigation could boost farm productivity significantly.
- Farmers in the region have adopted to the dry conditions in the past by implementing practices for more effective water use and soil moisture management. But these practices are labor intensive and not enough to balance crops water requirement.
- Climate-Smart agriculture would be a way forward to increase co-benefits for productivity, climate resilience through adaptation, and improve the footprint in water management for mitigation. But climate-smart agriculture is a relatively new concept for farmers and requires a policy framework for implementation and capacity building for farmers.

Climate Rationale for Adaptation

Main Climate Risks for Jamaica

Multiple studies show that climate change is likely to have adverse effects on Jamaica's agriculture sector (Selvaraju 2013; CIAT 2016). Jamaica will face future climate trends marked by increases in the intensity and frequency of climate extremes, escalating rainfall variability, and increased droughts and floods; combined with fragile ecosystems and sensitive coastal zones, the result is that Jamaica has a relatively high vulnerability to climate change. The projected climate impacts on island agroecosystem services could accentuate a myriad of social and ecological risks. For example, Arnold et al. (2018) studied the pollinator population on farms across three Caribbean countries. They found that without proactive farm management practices, the projected impacts of climate change on drought patterns constitute a significant threat to food production.

Future climate models, selected for their strong performance in the Latin American and the Caribbean (LAC) region, show that Jamaica's seasonal maximum temperature is predicted to increase by 2–4 °C, and minimum temperatures by 1–3 °C. In general, the Caribbean is projected to warm at higher rates than Central America's more temperate areas and the Southern Cone of South America. Temperature increases are likely to be accompanied by increased solar radiation in Jamaica, especially evident in the cooler 'winter' months from September to February. Changes in rainfall patterns will lead to drier seasonal conditions between March and August, but wetter conditions between September and December, with increased rainfall for the typically rainiest month of October. Overall long-term projections associated with the PRECIS regional climate model show that the Caribbean is expected to be significantly drier by the century's end, especially during its primary rainy season from May to November (Taylor et al. 2013). Under a two °C target, a further extension of warm spells can be expected by up to 70 days, leading to a shift to a pre-dominantly drier region (5%–15% less than present-day) and a more significant occurrence of droughts (Taylor et al. 2018). Combined increases in maximum temperatures, accompanied by decreases in precipitation, are likely to increase agricultural droughts, especially in rainfed dominated agricultural systems.

Climate Extremes

Damage to the agricultural sector from climate extremes, for example, Hurricane Ivan that cost US$ 121.4 in 2004, and Hurricane Dean in 2007 that cost US$128.6 million (Campbell, Barker, and McGregor 2011), is among the main risks for Jamaican farmers. This is particularly so along the Southern coastline, where most hurricanes make landfall. In Table 1, entries from a global disaster database (EM-DAT 2020) show major historical natural hazard events for Jamaica, including three droughts (1981, 2000, and 2014), four flood events (1987, 1991, 2006, and 2020), and 19 Tropical cyclones since 1980. Reviewing historical climate records, Gamble et al. (2010) found a total of thirty-one drought events and thirteen drier than typical months during the period 1980 to 2007 in Jamaica.

Table 1. Major climate extreme events from 1980 to 2019, taken from the EM-DAT database.

Year	Disaster Type	Disaster Subtype	Event Name	Start Month	Total Affected Population	Total Damages ('000 US$)
1980	Storm	Tropical cyclone	Allen	7	30,009	64,000
1981	Drought	Drought	-	1	-	-
1985	Storm	Tropical cyclone	Kate	11	300	5,200
1987	Flood	Riverine flood	-	11	26,000	31,000
1988	Storm	Tropical cyclone	Gilbert	9	810,000	1,000,000
1991	Flood	Flash flood	-	5	551,340	30,000
1996	Storm	Tropical cyclone	Marco	11	800	3,000
2000	Drought	Drought	-	3	-	6,000
2001	Storm	Tropical cyclone	Michelle	11	200	55,487
2002	Flood	Riverine flood	-	5	25,000	20,000
2002	Storm	Tropical cyclone	Lili	9	1,500	30
2002	Storm	Tropical cyclone	Isidore	9	-	1,000
2004	Storm	Tropical cyclone	Ivan	9	350,000	595,000
2004	Storm	Tropical cyclone	Charley	8	126	30,0000
2005	Storm	Tropical cyclone	Hurricane "Wilma"	10	100	3,500
2005	Storm	Tropical cyclone	Hurricane "Dennis"	7	8,000	30,000
2005	Storm	Tropical cyclone	Emily	7	2,296	1,000
2006	Flood	Riverine flood	-	11	5,000	-
2007	Storm	Tropical cyclone	Dean	8	33,188	300,000
2007	Storm	Tropical cyclone	Noel	10	-	-
2008	Storm	Tropical cyclone	Hurricane "Gustav"	8	4,000	66,198
2008	Storm	Tropical cyclone	Tropical Storm "Fay"	8	-	-
2010	Storm	Tropical cyclone	Tropical storm Nicole	9	2,506	150,000
2012	Storm	Tropical cyclone	Hurricane Sandy	10	215,850	16,542
2014	Drought	Drought	-	1	91,545	-
2016	Storm	Tropical cyclone	Hurricane Matthew	9	125,000	-

While it is nearly impossible to fully mitigate the acute risk from hurricanes, addressing more chronic risks associated with climate vulnerability will help in general terms by way of creating a more resilient agricultural system.

Vulnerabilities of the ecosystem and agricultural system

In Southwestern Jamaica, water is the crucial factor in creating and overcoming climate exposure. Farmers in this region have extensive experience dealing with drought and have developed a robust ethno-climatological tradition; people in the region know the local meteorological conditions and their relationship to drought (Gamble, Curtis, and Popke 2017; Campbell, Barker, and McGregor 2011). To optimize production and profit for farmers in southwestern Jamaica, the timing of droughts and cropping calendars are essential to farmers. Farmers have adapted their strategies due to the growing demand from the hotel industry for most vegetable crops grown in relatively short cycles of around eight weeks. Between December and March and in July, they typically grow these crops during the dry periods in relatively small areas. Receiving the quick cash, they use the generated income to plant the primary staple crops in the rainy season and larger areas.

Nevertheless, suppose farmers experience drought during the short cycles. In that case, it affects the current cycle. It reduces cash available for the coming rainy season in October (Gamble et al. 2010). Drought during certain months of the year can thus impact multiple growing seasons. A midsummer dry spell in July - which usually has a low frequency of climatological drought - can have a considerable impact on agricultural production.

Farmers have noticed changes in weather patterns in recent decades (Rhiney et al. 2017). Rhiney et al. (2017) highlight that 84.7% of farmers indicated experiencing changes in the traditional rainy season's timing and 78% of the study participants reported observing changes in rainfall patterns over the last 20 years. Despite these observations, the study results show a low adaptive capacity of cocoa farmers that, even though they perceived changes in rainfall patterns, rarely adjusted their farm management practices. In contrast, farmers in Southwestern Jamaica have demonstrated adaptive capacity, displaying good knowledge of seasonal drought and climate variability and awareness of and concern with the interaction of drought and their cropping schedules (Gamble et al. 2010). Farmers in St. Elizabeth often rely on local knowledge to monitor early warning signals for episodic environmental events, especially regarding temperature and rainfall changes.

In many cases, local knowledge is the only tool farmers must negotiate multiple livelihood stressors. Case studies of agricultural transformation through innovation projects in Southwestern Jamaica show that not all farmers can uptake available innovations to cope with changes, as underlying social vulnerabilities often constrain uptake within the region (Popke, Curtis, and Gamble 2016). Current vulnerabilities are influenced by historical patterns of structural imbalances as well as novel economic and environmental challenges. The sector exhibits the historical dualistic structure in which large-scale commercial farms and small-scale production units co-exist side-by-side (Barker 1993). This pattern is also reflected in current domestic agricultural policies and strategies which seek to redress biases against the non-traditional sub-sector (Beckford 2002). Thus, greater attention to underlying social vulnerability within Caribbean climate policy is required to achieve a just transformation of agriculture towards greater resilience to climate change.

The overall vulnerability of Jamaican farmers is like that of farmers around the region. Eitzinger et al. (2011) conducted a vulnerability assessment of farmers in Colombia, Guatemala, and Jamaica. The study generated vulnerability indices for the three case studies using a crop model to measure farmers' exposure to climate impacts and a sustainable livelihood assessment to determine farmers' sensitivity, adaptive capacity, and motivation to adapt across the three study areas. Compared to farmers from the other two countries, Jamaican farmers showed similar exposure and sensitivity but low adaptive capacity and the lowest motivation to adapt. The overall vulnerability index shows a similar result in Jamaica as in Colombia, with high variability among farmers.

Studies that focused on modeling of crop-climate-suitability and the biophysical impact from climate change using climate indicators derived from rainfall and temperature predict a reduction of available areas for agriculture (Eitzinger et al. 2013) and show the difference of potential impacts from a + 1.5 °C and + 2 °C warming scenario (Rhiney et al. 2018).

Climate Rationale for Mitigation

In Jamaica, agriculture contributes 19% to the country's total greenhouse gas (GHG) emissions, much lower than the global average of 30% (Richards, Wollenberg, and Buglion-Gluck 2015). Agricultural emissions include methane (CH_4) and nitrous oxide (N_2O) emissions from livestock, manure management, flooded rice cultivation, agricultural soils, and fertilizers, and burning of crop residues and savannas, as well as carbon dioxide (CO_2) from liming and urea application. Measured agricultural emissions do not include emissions from land-use change and forestry (LULUCF). Overall, the Caribbean has lower emissions per capita (0.57-0.85 tCO_2e) compared to other regions, for example, South America (1.94-2.56), North America (1.19-1.68), Europe (0.63-1.08), Sub-Saharan Africa (0.57-1.15), and Southeaster Asia (0.53-1.05) (Richards, Wollenberg, and Buglion-Gluck 2015).

Agricultural GHG emissions vary widely across value chains. They do not necessarily correspond with the sub-sector's overall size (Josling et al. 2017). The three largest value chains in Jamaica are poultry, yams, and sugar. Over one-quarter of Jamaican agriculture's value comes from poultry production, and the poultry sector accounts for almost 40% of emissions. In contrast, the beef sector contributes to 10% of GHG emissions but only 3% of production value. The banana value chain contributes less than 3% production value but about 6% of GHG emissions. Other GHG high contributing crops are sugarcane and coffee. In comparison, yams, pineapples, and most other products, including vegetables, contribute substantially less to GHG emissions. Despite having lower emissions from agriculture, Jamaica remains committed to contributing to global mitigation goals as the world moves to address the challenge of climate change. In its recently published update of Nationally Determined Contribution (NDC), the country announced specific actions for agriculture:

> Strategic aims include facilitating water use (and hence energy) efficient agricultural methods, improved food storage systems, and diversifying food production techniques, including the expansion of agroforestry and aquaculture. Consistent with these strategic priorities, several important ongoing important projects in the sector are contributing to both GHG emissions reductions, carbon sequestration, and enhanced climate resilience. For example, the Integrated Management of the Yallahs and Hope River Watershed Management Areas (Yallahs-Hope) Project aims to improve the conservation and management of biodiversity and provide ecosystem services within the region; the watersheds accounts for around 7% of the island's farmlands. This will be done by implementing sustainable agriculture (including renewable power generation), forestry, land management, and livelihood practices within targeted communities. An initial estimate suggests that the avoided deforestation, reforestation, and sustainable land management outcomes of the project could yield emission reductions of more than 550,000tCO_2e for the four years of the project. Other projects expected to contribute to low-emissions development in the agriculture sector include The Essex Valley Agriculture Development Project and a project focused on Promoting Community-Based Climate Resilience in the Fisheries Sector.

Source: NDC of Jamaica to the United Nations Framework Convention on Climate Change (UNFCCC)

Implementing climate change strategies

Adaptation and Mitigation needs

Decoupling environmental impacts from economic growth and improved human well-being is one of the primary challenges brought to light by the United Nations Environment Programme (UNEP) International Resource Panel (UNEP 2011). Implementing decoupling strategies in agriculture means decoupling environmental externalities (e.g., pollution of runoff, GHG emissions, etc.) from agricultural goods (i.e., the produce and jobs provided by the sector). This "win-win" outcome can be achieved through various approaches, such as transitioning to a low carbon, more resource-efficient set of agriculture practices.

In order to understand ongoing decoupling processes in the LAC region, the FAO Regional Office for Latin America and the Caribbean introduced a performance ratio to explore the relationship between production and GHG emissions in the agricultural sector and compared countries in the LAC region (Saravia-Matus, AGUIRRE Hörmann, and Berdegué 2019). Countries with performance ratios in the top 25% and under the best-case elasticity scenario (of strong decoupling) are not necessarily the same as those usually identified when using factor productivity analyses. This finding suggests that environment-specific policies and tools play a crucial role in enhancing sustainable agricultural production. Within the LAC region, only five countries achieved a state of "strong-decoupling," namely Colombia, Costa Rica, El Salvador, Suriname, and Jamaica. Most other small island states in the Caribbean reported a healthy negative decoupling state wherein emissions grow faster than agricultural production.

Systematic approaches for improving environmental outcomes with agriculture are often organized under climate-smart agriculture or CSA. Approaches such as CSA can transform and reorient agricultural systems to support food security in the face of climate change (Lipper et al. 2014). CSA aims to achieve three objectives or pillars: sustainable increases in agricultural productivity, enhanced resilience (adaptation), and reduction or elimination of greenhouse gas emissions (mitigation).

Several studies have identified local adaptation needs and strategies for the Jamaican agriculture sector (Eitzinger et al. 2013; Selvaraju 2013; Tomlinson and Rhiney 2018; A. Moulton et al. 2015; Campbell, Barker, and McGregor 2011; Rhiney et al. 2017; A. A. Moulton and Popke 2017). Most strategies include:

- Drought resilient crop varieties
- Storage containers for harvested crops
- Plant nurseries and shelters to protect seeds and seedlings during hurricane season
- Water management strategies, including Irrigation systems and water harvesting infrastructure
- Year-round efficient vegetable production in greenhouses (using efficient irrigation systems)
- Soil restoration and conservation
- Optimize and adapt planting dates to climate change and risk season, e.g., harvest bevor hurricane season
- Organize farmers in groups
- Training and Information sharing of clime-proof agricultural best practices
- Demonstrations of best agricultural practices, including tutorials and testing kits
- Use of Traditional and Local Knowledge to Speed Up Adaptation Planning
- Financing at the organizational level to invest in tools and land titles for the community
- Incentives for farmers to practice sustainable and climate-proof practices

Farmers' awareness of adaptation needs best happens through peer-to-peer learning like farmer-field schools and other participatory approaches (Tomlinson and Rhiney 2018).

Constraints, Barriers, and Coping Strategies

Longstanding local stresses continue to alter the adaptive capacity of farmers. In St. Elizabeth, some of the stresses facing farmers include a lack of essential services, poverty, high fertilizer price, cheap food imports, insecure marketing arrangements, and droughts.

Access to water is a crucial issue in the region and is inhibited by economic and bureaucratic constraints. Small farmers have low or no access to financial instruments like credit and insurance. Although the onset of a drought occasionally presents a unique opportunity for farmers to capitalize on the shortfall in supply and the resultant high prices on the market, only larger farmers can take advantage of this "opportunity." Campbell, Barker, and McGregor (2011) found that more than 90% of the farmers in South St. Elizabeth indicated that they did not receive any government assistance following the 2008 drought. Coping strategies of farmers concerning drought are often in response to events' immediate negative impacts (Campbell, Barker, and McGregor 2011). They are not transformative towards more overall resilience. Reasons for not addressing the stressors through coping strategies are often related to more profound underlying vulnerabilities within the sector, maladaptation, or access to resources. These issues increase the overall cost of agricultural production, while other factors, like access to markets, financing, and information that affect innovation potential, are often constrained by issues preset in specific value chain networks.

Canevari-Luzardo (2019) found that "the capacity of actors to innovate and adapt is significantly enhanced when actors work collectively and collaboratively. The network strongly influences some of the factors constraining collaboration (such as information sharing). In contrast, others can be primarily driven by the level of embeddedness forged in business-to-business relationships, for example, trust" (Canevari-Luzardo 2019, p 2,541). This observation points to the importance of farmer associations and strong local relationships. Though these networks do not automatically lead to adaptation, closing knowledge gaps, and improve information flows are essential to enable peer-to-peer learning (Tomlinson and Rhiney 2017) and more coordinated responses.

Non-climatic drivers for change

The Jamaican agriculture sector is highly dynamic both in environmental and economic terms. Trade liberalization has shaped Jamaican agriculture since the 1980s (Weis 2005; Rhiney 2016). The agricultural sector, both commercial and small-scale agriculture, experienced a significant decline during trade liberalization (Kinlocke and Thomas-Hope 2019). Jamaica has since become one of the five largest food importers within the Caribbean Community (CARICOM). The agriculture sector is particularly vulnerable to the threat of food imports that can permanently displace domestic production. Although the transition happened gradually, domestic agriculture production struggled to compete with often-subsidized imported produce. The hotel industry is particularly notable, driving demand for a stable quantity and quality of fresh vegetables like onions, tomato, carrot, and cabbage, which are often purchased and inexpensively imported from the United States and Europe (Selvaraju 2013). This has affected many farmers who were forced into unfavorable competitive situations, and many stopped farming (Dorodnykh 2017).

Bolstering the resilience Jamaican agriculture sector can be a win-win for both the farmers and the environment alike. Long term resilience will support increased domestic production. It will help maintain the vital role of Jamaican farmers, both as a crucial part of the national economy and a cornerstone of the Jamaican contributions to climate change mitigation activities.

Water Management Strategies

Farmers' main problem in the Southern Agricultural Plains is lack of irrigation water from an insufficient water supply system and related elevated water cost for irrigation (Selvaraju 2013). To solving the problem, the Government of Jamaica (GOJ) is implementing two irrigation projects: the Essex Valley Agricultural Development Project (EVADP) and the Southern Plains Agricultural Development Project (SPADP). Both projects are looking to address the challenges of water supply for farmers. The EVADP is designing a multi-loop pipe network to meet the water demand for agriculture in the region, including six wells with a water production of 270 m3/h each, pumping the water from the well to the pipe network. The SPADP is implementing irrigation initiatives in two former sugar cane estates in Amity Hall in Southern St. Catherine in the Rio Cobre Hydrological Basis and Parnassus in Southern Clarendon in the Rio Minho water basin. Implementing agencies for both projects are the Ministry of Agriculture and Fisheries (MoAF) and its support agencies, the National Irrigation Commission (NIC), the Agro-Investment Corporation (AIC), and the Rural Agricultural Development Authority (RADA). The following reports are considered to be relevant for this study:

- Essex Valley Agricultural Development Project:
    - Climate Vulnerability Assessment
    - Water Availability and Use Report
    - Design Recommendations Report
- South St. Catherine and Clarendon Plains for Agricultural Development Project (SCCADP)
    - Climate Vulnerability and Risk Assessment

Water Balance model

The region for calculating the water balance model includes the parishes of Clarendon, St Catherine, Manchester, and St Elizabeth in Jamaica. This region (Figure 3) has a total area of 4,414 km^2 and it was used for the calculating a water balance. The main land use/land cover classes present in this region are evergreen broadleaved forest (29.8%), mixed forest (17.9%), grasslands (16.3%), and rainfed croplands (16.2%). In addition, the highest elevation point is located at 990 m.a.s.l. The most intense rains occur in May with maximum values that can be around 414 mm, while the months DJF represent the dry season.

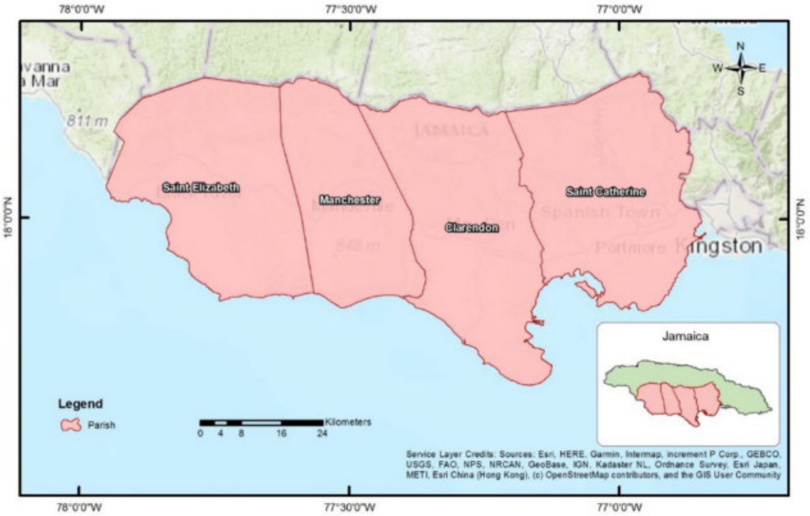


Figure 3. Area for applying the water balance model.

Knowing the water balance of a geographical area is essential to understand and anticipate the necessary actions that ensure the sustainability of any agricultural system. At the same time, it allows for the conservation and restoration of ecosystems, especially those related to water resources. In this study, one of the most known water balance schemes was used, as it is the Thornthwaite and Mather (1955) water balance model. This model involves the principal hydrological cycle components (runoff, effective precipitation, soil moisture, percolation, potential, and actual evapotranspiration) monthly. Figure 4 shows the scheme followed in this project, which is an adaptation of that used by Ulmen (2000a, b). In this scheme, effective precipitation is the difference between monthly precipitation and surface runoff. Thus, dry, or humid months are defined through the comparison with potential evapotranspiration, being the dry months when evapotranspiration exceeds effective precipitation.

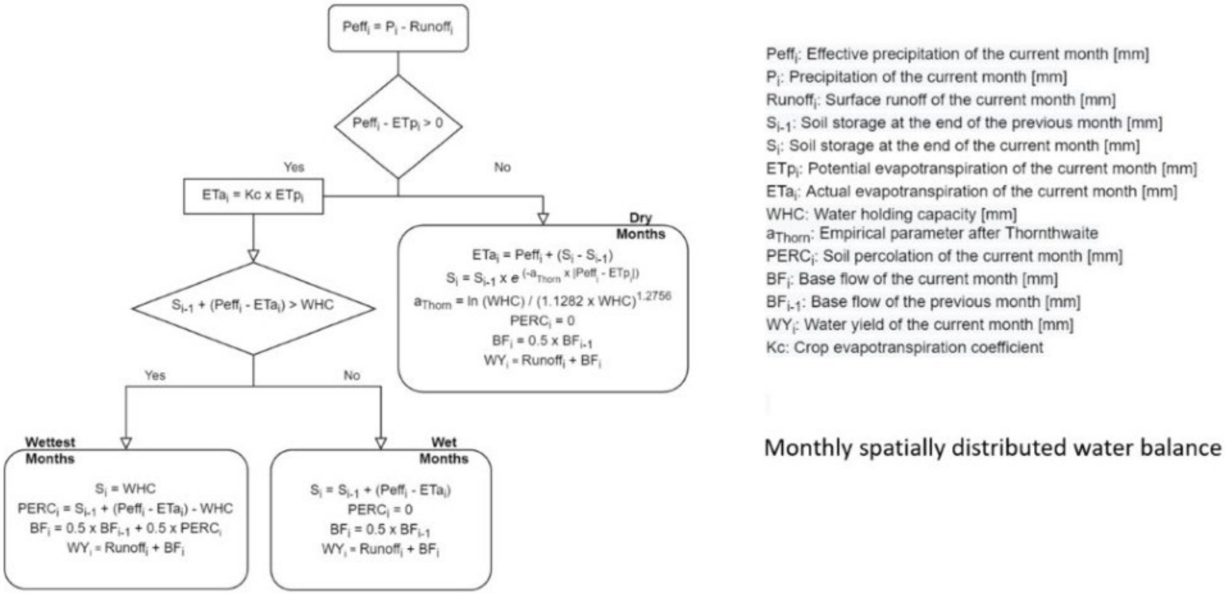


Figure 4. Water balance model.

The study area presents limitations for available data sources. For this reason, it was decided to gather secondary information from global sources to implement the water balance and crop model at the parish level (Clarendon, St Catherine, Manchester, and St Elizabeth) for Jamaica (Table 2).

Table 2. Gathered information sources.

Layer	**Description**	**Spatial resolution**	**Period**	**Units**	**Source**
Administrative Boundaries	Official boundaries of Jamaica	-	since 2018	-	GADM
DEM	Digital Elevation Model	≈ 30 m	since 2000	m	SRTM
Land use/Land cover	This layer contains 22 land use/land cover classes of the entire globe, which were determined from the United Nations (UN) land cover classification system (LCCS). The provider generated this layer with time series mosaics of the global PROBA-V satellite	≈ 300 m	2016	-	C3S
Rainfall	This layer corresponds to the precipitation estimated from stations (rain gauges) and satellite observations at a global level, which are useful for areas with low station density and difficult to access. Precipitation was downloaded on monthly basis.	≈ 5 km	2000 - 2016	mm	CHIRPS
Soil texture classes	This layer contains the global soil textural classes (USDA system) at six depths (0, 10, 30, 60, 100 and 200 cm). The provider with the *soiltexture* package of the R language and samples of textural classes estimated them.	≈ 250 m	1950 - 2017	-	LandGIS
Temperature max	This layer contains daily maximum temperature worldwide.	≈ 5 km	2000 - 2016	°C	CHIRTS
Temperature min	This layer contains daily minimum temperature worldwide.	≈ 5 km	2000 - 2016	°C	CHIRTS
Water Holding capacity	Maximum amount of water that the soil can hold. This was calculated with a pressure of 2.5 (pF=2.5).	≈ 250 m	1950 - 2015	V%	ISRIC

Adjustment of gathered information for the water balance model

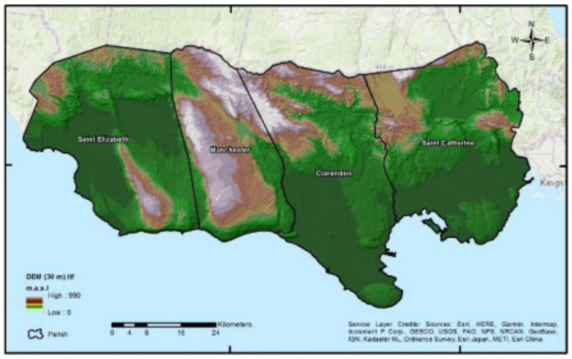
The standardization of gathered datasets allowed for the homogenization of all layers for the study area. In this case, the gathered datasets represent each one of the variables required (i.e., DEM, rainfall, temperature, evapotranspiration, land use/land cover, soil texture classes, water holding capacity) to implement the water balance. Therefore, we proceeded to perform the corresponding adjustments to standardize these layers according to the parameters presented in Table 3.

Table 3. Parameters defined to standardize the gathered datasets.

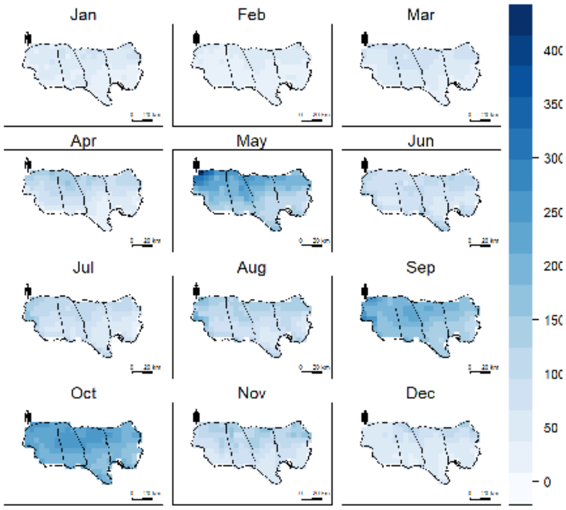
Parameter	Value
Coordinate system	JAD_2001_Jamaica_Grid; Datum: D_Jamaica_2001
Extent	Top: 678728.4; Left: 649144.1; Right: 767014.1; Bottom: 617408.4
Columns and rows	3929 – 2044
Number of cells	4’903,275
Spatial resolution	30 meters
Period	2000 - 2016

We used global data for each variable in the implementation of the water balance. For example, rainfall was obtained from CHIRPS (Climate Hazards Group InfraRed Precipitation with Station data), temperature from CHIRTS (Climate Hazards Group InfraRed Temperature with Station data), and evapotranspiration was derived using both rainfall and temperature datasets

Digital Elevation Model: The SRTM (Shuttle Radar Topography Mission) DEM was downloaded from the Google Earth Engine platform (GEE) at 1 arc-second of spatial resolution (approx. 30 meters) for the whole of Jamaica. Then, the first procedure to obtain a corrected DEM was to execute the algorithm Fill Sinks, which removes areas of undefined flow directions. Finally, the resulting raster was clipped for the study area, and it was projected to the coordinate system JAD 2001.



Rainfall was represented by continued surfaces from CHIRPS, which are useful for areas with low station density and difficult/restricted access to weather data. Then, monthly and pentadaily (last five days of each month) global datasets were downloaded for the period 2000 – 2016 and adjusted according to the parameters defined in Table 2. These surfaces were finally averaged on a multi-year monthly basis to analyze the rainfall spatial patterns in Jamaica.



Climate

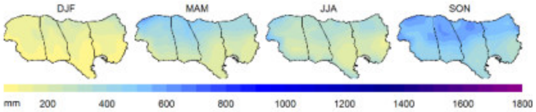
A: Annual rainfall distribution marks two season, May, Sep and Oct are the rainiest months with rains occurring especially in the northwestern part of the study area, while January is the driest month. Seasonally speaking, the analysis shows that December - February (DJF) represent the dry season and SON quarter is characterized by the highest accumulated rains occurring mainly in the north region.

B: Spatial temperature tiles were obtained from CHIRTS, the period between June and August (JJA) is represented by the highest temperature (32.3°C) in the study area.

C: December to February (DJF) is the season with the lowest minimum temperature (16.2°C) in the study area.

In general, the highest temperatures occur in the flat zones of the study area, which are specially located near its coastal borders, being more significant in the south and west parts. The maximum and minimum temperatures were used to calculate the potential evapotranspiration, which is a fundamental input of the water balance.

A



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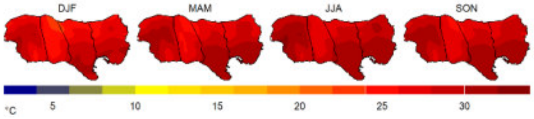

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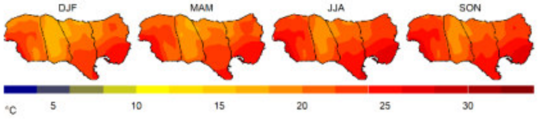
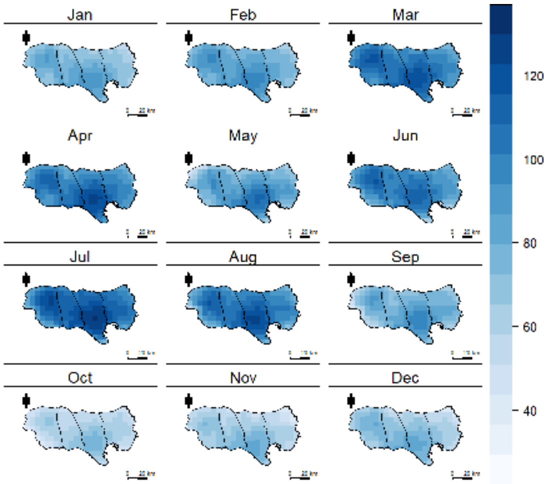


Evapotranspiration: One of the main inputs of any water balance is the potential evapotranspiration. Therefore, this variable can be generated at a monthly level using the modified equation of Hargreaves (Droogers & Allen, 2002), which uses extraterrestrial radiation, average daily temperature, daily temperature range, and monthly precipitation. According to Droogers & Allen (2002), this modification of the standard equation of Hargreaves can better represent potential evapotranspiration in limited availability conditions of weather data than even the Penman-Monteith method. Monthly potential evapotranspiration for the study period is presented below.



Land use cover: The study area presents 17 land use/land cover classes according to the Land Cover Classification System (LCCS). These classes were associated with relevant information (i.e., curve number according to each hydrological soil group and crop evapotranspiration coefficient) that is used principally in the water balance. In summary, the most significant land use/land cover classes are evergreen broadleaved forest, mixed forest, grasslands, and rainfed croplands (Table 4).

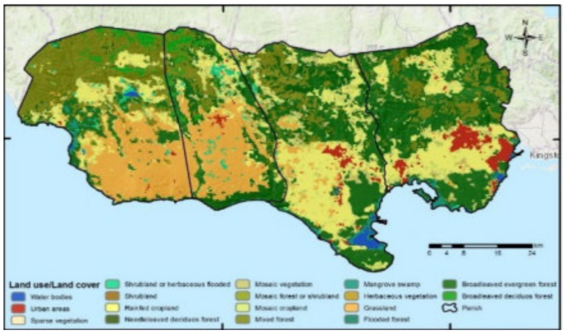


Table 4. Curve number (CN) by hydrological soil group (A-D) and crop evapotranspiration coefficient (kc).

Value*	Class	CN-A	CN-B	CN-C	CN-D	kc	Area (ha)	Area (%)
50	Evergreen broadleaved forest	30	55	70	77	1,000	131,693	29.84
90	Mixed forest	30	55	70	77	1,000	79,025	17.91
130	Grassland	49	69	79	84	925	71,968	16.31
10	Rainfed cropland	66	77	85	89	650	71,422	16.18
30	Mosaic cropland	63	73	80	83	650	26,086	5.91
40	Mosaic vegetation	49	69	79	84	398	22,430	5.08
190	Urban areas	89	92	94	95	300	12,110	2.74
60	Deciduous broadleaved forest	36	60	73	79	1,000	9,225	2.09
170	Mangrove swamp	45	66	77	83	1,200	6,556	1.49
180	Shrubland or herbaceous flooded	49	69	79	84	1,200	5,772	1.31
210	Water bodies	80	80	80	80	952	3,535	0.80
100	Mosaic forest or Shrubland	43	65	76	82	1,000	799	0.18
110	Herbaceous vegetation	55	71	81	83	925	381	0.09
80	Deciduous Needle leaved forest	36	60	73	79	1,000	112	0.03
150	Sparse vegetation	68	79	86	89	398	89	0.02
160	Flooded forest	45	66	77	83	1,200	46	0.01
120	Shrubland	63	71	81	89	925	46	0.01

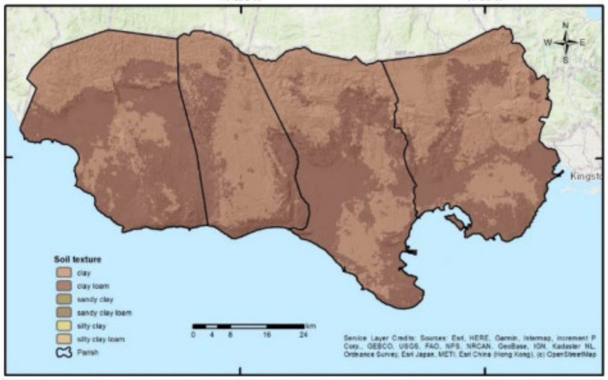
Soil variables

The soil variables (Table 5) considered for the water balance are the soil texture classes and water holding capacity. These variables were obtained from global datasets that have been adjusted with the parameters.

Table 5. Soil texture classes and hydrological soil groups.

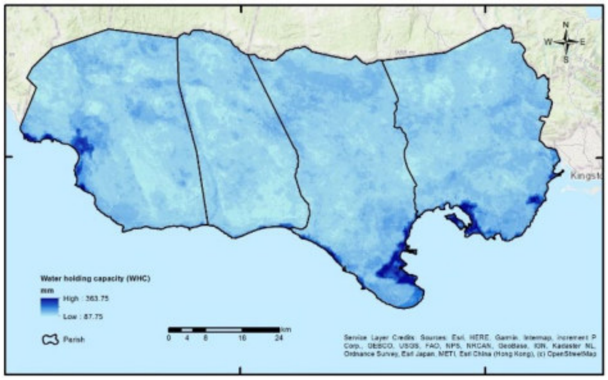
Value	**Class**	**HSG**	**Area (ha)**	**Area (%)**
1	clay	D	224,939	50.97
4	clay loam	D	214,416	48.59
6	sandy clay loam	C	1,917	0.434
3	sandy clay	D	10	0.002
5	silty clay loam	D	7	0.002
2	silty clay	D	5	0.001

Soil texture classes: The layers downloaded from the source contain six global soil texture classes (USDA classification system) at six depths (0, 10, 30, 60, 100, and 200 cm) as continuous surfaces for the study area. In consequence, cell statistics (majority) were used to determine the soil texture class for each location of the study area (Figure 9). Then, the hydrological soil group (HSG) was derived from the resultant soil texture surface



Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap

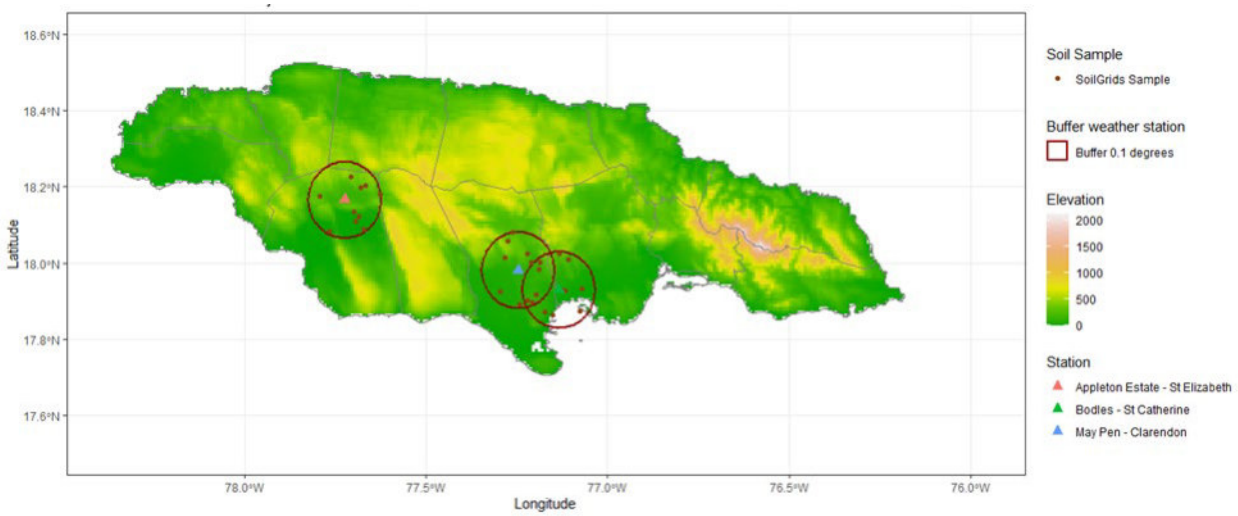
Water holding capacity (WHC): This layer provides the soil water holding capacity in volumetric fraction (V%) at different depths (0, 5, 15, 30, 60,100, and 200 cm) and was downloaded as a raster stack. Therefore, a weighted average was calculated to determine the final WHC raster in mm for each location in the study area, considering all the different depths. Figure 10 shows the spatial distribution of the soil water holding capacity.



Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap

Crop Modelling

A crop-water-productivity simulation model was parametrized for four crops. The model was implemented for the closest available weather station sites for the project intervention areas in Amity Hall Agro Park in St Catherine Parish, Parnassus Agro Park in Clarendon Parish, and several farming communities in the St. Elizabeth Parish, see Figure 5.



Study location	Weather station	Latitude	Longitude	Elevation
Essex valley	Appleton Estate	18.16556	-77.7247	155
Parnassus	May Pen	17.98139	-77.2464	84
Amity hall	Bodles	17.92972	-77.1342	29

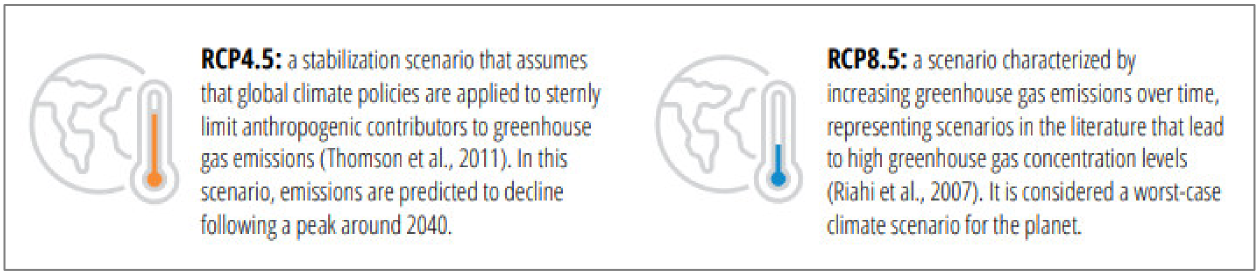
Figure 5. Map shows the location of weather stations from where the climate baseline was derived, the soil data grid and the areas elevation.

For each region, climate scenarios composed of a baseline (1995 - 2020) and future projections (2025 - 2099) derived from four Global Circulation Models (GCM) from the World Climate Research Programme (WCRP) Coupled Model Intercomparison Project - Phase 5 (CMIP5) and two Representative Concentrative Pathways (RCP) scenarios (RCP4.5, RCP8) were generated and evaluated with two bias correction methods (Bias correction and Quantile Mapping) of the CCAFS-Climate platform. Based on the performance of GCMs in the study area (MICAF, 2019), four climate models (Table 6) and two RCP scenarios (RCP4.5 and RCP8.5) were selected.

Table 6. Selected Global Climate Circulation Models from CMIP5.

Model Acronym	Climate System Model
BCC_CSM1.1(m)	Beijing Climate Center Climate System Model version 1.1
Bnu_esm	Beijing Normal University Earth System Model version 1
Cesm1_cam5	Community Atmospheric Model version 5
Ec_earth	European community Earth-System Model

For each RCP scenario, the growth and development of the four crops were simulated using the AquaCrop model for two planting seasons, season one between April and June and season two between August and October, and for rainfed and irrigated water management.



RCP4.5: a stabilization scenario that assumes that global climate policies are applied to sternly limit anthropogenic contributors to greenhouse gas emissions (Thomson et al., 2011). In this scenario, emissions are predicted to decline following a peak around 2040.

RCP8.5: a scenario characterized by increasing greenhouse gas emissions over time, representing scenarios in the literature that lead to high greenhouse gas concentration levels (Riahi et al., 2007). It is considered a worst-case climate scenario for the planet.

The simulation outputs from the crop model using the **baseline** (1995-2020) were compared with historical records from FAOSTAT (https://www.fao.org/) to validate the model performance values. The simulations of the future scenarios were grouped by analysis periods in **near** (2024-2049), **mid** (2050-2074), and **end** (2075-2099). The relative changes were calculated with respect to the **baseline** reference period.

AquaCrop crop-water-productivity model

AquaCrop (Hsiao et al. 2009) is a crop-water-productivity model developed by the Food and Agriculture Organization of the United Nations (FAO) to improve water productivity in rainfed and irrigated fields. It simulates yield response to water of herbaceous crops. It is particularly suited to address conditions where water is a crucial limiting factor in crop production. AquaCrop was developed in 2009, and since then, it has been used worldwide in different agro-ecological conditions. AquaCrop is intended for practitioners working for extension services, governmental agencies, non-governmental organizations, and farmer associations, as a planning tool to aid management decisions in both irrigated and rainfed agriculture. It is also used as a tool to analyze the role of water in determining crop productivity.

Similarly, to many other crop-growth models, AquaCrop further develops a structure (sub-model components) that includes: the soil, with its water balance; the crop, with its development, growth, and yield; the atmosphere, with its thermal regime, rainfall, evaporative demand, and carbon dioxide concentration (CO2); and the management, with its central agronomic practice such as irrigation and fertilization. Simulation runs of AquaCrop are executed with daily time steps, using either calendar days or growing- degree-days. Several features distinguish AquaCrop from other crop growth models achieving a new level of simplicity, robustness, and accuracy.

Critical features of AquaCrop include:

- Canopy development expressed as canopy cover
- Root development is expressed in terms of adequate rooting depth as a function of time (either calendar or thermal);
- Biomass is calculated using water productivity and crop transpiration.
- Yield is determined as a product of biomass and harvest index, and
- Water stress is expressed through stress coefficients.

See the AquaCrop model flowchart in Figure 6.

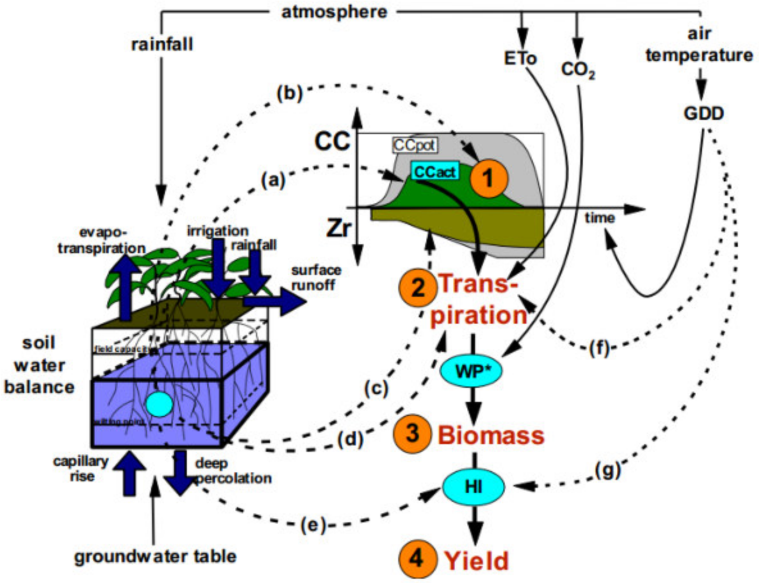


Figure 6. AquaCrop flowchart showing the main components of the soil-plant-atmosphere continuum. The dotted lines represent the processes affected by water stresses (a, b, c, d, e) and temperature (f, g), CC is the canopy cover, Zr the root depth, WP the normalized water productivity and HI the harvest index. Taken from (Food and Agriculture Organization of the United Nations, 2018)

The statistical program R (R Core Team, 2021) and the AgroClimR package (https://github.com/jrodriguez88/agroclimR) were used for the processes of data download and management, import and format conversion, analysis, and visualization of results.

Data and information

Table 7 shows the data and information requirement for the AquaCrop model.

Table 7. Required data and information for the AquaCrop model.

CLIMATE (daily)	**SOIL**	**MANAGEMENT**	**CROP**
Maximum temperature	Texture (% Silts, Sands and Clays)	Soil fertility (qualitative)	Seedtime
Minimum temperature	Soil water content (CAS) at saturation	Live or dead mulches (mulches)	Planting density
Precipitation	CAS to field capacity	Taipa height	Maximum canopy coverage
Reference evapotranspiration	CAS on the verge of permanent wilting	Irrigation method, frequency and quantity	Date of emergence
CO2 concentration	Saturated hydraulic conductivity	Irrigation water salinity	Flowering date
	Soil layer depth	Initial soil water content	Onset of senescence
	Penetrability**		Maturity date
	Gravel content (%) **		Crop duration
			Harvest index

Maximum root depth
Canopy coverage at different stages *
Aerial biomass in different stages *
Grain yield to maturity *

Climate data baseline

The University of West Indies Climate Studies provided observed data from the Meteorological service of Jamaica (https://metservice.gov.jm/), including daily information on precipitation, maximum and minimum temperature in the period 2013 to 2020 for the selected weather stations. An exploratory analysis of the data was performed to identify anomalous and missing data. The series were subjected to quality control that includes error tests, internal consistency, temporal consistency, and climatological limits by variable. Following the recommendations of (Ruane, Goldberg, & Chryssanthacopoulos, 2015; Van Wart et al., 2015), it is suggested to use a baseline of at least 25 years of precipitation and temperature records for the analysis of climate change scenarios. Therefore, we complemented the observed data from UWI Climate Studies with open data from NASAPOWER and CHIRPS. We carried out a control and correction of bias in propagation of climatic series (Table 8).

Table 8. Metrics for evaluation of climate baseline.

metric	description
n	number of observations
r	Pearson correlation coefficient
k	kendall tau correlation coefficient
RMSE	The Root Mean Square Error
NRMSE	Normalized Root Mean Square Error
MAE	Mean Absolute Error
MBE	Mean Bias Error
d	Index of Agreement (Willmott)
NSE	Nash Sutcliffe model Efficiency coefficient
rsq	R-squared correlation

Future climate projections

Data of future climate models and scenarios were downloaded from the CCAFS-Climate portal (http://www.ccafs-climate.org/). Two bias correction methods were evaluated: Bias correction and Quantile Mapping (http://www.ccafs-climate.org/bias_correction/).

Table 9. Summary table of climate data used for the crop model simulation.

Weather station	Climate scenario	Climate model	Period	Variables	Method
Appleton Estate	historical	obs (2013-2020) + nasapower (1990-2020)	1995-2020	tmax, tmin, rain	Observed data Quality control, Nasa Temperature bias correction, ensemble baseline

	rcp45	bcc_csm1_1_m, bnu_esm, cesm1_cam5, ec_earth	2024-2049		Bias Correction (with variability) - Quantile Mapping
	rcp45		2050-2074		
	rcp45		2075-2099		
	rcp85		2024-2049		
	rcp85		2050-2074		
	rcp85		2075-2099		
May Pen	historical	obs(2013-2020) + nasapower(1990-2020)	1995-2020	tmax, tmin, rain	Observed data Quality control, Nasa Temperature bias correction, ensemble baseline
	rcp45	bcc_csm1_1_m, bnu_esm, cesm1_cam5, ec_earth	2024-2049		Bias Correction (with variability) - Quantile Mapping
	rcp45		2050-2074		
	rcp45		2075-2099		
	rcp85		2024-2049		
	rcp85		2050-2074		
	rcp85		2075-2099		
Bodles	historical	obs(2013-2029) + nasapower(1990-2020)	1995-2020	tmax, tmin, rain	Observed data Quality control, Nasa Temperature bias correction, ensemble baseline
	rcp45	bcc_csm1_1_m, bnu_esm, cesm1_cam5, ec_earth	2024-2049		Bias Correction (with variability) - Quantile Mapping
	rcp45		2050-2074		
	rcp45		2075-2099		
	rcp85		2024-2049		
	rcp85		2049-2074		
	rcp85		2075-2099		

Soil data

The soil information was obtained from the SoilGrids database, from the International Center for Reference and Information on Soils (ISRIC) (https://soilgrids.org/). SoilGrids is an automated global soil mapping system based on public information and remote sensing (Hengl et al., 2017). It provides the variables of texture, organic carbon, and apparent density at different depths. Using the variables from SoilGrids, the other physical soil variables were calculated by using a pedotransfer function (PTF) (Wösten, Pachepsky, & Rawls, 2001). Using the location of the three weather stations, a buffer of 0.1 decimal degrees (approx 12km) was defined and ten soil data points were randomly chosen inside the buffer and extracted. For the data extraction of variables (Table 10) of six soil depth profiles (" 0-5cm "," 5-15cm "," 15-30cm "," 30-60cm "," 60-100cm "," 100-200cm "), an Application Protocol Interface (API) was used (https://rest.isric.org/soilgrids/v2.0/docs#/).

Table 10. Soil variables extracted from SoilGrids.

Var name	Description	Conventional units
bdod	Bulk density of the fine earth fraction	kg/dm³
cec	Cation Exchange Capacity of the soil	cmol(c)/kg
cfvo	Volumetric fraction of coarse fragments (> 2 mm)	cm3/100cm3 (vol%)
clay	Proportion of clay particles (< 0.002 mm) in the fine earth fraction	g/100g (%)

nitrogen	Total nitrogen (N)	g/kg
phh2o	Soil pH	pH
sand	Proportion of sand particles (> 0.05 mm) in the fine earth fraction	g/100g (%)
silt	Proportion of silt particles (≥ 0.002 mm and ≤ 0.05 mm) in the fine earth fraction	g/100g (%)
soc	Soil organic carbon content in the fine earth fraction	g/kg

Model parametrization

AquaCrop model parametrization was carried out for:

- Sweet Potato - Ipomoea batatas L.
- Groundnut - Arachis hypogaea
- Onion - Allium cepa L.
- Tomato - Solanum lycopersicum

Based on available data, four crops were selected and parametrized based on literature for AquaCrop model simulations, some parameters such as days of growth had to be estimated. The literature review included studies with use cases for selected crops and also reference manuals of AquaCrop (Raes, Steduto, Hsiao, & Fereres, 2012) and data from the Food and Agriculture Organization of the United Nations (FAO) (http://www.fao.org/land-water/databases-and-software/crop-information) were used for parametrization.

See parameters details in Table 11.

Table 11. Crop model parameters and units used for the crop-water simulation model.

component	group	param	description	unit
Crop Phenology	Threshold air temperatures	tbas	Base temperature below which crop development does not progress	(°C)
		tupp	Upper temperature above which crop development no longer increases with an increase in temperature	(°C)
	Development of green canopy cover	CCo	Soil surface covered by an individual seedling at 90% emergence	(cm2/plant)
		nph	Number of plants per hectare	(plant/ha)
		tse	Time from sowing to emergence	(growing degree day)
		CGC	Canopy growth coefficient	(fraction per growing
		CCx	Maximum canopy cover	(%)
		tsss	Time from sowing to start senescence	(growing degree day)
		CDC	Canopy decline coefficient	(fraction per growing
		tsm	Time from sowing to maturity, i.e. length of crop cycle	(growing degree day)
	Flowering	tsf	Time from sowing to flowering	(growing degree day)
		lfs	Length of the flowering stage	(growing degree day)
		cdlf	Crop determinacy linked with flowering	(yes- no)
	Development of root zone	Zn	Minimum effective rooting depth	(m)
		Zx	Maximum effective rooting depth	(m)
		sfrz	Shape factor describing root zone expansion	numeric
Crop transpiration	Crop transpiration	Kctr	Crop coefficient when canopy is complete but prior to senescence	numeric
		dcc	Decline of crop coefficient as a result of ageing, nitrogen deficiency, etc.	(%/day)
		eccr	Effect of canopy cover on reducing soil evaporation in late season stage	%
Biomass production and yield formation	Crop water productivity	WP	Water productivity normalized for ETo and CO2	(gram/m 2)
		WPyf	Water productivity normalized for ETo and CO2 during yield formation	(% WP* before yield)
	Harvest Index	HI	Reference harvest index	(%)
		HIpi	Possible increase of HI due to water stress before flowering	(%)
		epf	Excess of potential fruits	(%)
		HIpc	Coefficient describing positive impact of restricted vegetative growth during yield formation on HI	categorical
		HInc	Coefficient describing negative impact of stomatal closure during yield formation on HI	categorical
		HIam	Allowable maximum increase of specified HI	(%)
Stresses	Soil water stresses	Peup	Soil water depletion threshold for canopy expansion - Upper threshold	numeric
		Pelo	Soil water depletion threshold for canopy expansion - Lower threshold	numeric
		sfsc	Shape factor for Water stress coefficient for canopy expansion	numeric
		Psto	Soil water depletion threshold for stomatal control - Upper threshold	numeric
		sfss	Shape factor for Water stress coefficient for stomatal control	numeric
		Psen	Soil water depletion threshold for canopy senescence - Upper threshold	numeric
		sfcs	Shape factor for Water stress coefficient for canopy senescence	numeric
		Ppol	Soil water depletion threshold for failure of pollination - Upper threshold	numeric
		vap	Vol% at anaerobiotic point (with reference to saturation)	categorical
	Air temperature stress	tmcs	Minimum air temperature below which pollination starts to fail (cold stress)	(°C)
		tmhs	Maximum air temperature above which pollination starts to fail (heat stress)	(°C)
		mgdf	Minimum growing degrees required for full biomass production	(°C - day)
	Salinity stress	ECen	Electrical conductivity of the saturated soil-paste extract: lower threshold (at which soil salinity stress start	numeric
		ECex	Electrical conductivity of the saturated soil-paste extract: upper threshold (at which soil salinity stress has	numeric

Given the complexity of simulating the growth of roots and tubers, an initial parameterization of **Sweet Potato** was achieved by using multiple parameters were based on the study developed in two regions of Jamaica by (Rankine et al., 2015). Rankine concludes that the AquaCrop model provides a fairly accurate prediction of Sweet potato yield and biomass under both rainfed and irrigated conditions.

The parameterization of **Groundnut** was supported by the study of (Chibarabada, Modi, & Mabhaudhi, 2020) and (Karunaratne, Azam-Ali, Izzi, & Steduto, 2011) which was developed in three regions of South Africa. The AquaCrop model was calibrated and evaluated for its ability to simulate canopy cover (CC), biomass, yield, and evapotranspiration of the groundnut crop under conditions of water deficit. In general, the model showed potential to simulate the yield and the evapotransfer of groundnuts under conditions of water deficit.

Similarly, for the cultivation of **Onion** parameters obtained by (Ortola, 2013) were adapted. Ortola sought to evaluate the impacts of variability in soils and irrigation on the yield and quality of the onion crop. Field data and industrial sector surveys were used to calibrate and evaluate the Aquacrop model in multiple management conditions and production environments for brown onion. The performance of the model under ideal management conditions was within the ranges found in the literature, meanwhile the variation in non-optimal conditions was equal to that reported by the producers.

For the fourth crop **Tomato**, the default values available in the AquaCrop were used from the file - TomatoGDD.CRO.

AquaCrop configuration for simulations

A total of 21 climate scenarios were generated per location (1 baseline + (5 GCM * 2 RCP * 2 BiasCorr)). In each scenario, two seasons were evaluated as sowing windows (window A = Apr-May-Jun and window B = Aug-Sep-Oct), corresponding to the traditional times due to the onset of rains. During the period of the sowing window, simulations were carried out with a frequency of 5 days, resulting in between 18 and 19 sowing dates per season.

The four crops were simulated with two water management scenarios:

- **Rainfed**, where the water inputs depend clearly on precipitation
- **Automatic Supplementary Irrigation**, where the model identifies a depletion level of 20% in the available water in the soil and automatically Irrigation is applied to bring the soil to field capacity.

This methodology allows calculating the supplementary water demand of the crop to avoid water stresses and achieve a yield potential in addition to identifying the yield gap between management conditions. In total, we run **13,444,400** simulations.

Yield evaluation of baseline simulations with FAOSTAT data

A comparison of the simulation results from the **baseline** simulation was carried out with historical performance statistics from FAOSTAT (http://www.fao.org/faostat/en/#data).

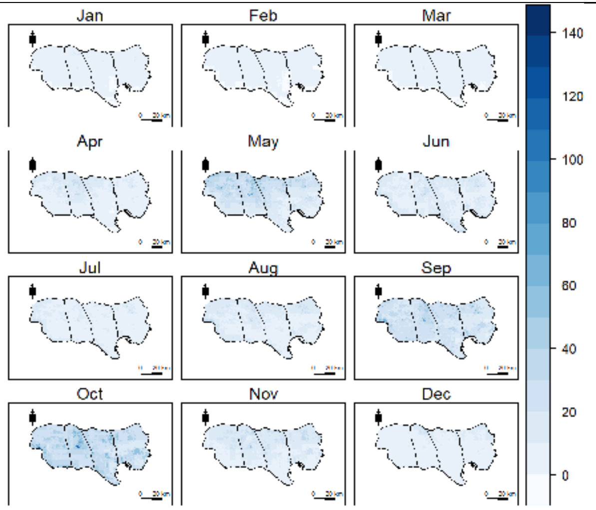
It was necessary to transform the simulated yield values (dry matter) and convert them to commercial fresh weight, referenced in FAOSTAT. We converted tomato yield to 90% humidity, Sweet Potato to 75%, Groundnut to 15% and Onion to 90%. The baseline and FAOSTAT simulations were grouped by channel periods for visual analysis. The simulated baseline data were grouped into different factors: locality, cropping system, planting season, and cultivar (id_name, crop_sys, sow_season, cultivar). The annual average was calculated and subjected to an observed (FAOSTAT) vs simulated (AquaCrop) evaluation.

Results and Findings

Water Balance for the parishes of Clarendon, St Catherine, Manchester, and St Elizabeth

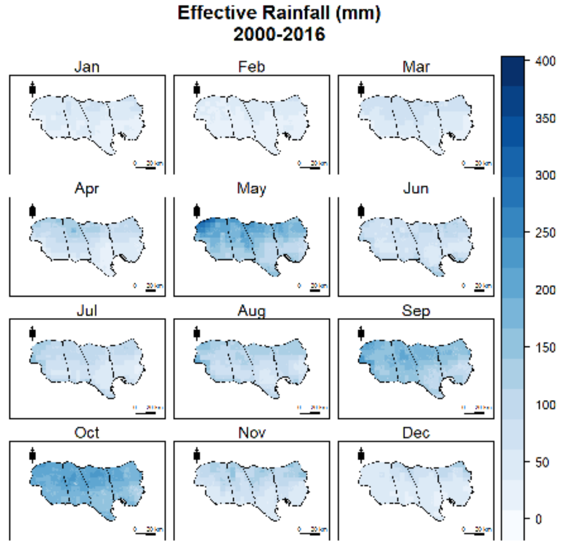
This water balance was calculated pixel by pixel from 2000 - 2016 for the parishes of Clarendon, St Catherine, Manchester, and St Elizabeth in Jamaica monthly. This period was chosen according to the availability of the data collected. On the other hand, October was defined as the starting month, which follows the wettest month (September). In this sense, the first year (2000) was left as the warm-up year. Besides, the recession constant (k) was assumed as 0.5 and the initial base flow as 10 millimeters.

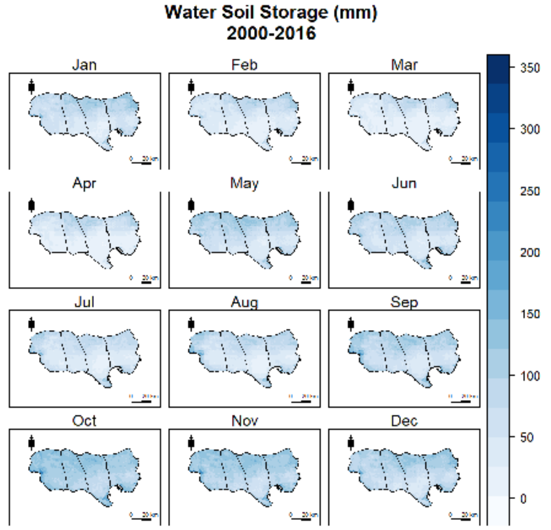
Estimation of surface runoff is one of the most important components of the water balance since it summarizes many hydrological aspects. In this case, the surface runoff was estimated using the curve number (CN) approach, which relates the amount of precipitation generated in a storm with the runoff generated according to the type of soil, land cover, and the condition of the soil moisture (Ponce & Hawkins, 1996; Williams et al., 2012). The highest runoff occurs in October (158 mm/month) but being May and September months with significant values that reach 125 mm/month and 126 mm/month, respectively. These spatial estimations were used as inputs for the generation of the water balance.

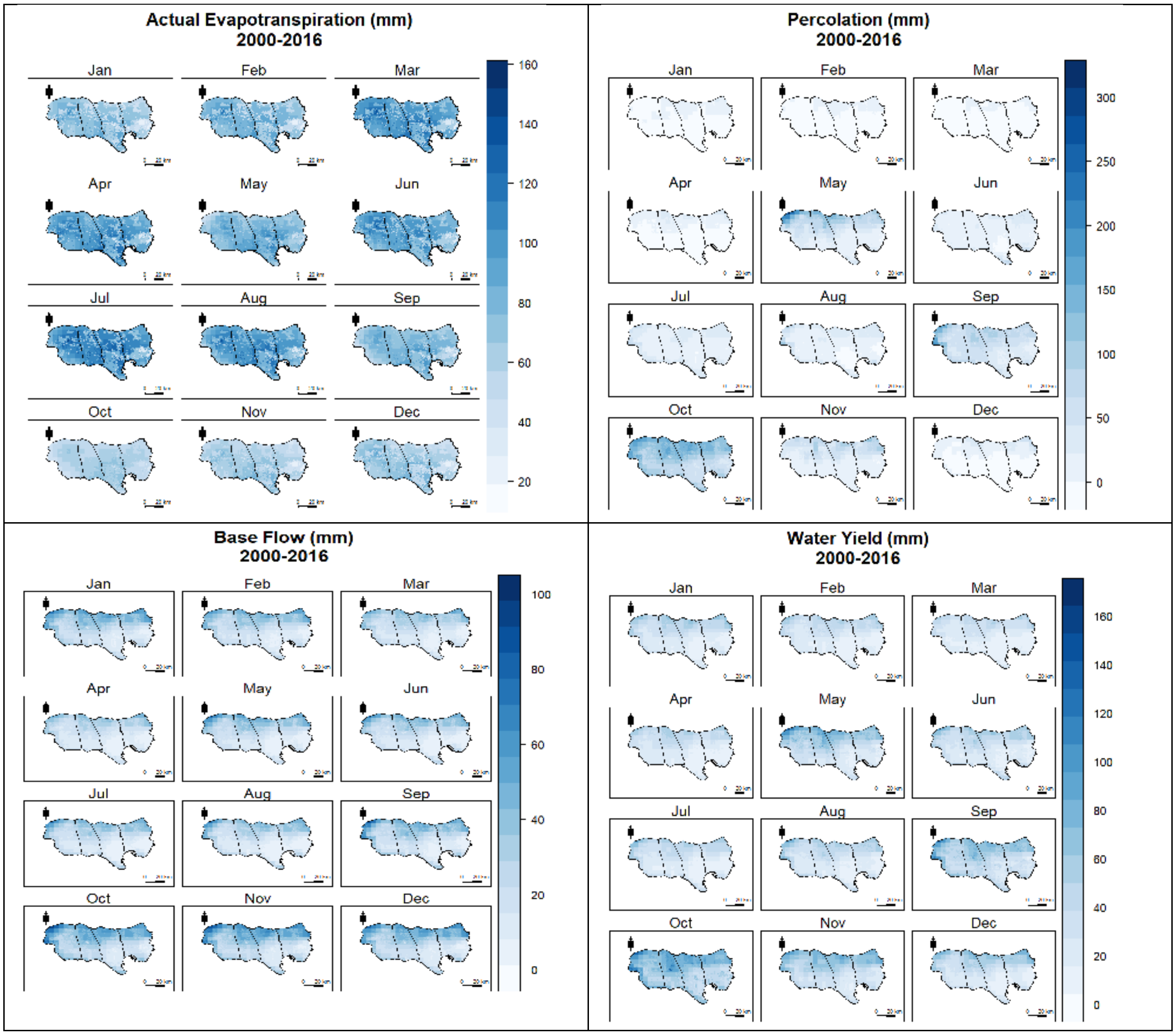


The conceptual model of Thornthwaite and Mather (1955) was used to determine the effective precipitation, water soil storage, and actual evapotranspiration. In addition, surface runoff, percolation, base flow (critical in the dry season), and water yield were derived (Table 12). The latter represents the water contribution of the landscape to the flow (mm) in the study area. Water yield shows this monthly contribution during the period 2000 – 2016; areas with dark blue tones are those that most contribute to the flow. Unfortunately, we could not obtain streamflow series to calibrate this variable, however, the obtained results are still useful to determine those areas that need to be prioritized for conservation and implementation of agricultural practices and where the impact of climate change scenarios can be evaluated.

Table 12. Monthly estimation of the water balance variables.






Actual Evapotranspiration (mm)
2000-2016
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
160
140
120
100
80
60
40
20
Percolation (mm)
2000-2016
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
300
250
200
150
100
50
0
Base Flow (mm)
2000-2016
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
100
80
60
40
20
0
Water Yield (mm)
2000-2016
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
160
140
120
100
80
60
40
20
0

Crop-water-productivity simulation model outputs

As outlined in the above section, we used input data from three different resources to establish a climate baseline. We used data from the Meteorological service of Jamaica and complemented missing years with data from NASA POWER and the Climate Hazards group Infrared Precipitation with Stations (CHIRPS) (Funk et al. 2015). The Nasa POWER data set was obtained from the National Aeronautics and Space Administration (NASA) Langley Research Center (LaRC) Prediction of Worldwide Energy Resource (POWER) Project funded through the NASA Earth Science/Applied Science Program.

Figure 7 summarizes the evaluation of different databases resulting from the combination of NASAPOWER, CHIPRS and the application of bias correction methods by variable, versus the observed data. The results show a good correlation of different configurations.

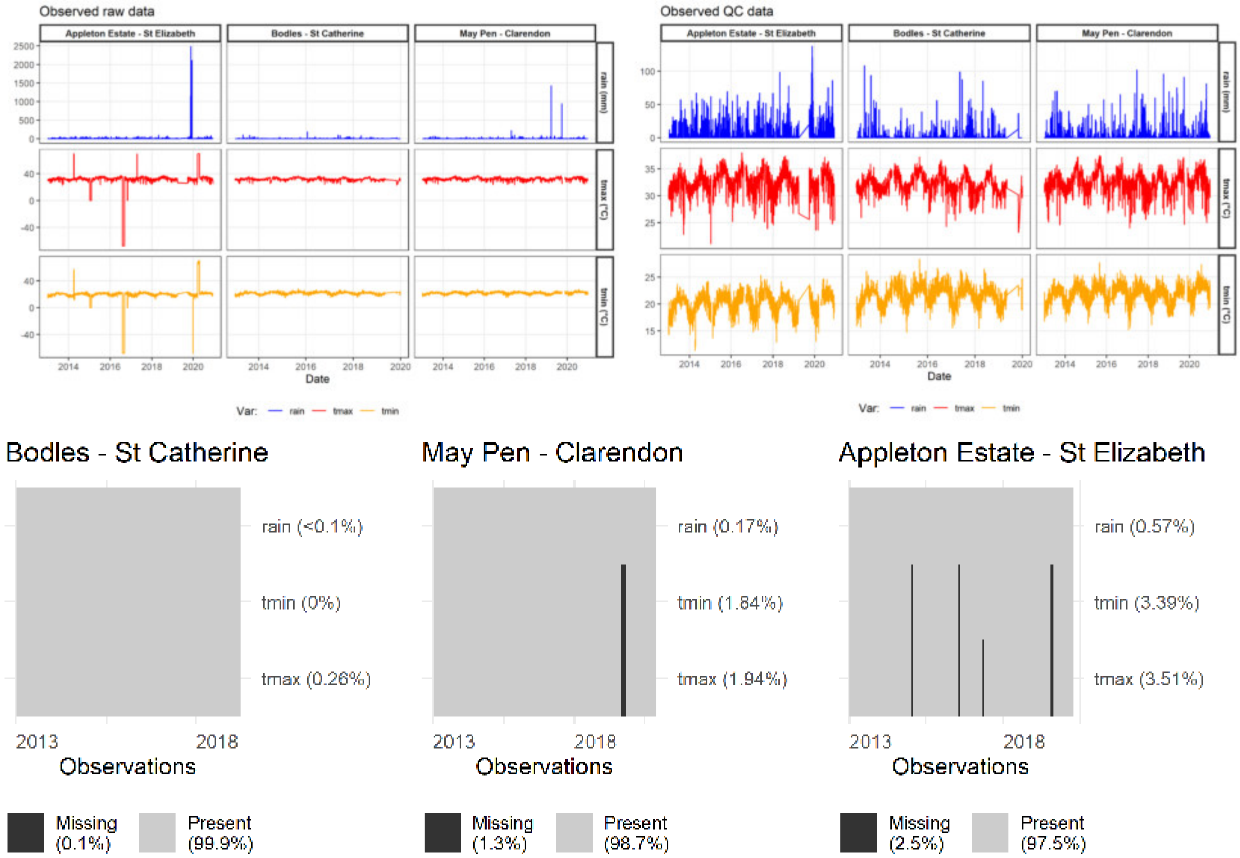


Figure 7. Evaluation of bias corrected baseline climate data.

All bias corrected values are mapped in Figure 8 and Table 13. Evaluations show that while the mean absolute error and mean bias error is higher for monthly rain data, the normalized root mean square error is higher for daily rain data. Also, correlations are lower for rain data than for temperature data. The Nash Sutcliffe model Efficiency coefficient also shows that minimum temperature data are less efficient in data evaluations. Overall, there is higher confidence in temperature data than in rainfall data.

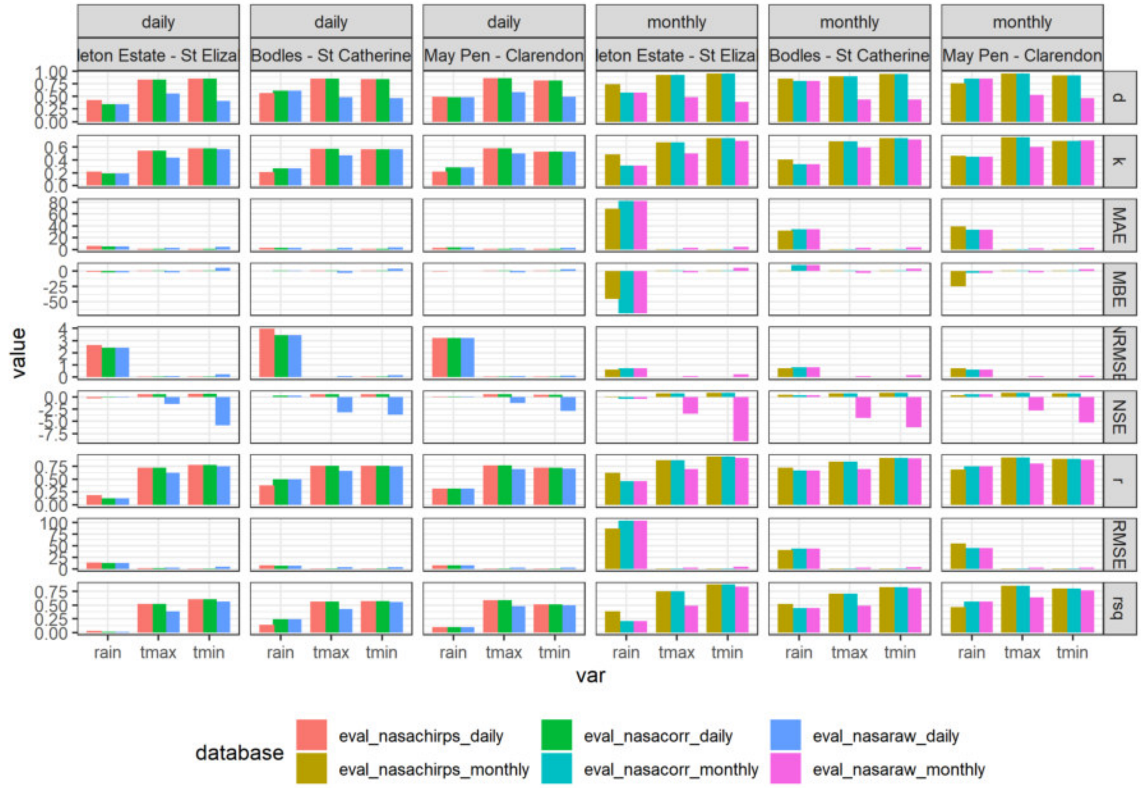


Figure 8. Mapped values of evaluation metrics.

Table 13. Evaluation metrics at different time scales and methods.

id	station	var	time	database	n	r	k	RMSE	NRMSE	MAE	MBE	d	NSE	rsq
Amity Hall	Bodles - St Catherine	tmx	daily	eval_nasacorr_daily	2263	0.753	0.572285	1.10016	0.034174	0.823815	0.190233	0.850922	0.5494	0.567049
Amity Hall	Bodles - St Catherine	tmn	daily	eval_nasacorr_daily	2269	0.753	0.568657	1.228536	0.056679	0.953038	0.241325	0.836853	0.549575	0.567707
Amity Hall	Bodles - St Catherine	rain	daily	eval_nasaraw_daily	2268	0.494	0.267317	6.511412	3.464687	2.552288	0.169511	0.610734	0.240113	0.244222
Amity Hall	Bodles - St Catherine	rain	mthy	eval_nasachirps_monthly	78	0.721	0.408796	41.25537	0.758085	32.05573	0.295553	0.845729	0.44103	0.52031
Amity Hall	Bodles - St Catherine	tmx	mthy	eval_nasacorr_monthly	73	0.837	0.689498	0.784415	0.024429	0.488375	0.225458	0.898185	0.675201	0.702077
Amity Hall	Bodles - St Catherine	tmn	mthy	eval_nasacorr_monthly	79	0.905	0.742087	0.642529	0.029605	0.489399	0.226674	0.938742	0.793392	0.820584
Parnassus	May Pen - Clarendon	tmx	daily	eval_nasacorr_daily	2458	0.764	0.581743	1.20511	0.037091	0.919252	0.260717	0.86006	0.553117	0.584658
Parnassus	May Pen - Clarendon	tmn	daily	eval_nasacorr_daily	2461	0.718	0.532445	1.172638	0.05368	0.933126	0.344336	0.808857	0.471054	0.516781
Parnassus	May Pen - Clarendon	rain	daily	eval_nasachirps_daily	2509	0.321	0.216925	8.217621	3.203644	3.062749	-0.94498	0.491975	0.023431	0.103103
Parnassus	May Pen - Clarendon	rain	mthy	eval_nasaraw_monthly	81	0.748	0.451135	44.58699	0.608722	33.54605	-3.64778	0.846468	0.556693	0.560254

Parnassus	May Pen - Clarendon	tmx	monthly	eval_nasacorr_monthly	79	0.920183	0.754423	0.561334	0.017286	0.448504	0.234395	0.950255	0.806225	0.846737
Parnassus	May Pen - Clarendon	tmn	monthly	eval_nasacorr_monthly	82	0.891305	0.693675	0.653695	0.02996	0.511479	0.35432	0.915353	0.708327	0.794425
Essex Valley	Appleton Estate - St Elizabeth	tmx	daily	eval_nasacorr_daily	2254	0.723238	0.545405	1.337447	0.041021	1.011831	0.170166	0.834556	0.505176	0.523073
Essex Valley	Appleton Estate - St Elizabeth	tmn	daily	eval_nasacorr_daily	2256	0.775909	0.58426	1.208331	0.060307	0.922309	0.297848	0.852048	0.575906	0.602035
Essex Valley	Appleton Estate - St Elizabeth	rain	daily	eval_nasaraw_daily	2293	0.132705	0.192474	12.50315	2.422617	5.537444	-2.88052	0.34251	-0.13628	0.017611
Essex Valley	Appleton Estate - St Elizabeth	rain	monthly	eval_nasachirps_monthly	76	0.621588	0.489321	87.00162	0.622271	68.84368	-45.2408	0.735585	0.025161	0.386372
Essex Valley	Appleton Estate - St Elizabeth	tmx	monthly	eval_nasacorr_monthly	70	0.865904	0.673431	0.692779	0.02128	0.560394	0.213653	0.923061	0.700191	0.749789
Essex Valley	Appleton Estate - St Elizabeth	tmn	monthly	eval_nasacorr_monthly	71	0.934656	0.738177	0.59896	0.029768	0.455897	0.272886	0.953637	0.837839	0.873582

Bias correction (BC) and quantile mapping (QM) applied to future scenarios show relative projected changes of temperature and rainfall for the near future of the century, mid and end (Figure 9, Figure 10, Figure 11). While increase of temperature is similar between BC and QM, rainfall trends show quite some differences in the signal of trend.

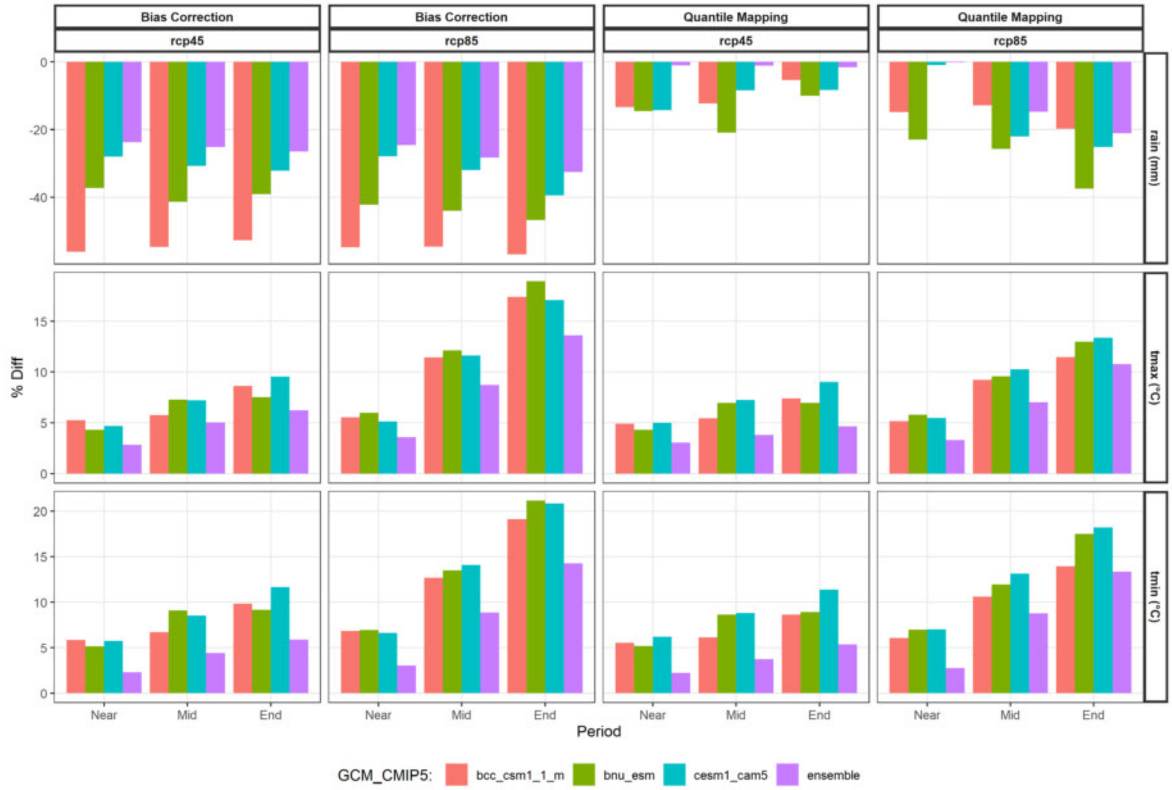


Figure 9. Relative change in % (below) for St. Elizabeth (Appleton Estate).

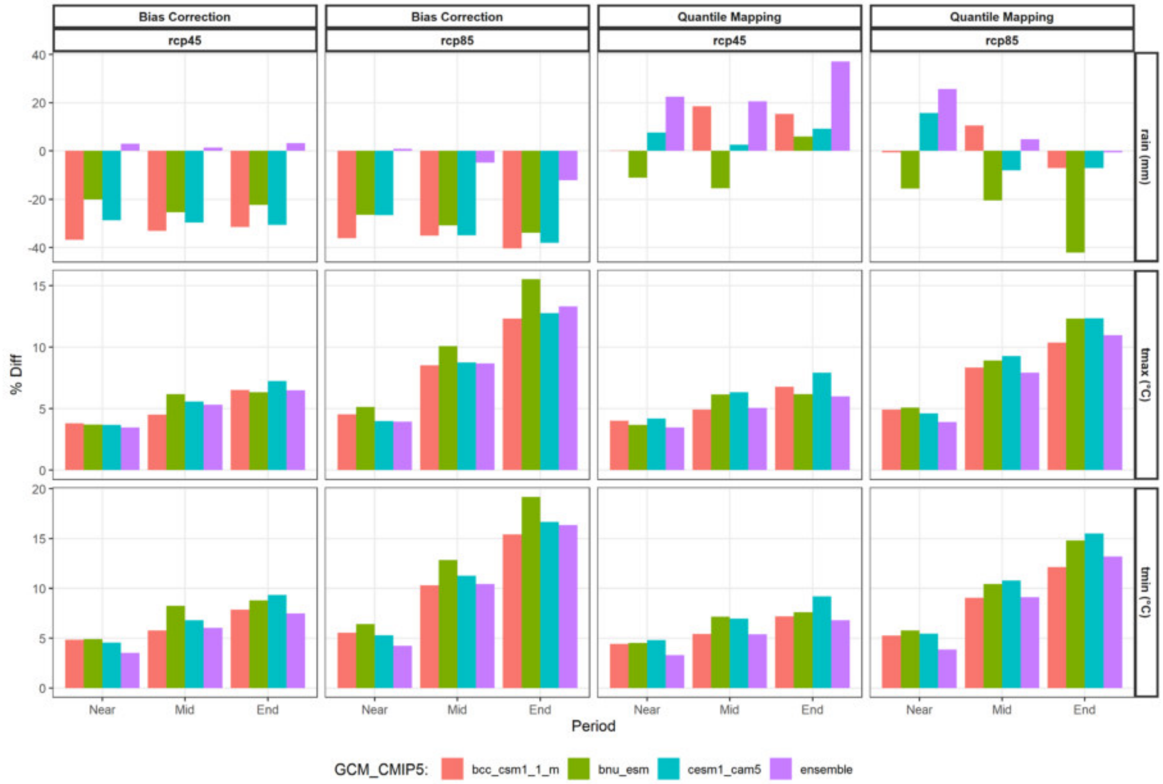


Figure 10. Relative change in % (below) for St. Catherine (Bodles).

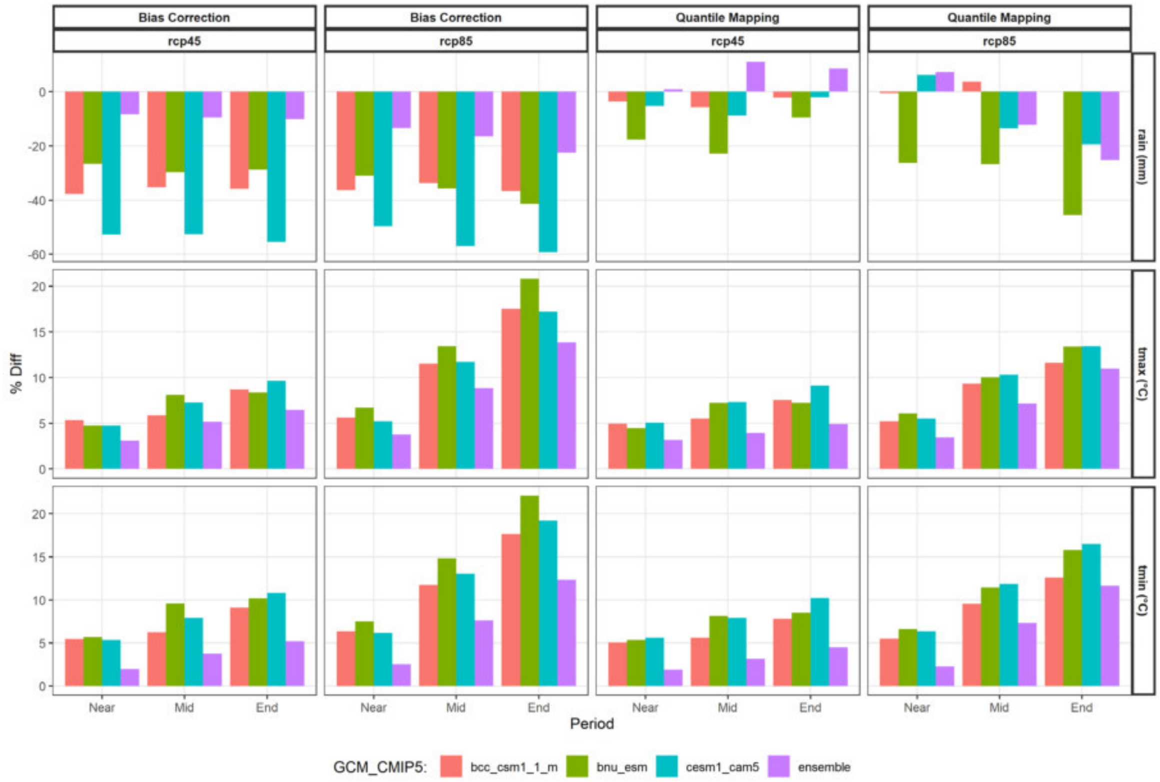


Figure 11. Relative change in % (below) for Clarendon (May Pen).

Results of crop parametrization

The Baseline simulation results of AquaCrop show the importance of using model parameters that are estimated for the study area. Despite the difficulty of modeling root and tuber crops in AquaCrop, the best statistical metrics were obtained from the comparison of model outputs with FAOSTAT data for Sweet Potato, using model parameters from a study carried out in Jamaica, followed by Tomato, using the standard parameter for tomato in AquaCrop, and with lower levels of statistical metrics for Onion and Groundnut, using parameters from other studies (not from Jamaica).

Table 14. Configurations with better evaluation metrics with respect to the annual performance registered in FAOSTAT.

Crop	Site	SYS	SS	n	r	k	RMSE	NRMSE	MAE	MBE	d	NSE	Rsq
Groundnut	Amity Hall	RF	A	225	0.311	0.23	0.239	0.191	0.19	0.053	0.43	5.15	0.0968
Groundnut	Essex Valley	RF	A	250	0.090	0.0836	0.324	0.259	0.27	0.176	0.30	10.3	0.0082
Groundnut	Parnassus	RF	A	250	0.206	0.148	0.289	0.232	0.23	0.012	0.33	8.01	0.0426
Onion	Amity Hall	IRR	A	225	0.305	0.212	2.91	0.279	2.32	2.16	0.47	1.05	0.093
Onion	Parnassus	IRR	A	250	0.151	0.118	3.04	0.292	2.43	2.27	0.45	1.24	0.0228
Onion	Essex Valley	IRR	B	250	0.071	0.105	2.25	0.216	1.86	0.634	0.29	0.22	0.0051
Sweet Potato	Amity Hall	IRR	A	225	0.803	0.627	8.23	0.496	8.21	8.21	0.12	118	0.645
Sweet Potato	Parnassus	IRR	A	250	0.798	0.616	8.26	0.498	8.24	8.24	0.12	119	0.637
Sweet Potato	Essex Valley	IRR	A	250	0.742	0.582	7.84	0.472	7.82	7.82	0.13	107	0.55
Tomato	Amity Hall	IRR	A	225	0.464	0.24	13.3	0.791	13.3	13.3	0.13	94.7	0.216
Tomato	Parnassus	IRR	A	250	0.46	0.239	13.4	0.796	13.3	13.3	0.13	96	0.212
Tomato	Essex Valley	RF	B	250	0.241	0.128	13.8	0.82	13.7	13.7	0.13	102	0.0582

Crop Simulations for climate baseline

For all modeled scenarios, two seasons were evaluated as sowing windows (window A = Apr-May-Jun and window B = Aug-Sep-Oct), corresponding to the traditional times due to the onset of rains. During the period of the sowing window, simulations were carried out with a frequency of 5 days, resulting in between 18 and 19 sowing dates per season. First, the model outputs were compared to reported data in FAOSTAT. Figure 12 and Figure 13 show outputs for rainfed and irrigated systems. Since in many cases farmers would not be able to apply water optimized irrigation scenario, for most farmers the rainfed scenario compares better with data reported in FAOSTAT. However, FAOSTAT data do not distinguish between season A and B, and the same values were used for comparison.

Model outputs show that the model simulates groundnut for season A like yield outputs reported in FAOSTAT. However, season B achieves higher model outputs for groundnuts in rainfed systems. Onions were underestimated by the model compared to FAOSTAT data, with high variability in yield estimations. Outputs for Sweet Potato show also similar levels of yield compared to FAOSTAT data, and overall higher yield for Season B. The Tomato outputs adjust better to FAOSTAT data in the second season B. The site comparison shows that St. Elizabeth in the Essex Valley has higher yields simulated by the model and compared to reported yields to FAOSTAT. The AquaCrop model simulates higher yield levels for irrigated systems compared to FAOSTAT. Most likely, data reported in FAOSTAT reflect farmers reality of not having enough access to water supply for their crops. Irrigated systems, however, would increase yield levels for all four crops, and reduce variability (Figure 13).

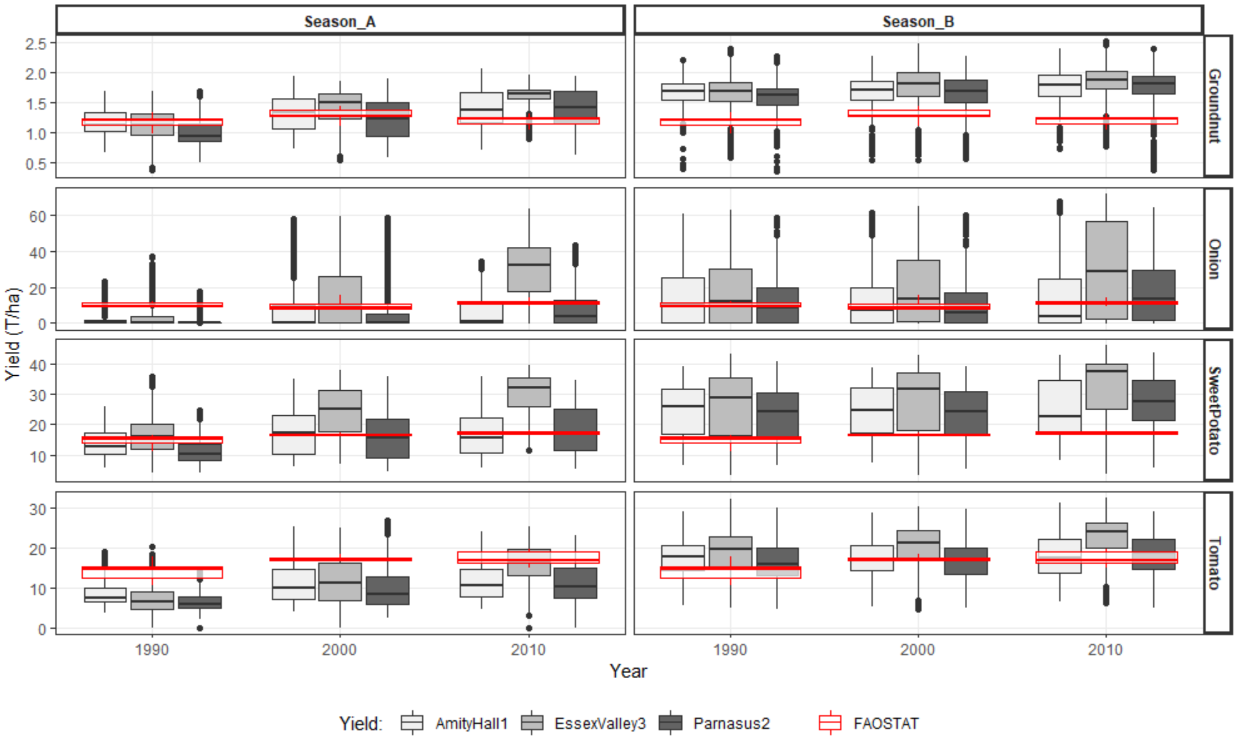


Figure 12. Yield simulated with AquaCrop and baseline climate versus FAOSTAT data (10 years average) - Rainfed.

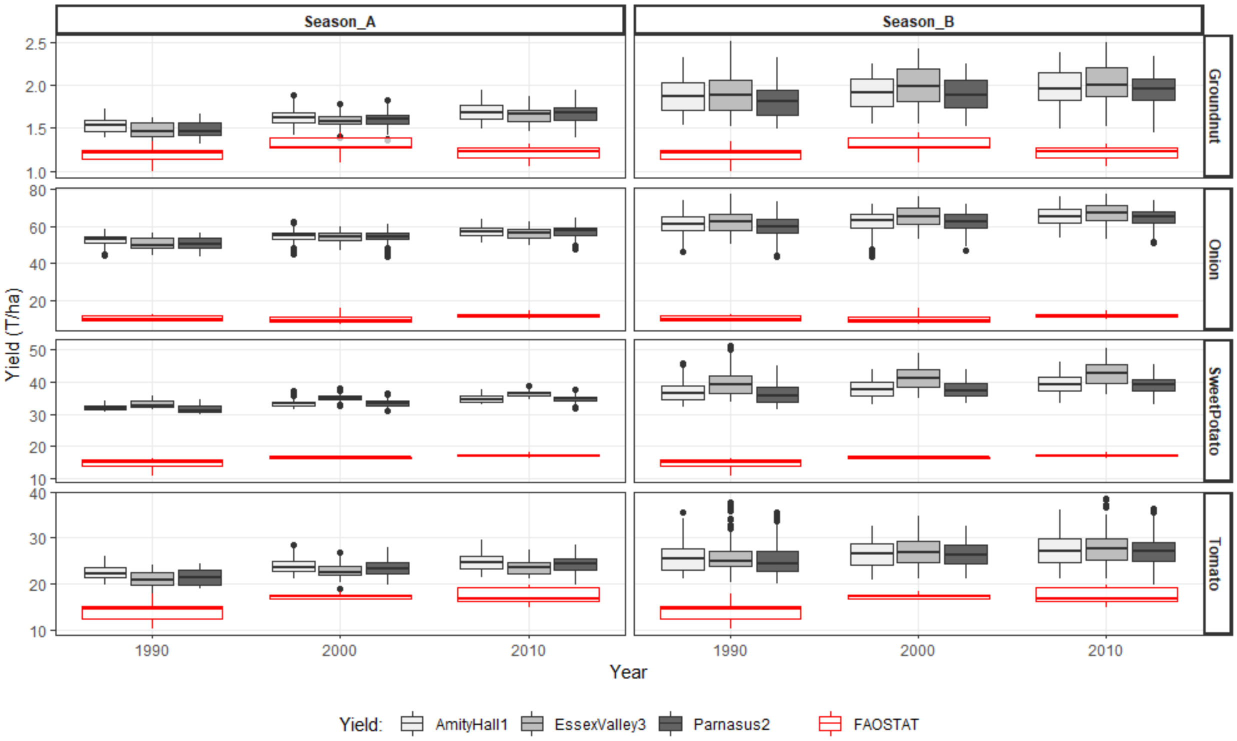


Figure 13. Yield simulated with AquaCrop and baseline climate versus FAOSTAT data (10 years average) - Irrigated.

After the comparison of simulated yield outputs of the AquaCrop model with reported data from FAOSTAT, we show averaged yield outputs by the model for the climate baseline, for two seasons (A and B), and two water management scenarios, rainfed and irrigated respectively. Figure 14 shows that most crops can achieve higher yields in season B, and when irrigated. For example, onions have very low levels of yield in both seasons when produced in rainfed systems, but also Sweet Potato and Tomato benefit from optimized water capacity in soils. Only groundnut does not show significant differences between rainfed and irrigated systems. The simulated crop cycle in days is higher in season B for all crops (Figure 15).

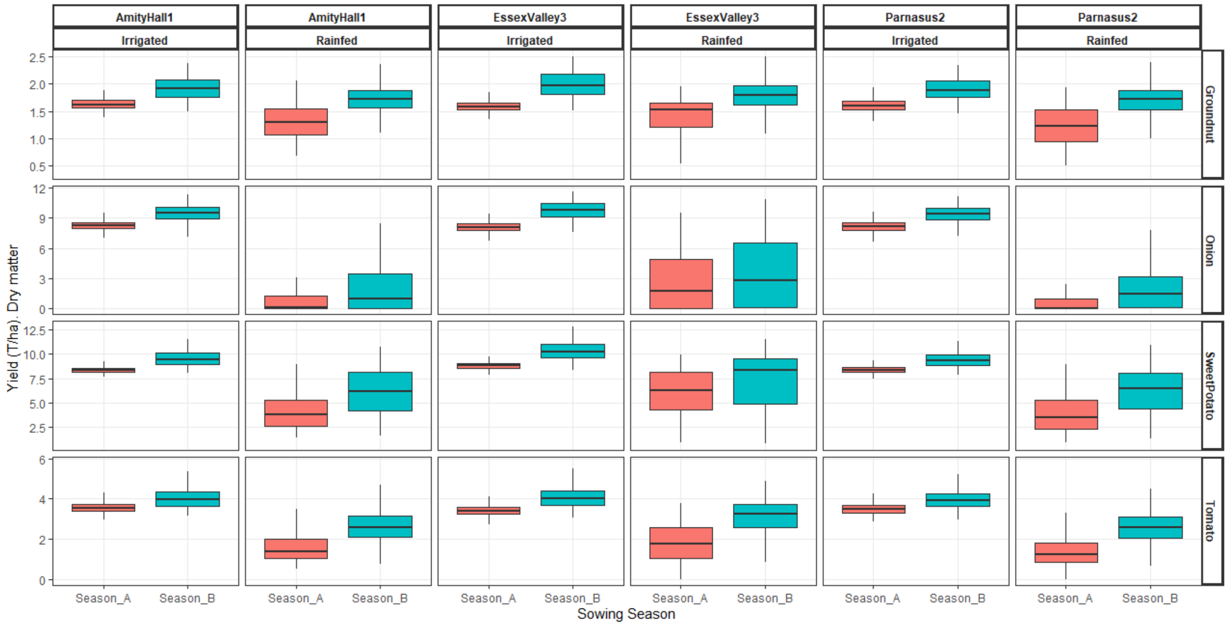


Figure 14. Dry matter yield in tons per hectare (T/ha).

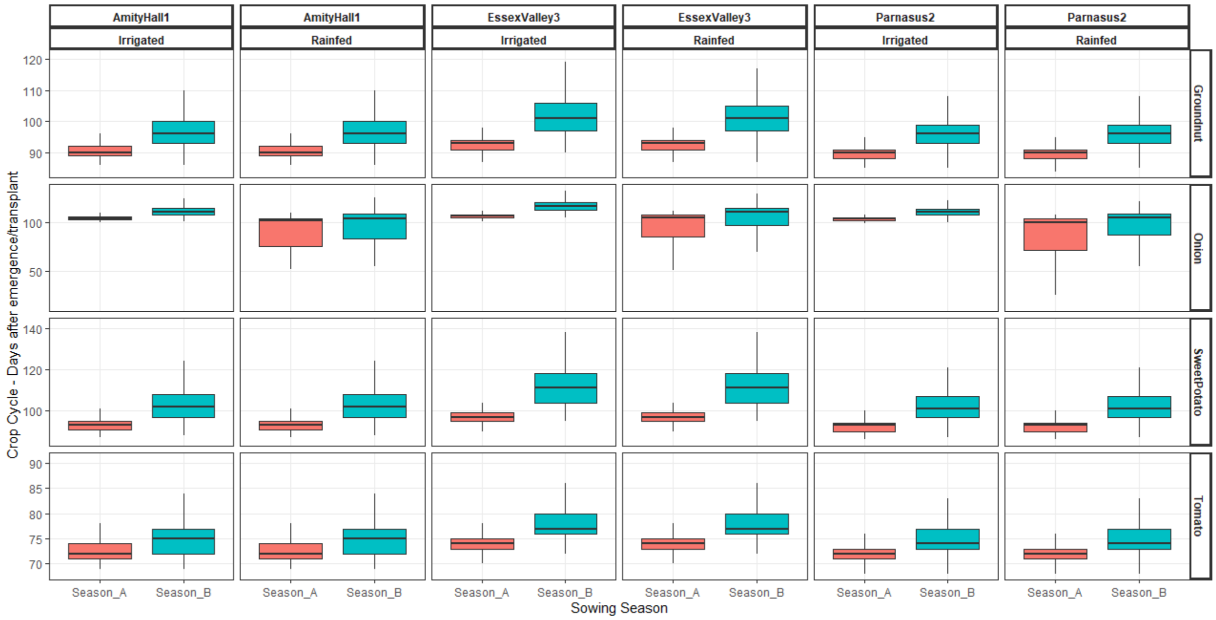


Figure 15. Simulated crop cycle in days after emergence/transplant.

Crop Simulations for future scenarios

Figures 16, 17, 18, and 19 show future scenarios of simulated yield for each crop. We present results using the data from Bias Correction (results from Quantile Mapping were not included).

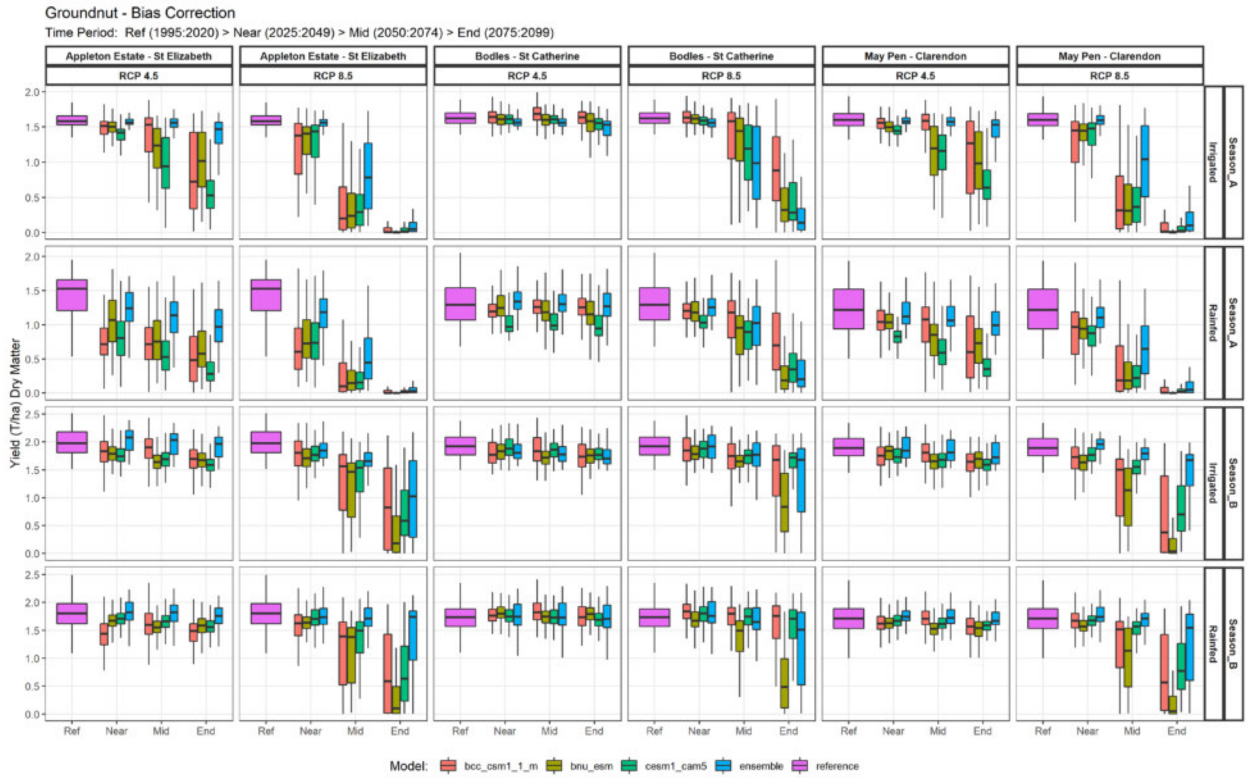


Figure 16. Groundnut - Ref (1995-2020) > Near (2025-2049) > Mid (2050-2074) > End (2075-2099) - Bias Correction.

Groundnut (Figure 16) can maintain current yield levels in the near future for all RCP Scenarios, Seasons and water management options. Yield levels start dropping in the Mid future. If ambitious global climate targets can be achieved, following the RCP 4.5 scenario, groundnut could maintain its levels in St. Catherine for both seasons, and in farmers in St. Elizabeth and Clarendon for Season B.

The model simulated for onions (Figure 17) that only Season A is a valid option to achieve similar yield levels compared to current yields, predicting the best outputs for St. Catherine parish and St. Elizabeth for the RCP 4.5 scenario.

Figure 18 shows that Sweet Potato is a good option for all three parishes under irrigated and most rainfed systems, some future climate model scenarios even show increasing yields, However, rainfed systems sow reduced yields for Season A compared to the reference system of current climate (Figure 18).

Outputs for Tomato (Figure 19) show overall lower yield levels for rainfed systems and lower variability in Season A.

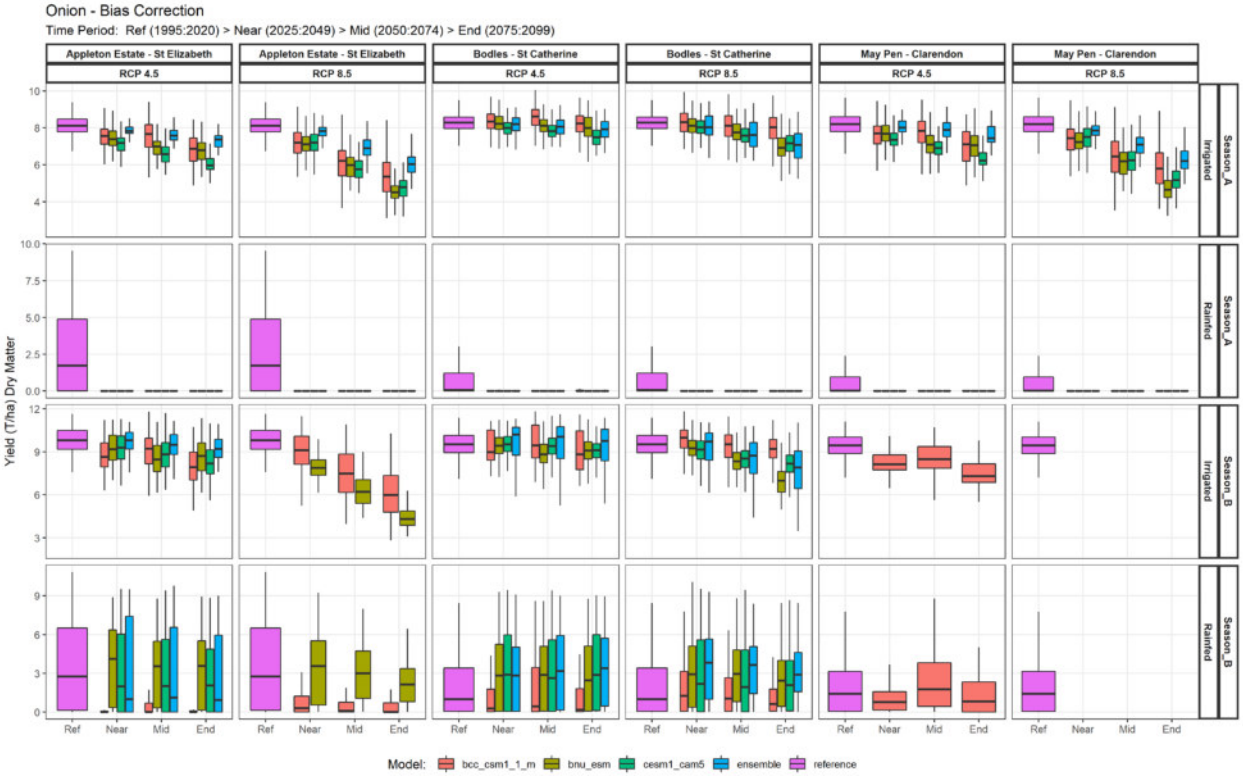


Figure 17. Onion - Ref (1995-2020) > Near (2025-2049) > Mid (2050-2074) > End (2075-2099) - Bias Correction.

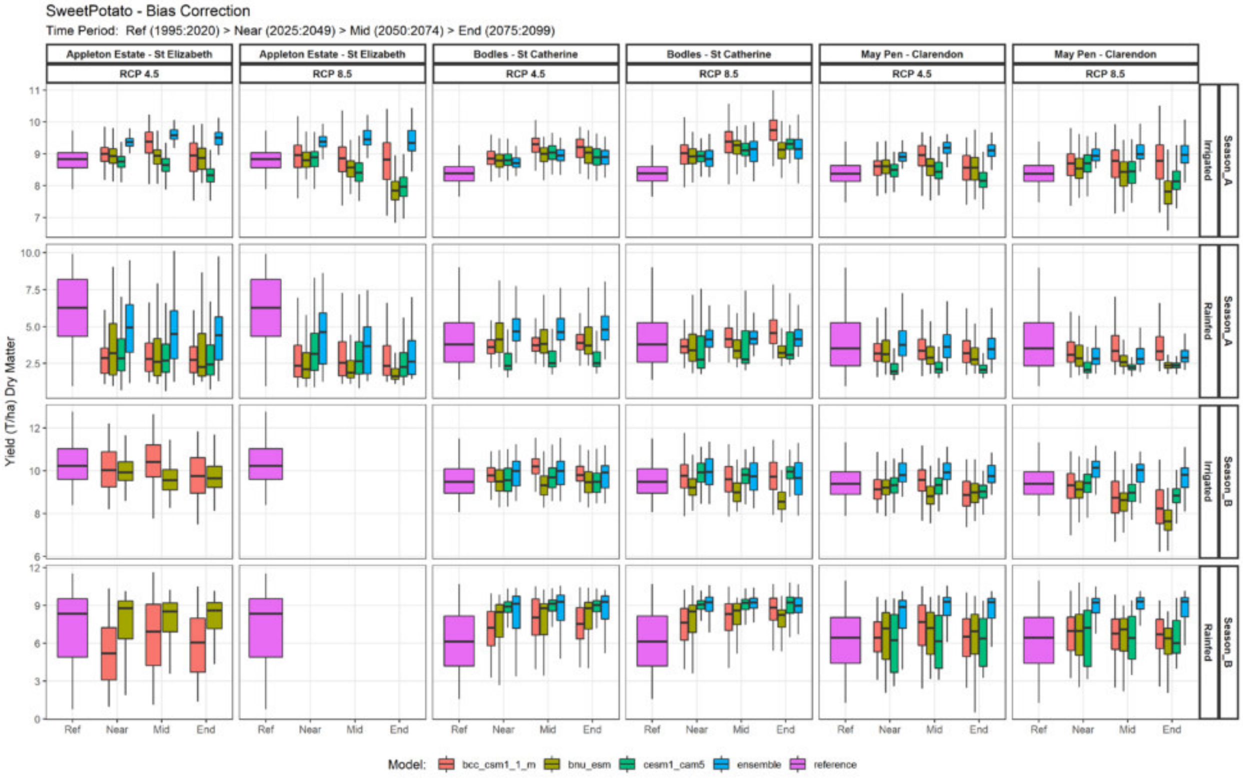


Figure 18. Sweet Potato - Ref (1995-2020) > Near (2025-2049) > Mid (2050-2074) > End (2075-2099) - Bias Correction.

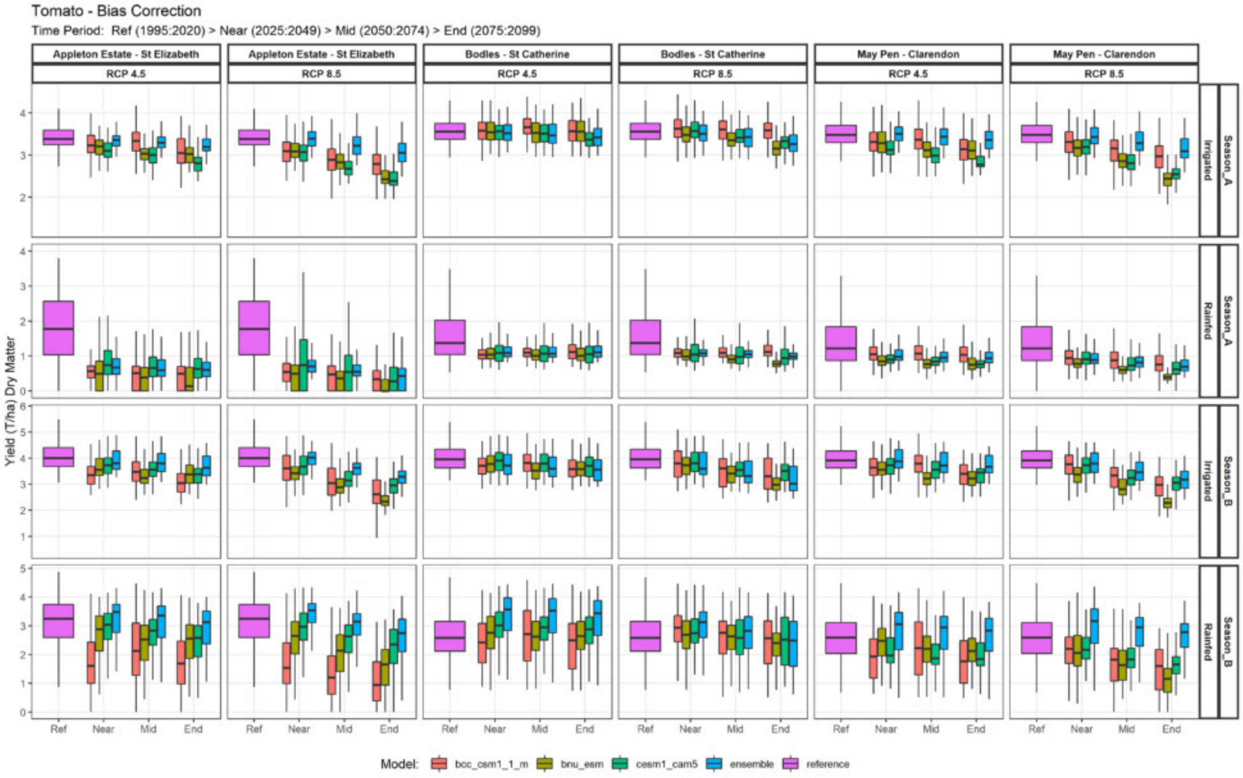


Figure 19. Tomato - Ref (1995-2020) > Near (2025-2049) > Mid (2050-2074) > End (2075-2099) - Quantile Mapping.

B. PRIORITIZATION OF CLIMATE-SMART AGRICULTURE INVESTMENT PORTFOLIOS FOR THE INTERVENTION AREAS

Methods

Climate-Smart Agriculture Rapid Appraisal

A multi-disciplinary team, which included team members from the Alliance of Bioversity International and CIAT in collaboration with the University of West Indies in Jamaica, conducted the CSA-RA between June and December 2021. Due to ongoing restrictions for field visit due to the global pandemic, the original methods of Mwongera et al. (2017) were adapted and phone surveys were used for collecting primary data. Focal workshops and guided discussions with farmers were used at the end of the project to complement the collected information. The following subsections include a short description of the tools employed in the CSA-RA. The CSA-RA tool is available for download and is freely available on the Harvard Dataverse web portal under the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) website.

Value chain characterization

We used a value chain approach to identify the major agricultural activities along four stages: input supply; on-farm production; harvesting, storage, and processing; and product marketing. The methodology also identified the type and scale (small, medium, or large) of the actors involved in the activities and gendered division of labor. We identified gender dynamics, key risk, activities, and consequences for the value chain. Prior to data collection with farmers, the value chains were selected based on expert consultations.

Phone interviews

We carried out qualitative phone interviews with farmers in St. Elizabeth, Parnassus, and Amity Hall for primary data collection. During the interviews, we asked farmers open questions about the selected value chains. We identified the role of actors along the value chain, and which gender is predominant. We asked farmers about key risks for the value chains and what are the consequences for production. We also identified the underlying factors that affect some farmer worse than others. We prioritized CSA practices based on importance for farmers and identified the barriers to adaptation, but also what is the enabling environment to support adaptation.

Guided group discussions

A workshop was held with 25 to 30 farmers and local stakeholders in each of the three study sites (Figure 20). These workshops were organized with the assistance of the Ministry of Agriculture and Fisheries and aimed to have good representation of men and women. A guided discussion was used as an ice-breaking exercise and to explain to farmers the concept of climate change and climate smart agriculture. After the ice breaker, we introduced to the group the CSA investment portfolios that were prioritized by experts. We used the following guided questions for the discussions:

- How did the practice implementation change over time?

- What is needed to maximize the adoption/implementation of the CSA practice at scale in the region (current and future)?
- What would be needed to consider ensuring that both men and women benefit in the future implementation of the practices?

Figure 20. Guided discussion in farmer workshop in Amity Hall.

Prioritization of Climate-Smart Agriculture Investment Portfolios

Climate-Smart agricultural practices are not one-size-fits-all solutions, therefore the prioritization of any agricultural initiatives and interventions on the field requires integration of both participatory and holistic approaches. Thus, the CSA Prioritization Framework (CSA-PF), provides a systematic and multicriteria process that combines qualitative and quantitative assessments from stakeholders through a series simple yet valuable steps, to generate investment portfolios of best-bet CSA practices. In the Jamaican case, the standard CSA-PF methodology, see figure below (Figure 21) was adjusted to fit the local conditions and stakeholders' considerations.

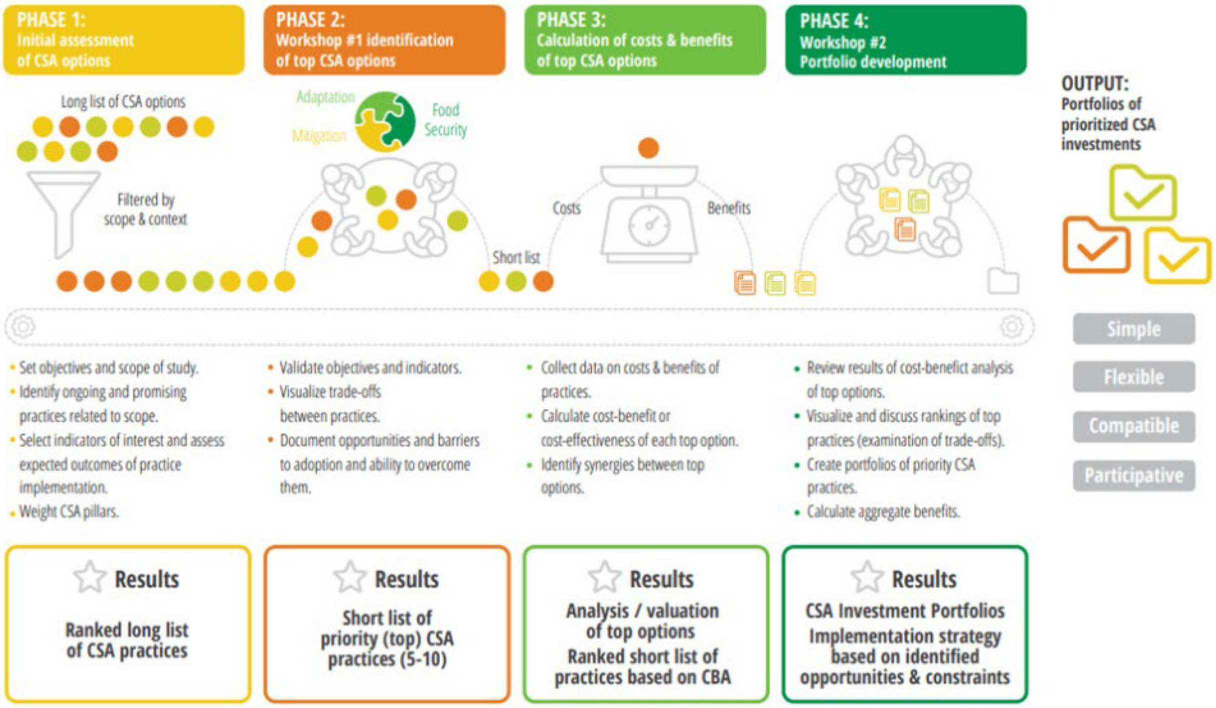


Figure 21. Overall CSA- Prioritization Framework methodology

For setting the scope and working context of the analysis, the *steering committee* integrated by project partners and other relevant actors, defined three major regions across the country in line with current governmental initiatives, such as the ¨Agro Parks¨ with the support of the National Irrigation Commission Limited. The intervention areas embraced: Amity Hall (St. Catherine), Parnassus (Clarendon), and the Essex Valley (Manchester/St. Elizabeth).

During the **initial phase (preparation)** of the process, a virtual workshop with expert stakeholders of the different regional contexts, was held to refine the bio-geographical characteristics and farmers' predominant typology for each region, delimitating the study context. Additionally, a list of current and potential agricultural production systems (crops[1]) was discussed identifying key crops based on socio-economic, productive, and environmental criteria. In parallel, the two most challenging climate-related hazards and impacts were analyzed and identified for each region. During the same session, it was planned to address **second phase (options evaluation)**, stakeholders brainstormed on multidimensional[2] guiding questions as a criterion for filtering a long list of CSA options compiled from national projects documentation and complemented with specialized literature in Latin America and the Caribbean context. CSA Practices in the list covered all value chain stages[3] and were ranked and prioritized by stakeholders through a qualitative assessment, based on the mentioned guiding questions as well as on a selection of

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[1] Agricultural production systems addressed fitted in five categories aiming to capture the variability of annual and perennial crops in each region: Vegetables, legumes, condiments, fruits, and tubers.

[2] Multidimensional analysis refers to filter questions covering socio-cultural, environmental, economic, policy-institutional, and educational-information perspectives of the CSA practices.

[3] Value chain stages included: Input supply; on-farm production; harvesting, storage and processing; and product marketing. Programmatic practices (off-farm) were also addressed.

Food and Nutritional Security, Adaptation and Mitigation indicators. This facilitated the identification of individual or crosscutting CSA options for the top four production systems recognized for each region.

In the **third phase (economic analysis)**, an ex-ante cost-benefit analysis was carried out for the top two practices in each crop by region, using input data from three Focus Group Discussions (FGDs) held virtually with local experts. The profitability of farmers' adoption of CSA practices was calculated through several financial indicators (NPV, IRR, C/B ratio, and PP)[4] contrasting a baseline and the CSA scenarios for each CSA practice, including the quantification of positive externalities associated with individual production systems.

Considering Covid-19 restrictions, the latest **phase (Portfolio design and analysis),** was adapted to a virtual session for stakeholders from the different regions go through the outputs from the previous phases, adding barriers of and opportunities to adoption of prioritized CSA practices combining once again a multidimensional perspective, and exploring aggregated characteristics of the investment portfolios by region.

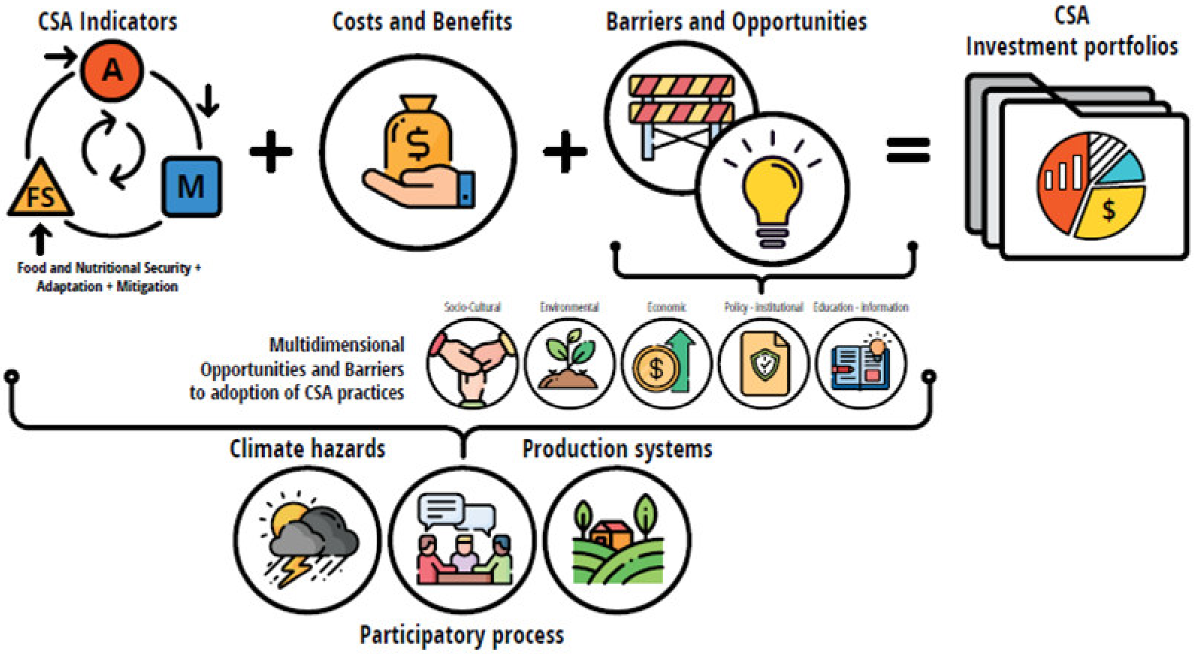

Figure 22. Summary of the components and criteria used for the prioritization process of CSA practices and technologies

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[4] Financial indicators assessed: Net Present Value (NPV), Internal Rate of Return (IRR), Cost-Benefit ratio (C/B), Payback Period (PP).

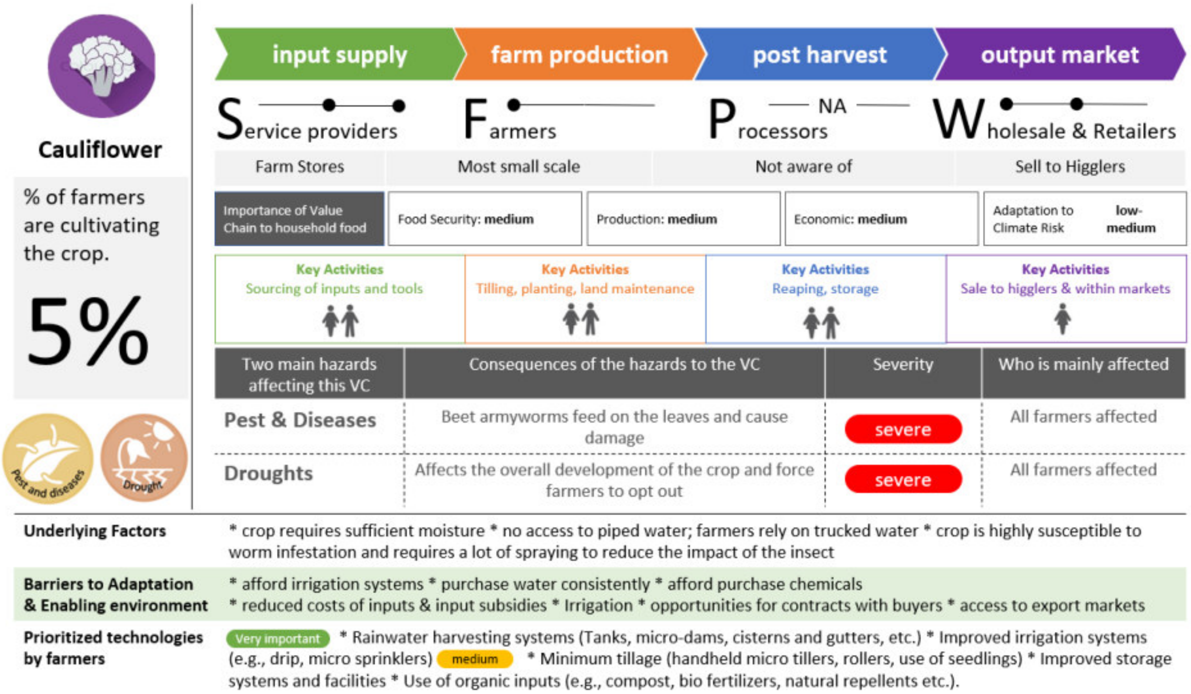
Results and Findings

Key Findings from Farmer interviews and focal groups

Value chain characterization St. Elizabeth

For St. Elizabeth, we characterized four value chains through interviews with farmers: cauliflower, scallion, watermelon, and peanut (Figures 23, 24, 25, 26). Most farmers grow on small scale scallion (95%) and watermelon (80%), and less farmers grow cauliflower (5%) and peanuts (less than 10%). Key activities along the value chain are mostly done by both, men, and women, except market sale is predominantly done by women, and production of watermelon is mostly done by men.

Hazards affecting the value chains are characterized with severe droughts and pest & disease impacts, mainly from worms attacking the leaves and cause damage to the crop. Peanuts are also at risk on flood events and when soils become saturated with moisture creating an environment for pest and diseases.



Cauliflower

% of farmers are cultivating the crop.

5%

input supply	farm production	post harvest	output market
Service providers	Farmers	Processors NA	Wholesale & Retailers
Farm Stores	Most small scale	Not aware of	Sell to Higglers

Importance of Value Chain to household food	Food Security: **medium**	Production: **medium**	Economic: **medium**	Adaptation to Climate Risk **low-medium**

Key Activities	Key Activities	Key Activities	Key Activities
Sourcing of inputs and tools	Tilling, planting, land maintenance	Reaping, storage	Sale to higglers & within markets

Two main hazards affecting this VC	Consequences of the hazards to the VC	Severity	Who is mainly affected
Pest & Diseases	Beet armyworms feed on the leaves and cause damage	severe	All farmers affected
Droughts	Affects the overall development of the crop and force farmers to opt out	severe	All farmers affected

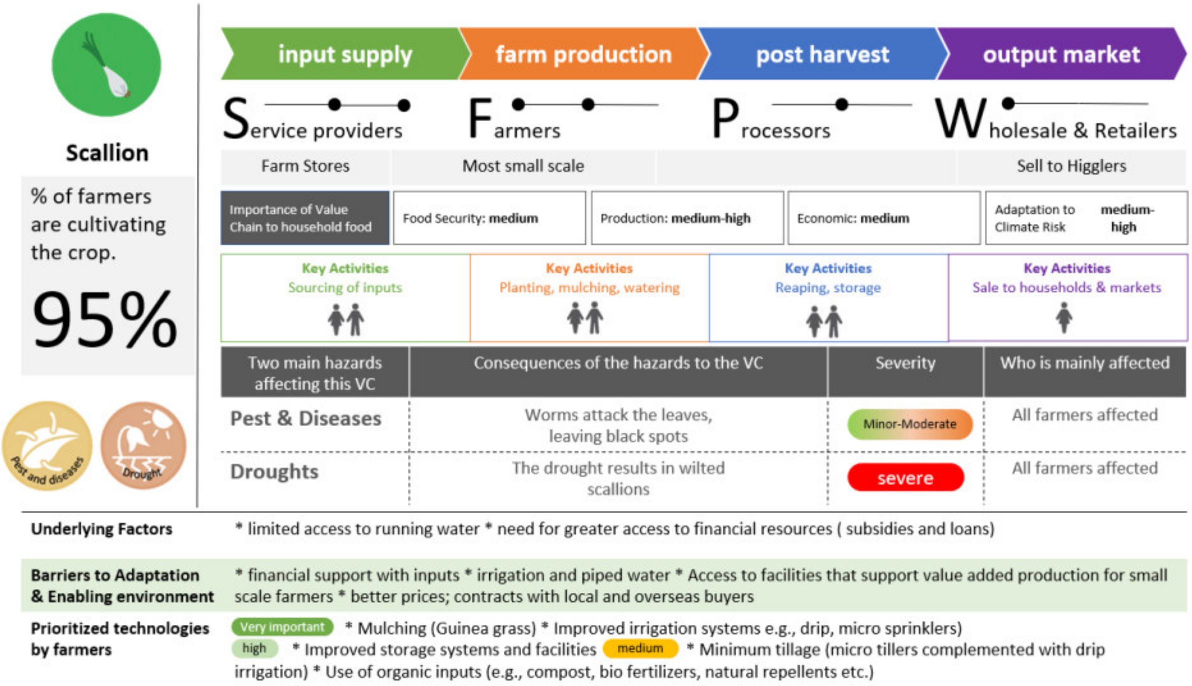
Underlying Factors	* crop requires sufficient moisture * no access to piped water; farmers rely on trucked water * crop is highly susceptible to worm infestation and requires a lot of spraying to reduce the impact of the insect
Barriers to Adaptation & Enabling environment	* afford irrigation systems * purchase water consistently * afford purchase chemicals * reduced costs of inputs & input subsidies * Irrigation * opportunities for contracts with buyers * access to export markets
Prioritized technologies by farmers	Very important * Rainwater harvesting systems (Tanks, micro-dams, cisterns and gutters, etc.) * Improved irrigation systems (e.g., drip, micro sprinklers) medium * Minimum tillage (handheld micro tillers, rollers, use of seedlings) * Improved storage systems and facilities * Use of organic inputs (e.g., compost, bio fertilizers, natural repellents etc.).

Figure 23. Cauliflower Value Chain in St. Elizabeth.

As underlying factors around the value chain development farmers mentioned the lack of access to water, and lack of access to financial instruments for developing a production (Figure 23, 24). Other value chains require a lot of inputs to reduce damage from pests and diseases (Figure 23).

Barriers for adaptation are often related to lack of infrastructure, like shared facilities for value added production, contract opportunities, and access to export markets.

Technologies that were prioritized high by farmers are improved irrigation and water harvesting systems, mulching using guinea grass, and the use of drought-tolerant varieties. High priority was given to improved storage systems, and crop rotation, and medium priority to minimum tillage, and use of organic inputs.



Scallion

% of farmers are cultivating the crop.

95%

input supply | farm production | post harvest | output market

Service providers | Farmers | Processors | Wholesale & Retailers

Farm Stores | Most small scale | | Sell to Higglers

Importance of Value Chain to household food	Food Security: **medium**	Production: **medium-high**	Economic: **medium**	Adaptation to Climate Risk **medium-high**

Key Activities	Key Activities	Key Activities	Key Activities
Sourcing of inputs	Planting, mulching, watering	Reaping, storage	Sale to households & markets

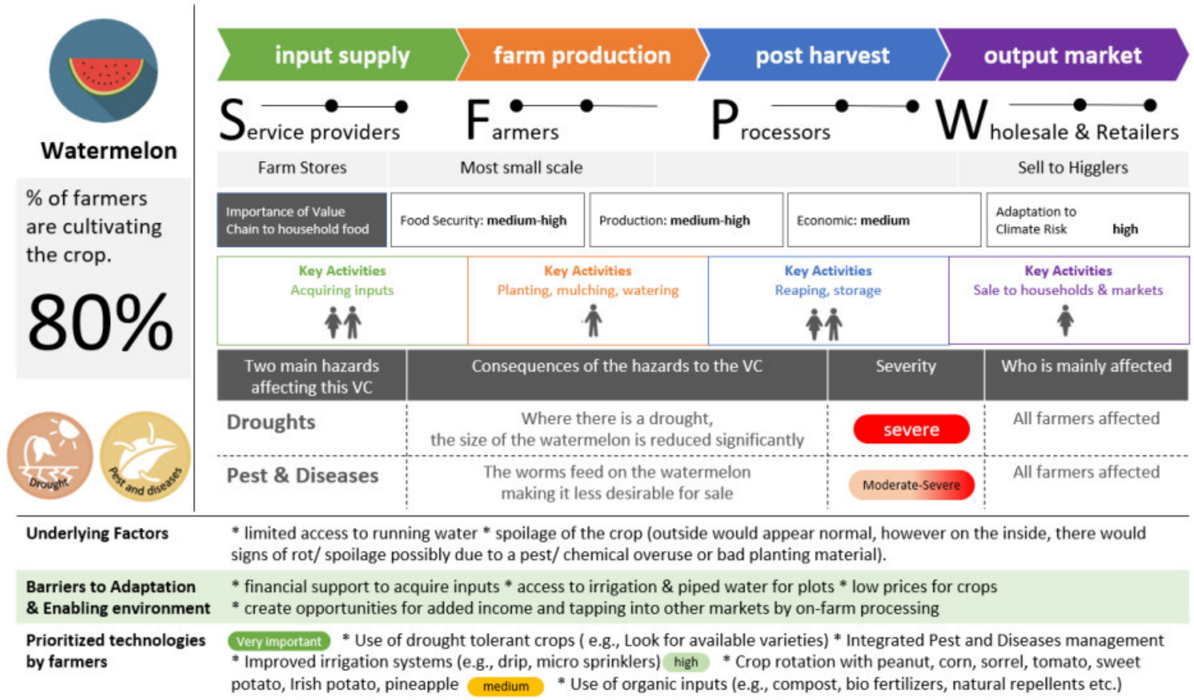
Two main hazards affecting this VC	Consequences of the hazards to the VC	Severity	Who is mainly affected
Pest & Diseases	Worms attack the leaves, leaving black spots	Minor-Moderate	All farmers affected
Droughts	The drought results in wilted scallions	severe	All farmers affected

Underlying Factors * limited access to running water * need for greater access to financial resources (subsidies and loans)

Barriers to Adaptation & Enabling environment * financial support with inputs * irrigation and piped water * Access to facilities that support value added production for small scale farmers * better prices; contracts with local and overseas buyers

Prioritized technologies by farmers Very important * Mulching (Guinea grass) * Improved irrigation systems e.g., drip, micro sprinklers) high * Improved storage systems and facilities medium * Minimum tillage (micro tillers complemented with drip irrigation) * Use of organic inputs (e.g., compost, bio fertilizers, natural repellents etc.)

Figure 24. Scallion Value Chain in St. Elizabeth.



Watermelon

% of farmers are cultivating the crop.

80%

input supply | farm production | post harvest | output market

Service providers | Farmers | Processors | Wholesale & Retailers

Farm Stores | Most small scale | | Sell to Higglers

Importance of Value Chain to household food	Food Security: **medium-high**	Production: **medium-high**	Economic: **medium**	Adaptation to Climate Risk **high**

Key Activities	Key Activities	Key Activities	Key Activities
Acquiring inputs	Planting, mulching, watering	Reaping, storage	Sale to households & markets

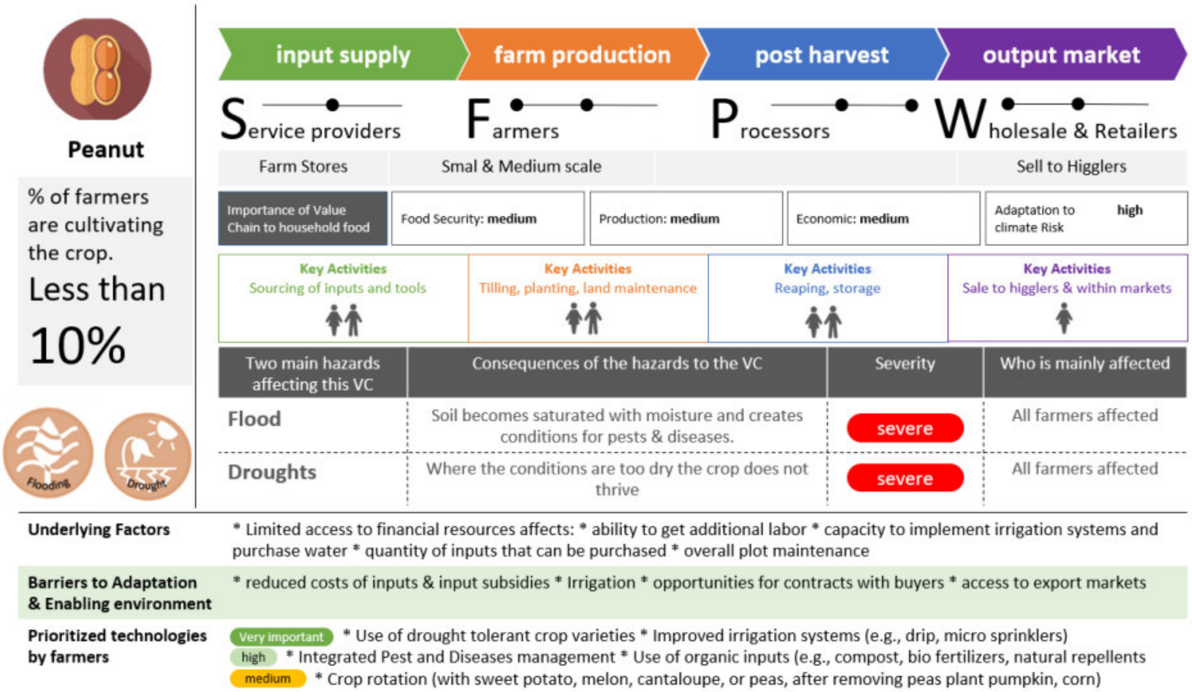
Two main hazards affecting this VC	Consequences of the hazards to the VC	Severity	Who is mainly affected
Droughts	Where there is a drought, the size of the watermelon is reduced significantly	severe	All farmers affected
Pest & Diseases	The worms feed on the watermelon making it less desirable for sale	Moderate-Severe	All farmers affected

Underlying Factors * limited access to running water * spoilage of the crop (outside would appear normal, however on the inside, there would signs of rot/ spoilage possibly due to a pest/ chemical overuse or bad planting material).

Barriers to Adaptation & Enabling environment * financial support to acquire inputs * access to irrigation & piped water for plots * low prices for crops * create opportunities for added income and tapping into other markets by on-farm processing

Prioritized technologies by farmers Very important * Use of drought tolerant crops (e.g., Look for available varieties) * Integrated Pest and Diseases management * Improved irrigation systems (e.g., drip, micro sprinklers) high * Crop rotation with peanut, corn, sorrel, tomato, sweet potato, Irish potato, pineapple medium * Use of organic inputs (e.g., compost, bio fertilizers, natural repellents etc.)

Figure 25. Watermelon Value Chain in St. Elizabeth.



% of farmers are cultivating the crop.
Less than 10%

Service providers — **F**armers — **P**rocessors — **W**holesale & Retailers

Farm Stores | Smal & Medium scale | Sell to Higglers

Importance of Value Chain to household food: Food Security: **medium** | Production: **medium** | Economic: **medium** | Adaptation to climate Risk **high**

Key Activities	Key Activities	Key Activities	Key Activities
Sourcing of inputs and tools	Tilling, planting, land maintenance	Reaping, storage	Sale to higglers & within markets

Two main hazards affecting this VC	Consequences of the hazards to the VC	Severity	Who is mainly affected
Flood	Soil becomes saturated with moisture and creates conditions for pests & diseases.	severe	All farmers affected
Droughts	Where the conditions are too dry the crop does not thrive	severe	All farmers affected

Underlying Factors * Limited access to financial resources affects: * ability to get additional labor * capacity to implement irrigation systems and purchase water * quantity of inputs that can be purchased * overall plot maintenance

Barriers to Adaptation & Enabling environment * reduced costs of inputs & input subsidies * Irrigation * opportunities for contracts with buyers * access to export markets

Prioritized technologies by farmers
Very important * Use of drought tolerant crop varieties * Improved irrigation systems (e.g., drip, micro sprinklers)
high * Integrated Pest and Diseases management * Use of organic inputs (e.g., compost, bio fertilizers, natural repellents
medium * Crop rotation (with sweet potato, melon, cantaloupe, or peas, after removing peas plant pumpkin, corn)

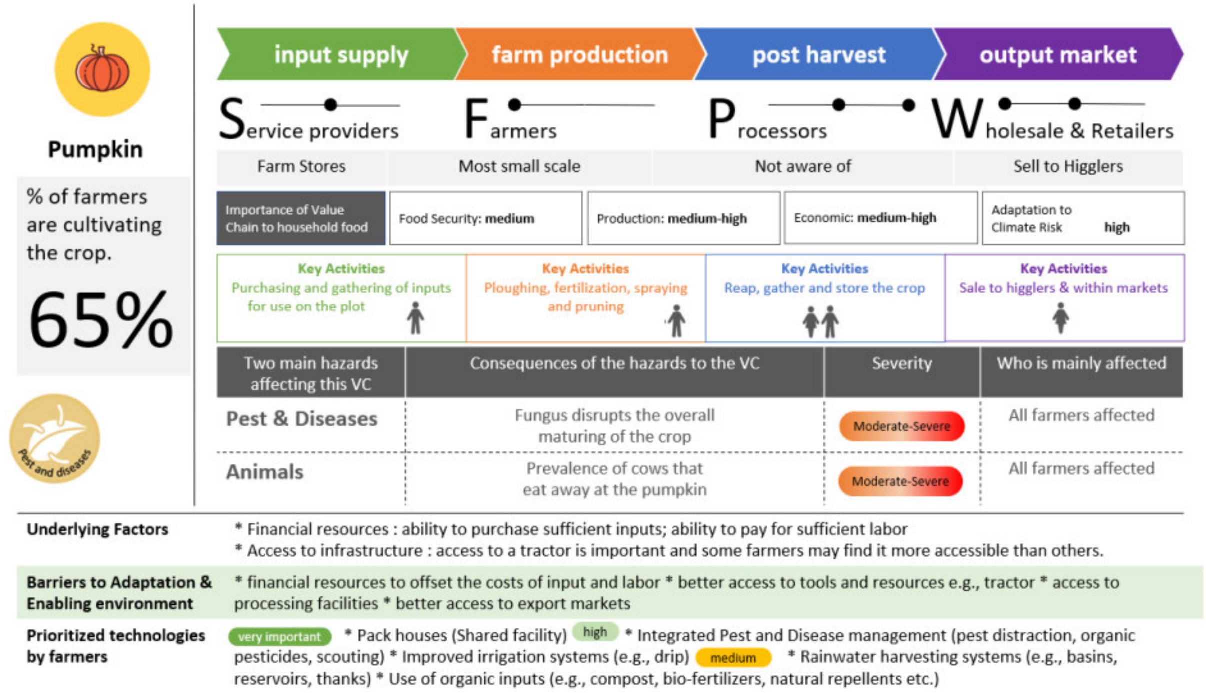
Figure 26. Peanut Value Chain in St. Elizabeth.

In Parnassus, we characterized four value chains through interviews with farmers: pumpkin, sweet potato, Irish potato, and hot pepper (Figures 27, 28, 29, 30). Most farmers grow on small scale pumpkin (65%) and less farmers grow sweet potato (less than 5%). The other two crops Irish potato and Hot pepper are not grown by farmers currently, but the Ministry of Agriculture and Fisheries wants to introduce them through new programs. Key activities along the pumpkin value chain are mostly done by men, both women and men are engaged in post-harvest activities, and like St. Elizabeth, market activities are predominated by women.

Hazards affecting the value chains are characterized with pest & disease impacts, mainly from a fungus that affects pumpkin, and pests that affect sweet potato production. Floods can cause moderate to severe issues of root rotting, and cows can damage the harvest.

Underlying factors that lead to barriers for adaptation are lack of financial resources to offset costs of input and labor, and overall lack of access to infrastructure, like for example tractors, processing facilities, and export markets.

Farmers found shared post-harvest processing facilities (e.g., pack houses) and integrated pest & disease management as very important technologies that should be prioritized. But they also ranked high improved irrigation systems and use of organic inputs for some value chains. Rainwater harvesting and crop rotation was prioritized with medium importance.



Pumpkin

% of farmers are cultivating the crop.

65%

input supply	farm production	post harvest	output market
Service providers	Farmers	Processors	Wholesale & Retailers
Farm Stores	Most small scale	Not aware of	Sell to Higglers

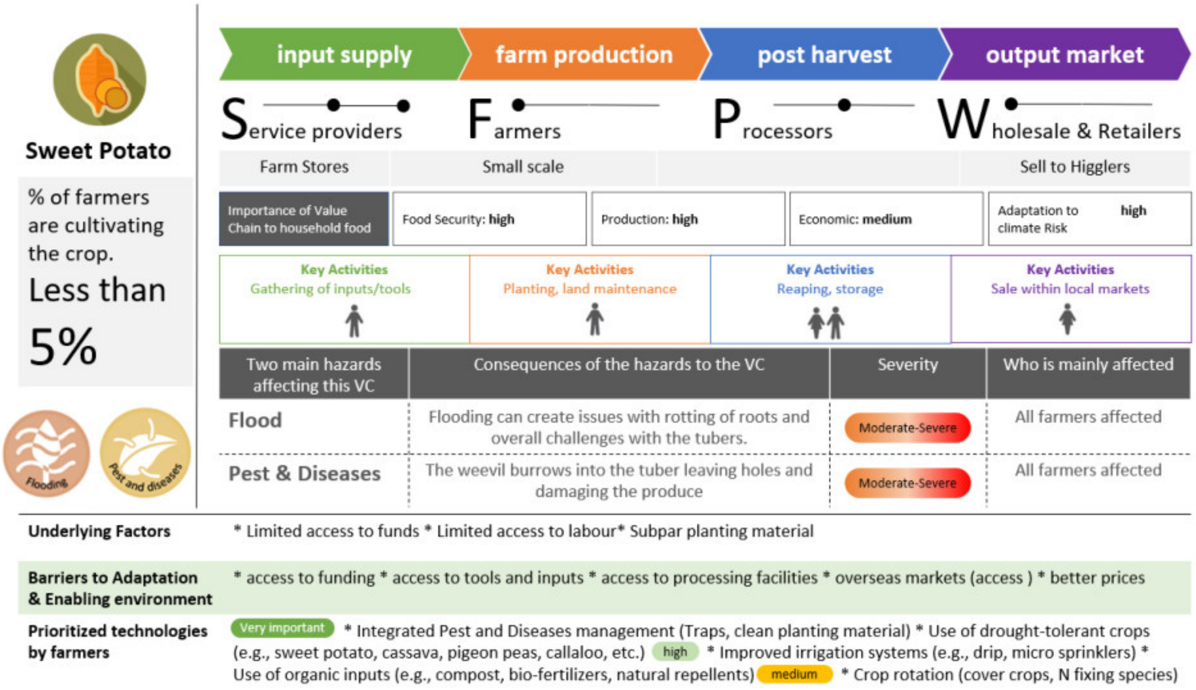
Importance of Value Chain to household food	Food Security: **medium**	Production: **medium-high**	Economic: **medium-high**	Adaptation to Climate Risk **high**

Key Activities	Key Activities	Key Activities	Key Activities
Purchasing and gathering of inputs for use on the plot	Ploughing, fertilization, spraying and pruning	Reap, gather and store the crop	Sale to higglers & within markets

Two main hazards affecting this VC	Consequences of the hazards to the VC	Severity	Who is mainly affected
Pest & Diseases	Fungus disrupts the overall maturing of the crop	Moderate-Severe	All farmers affected
Animals	Prevalence of cows that eat away at the pumpkin	Moderate-Severe	All farmers affected

Underlying Factors	* Financial resources : ability to purchase sufficient inputs; ability to pay for sufficient labor * Access to infrastructure : access to a tractor is important and some farmers may find it more accessible than others.
Barriers to Adaptation & Enabling environment	* financial resources to offset the costs of input and labor * better access to tools and resources e.g., tractor * access to processing facilities * better access to export markets
Prioritized technologies by farmers	very important * Pack houses (Shared facility) high * Integrated Pest and Disease management (pest distraction, organic pesticides, scouting) * Improved irrigation systems (e.g., drip) medium * Rainwater harvesting systems (e.g., basins, reservoirs, thanks) * Use of organic inputs (e.g., compost, bio-fertilizers, natural repellents etc.)

Figure 27. Pumpkin Value Chain in Parnassus.



Sweet Potato

% of farmers are cultivating the crop.

Less than

5%

input supply	farm production	post harvest	output market
Service providers	Farmers	Processors	Wholesale & Retailers
Farm Stores	Small scale		Sell to Higglers

Importance of Value Chain to household food	Food Security: **high**	Production: **high**	Economic: **medium**	Adaptation to climate Risk **high**

Key Activities	Key Activities	Key Activities	Key Activities
Gathering of inputs/tools	Planting, land maintenance	Reaping, storage	Sale within local markets

Two main hazards affecting this VC	Consequences of the hazards to the VC	Severity	Who is mainly affected
Flood	Flooding can create issues with rotting of roots and overall challenges with the tubers.	Moderate-Severe	All farmers affected
Pest & Diseases	The weevil burrows into the tuber leaving holes and damaging the produce	Moderate-Severe	All farmers affected

Underlying Factors	* Limited access to funds * Limited access to labour* Subpar planting material
Barriers to Adaptation & Enabling environment	* access to funding * access to tools and inputs * access to processing facilities * overseas markets (access) * better prices
Prioritized technologies by farmers	Very important * Integrated Pest and Diseases management (Traps, clean planting material) * Use of drought-tolerant crops (e.g., sweet potato, cassava, pigeon peas, callaloo, etc.) high * Improved irrigation systems (e.g., drip, micro sprinklers) * Use of organic inputs (e.g., compost, bio-fertilizers, natural repellents) medium * Crop rotation (cover crops, N fixing species)

Figure 28. Sweet Potato value Chain in Parnassus.

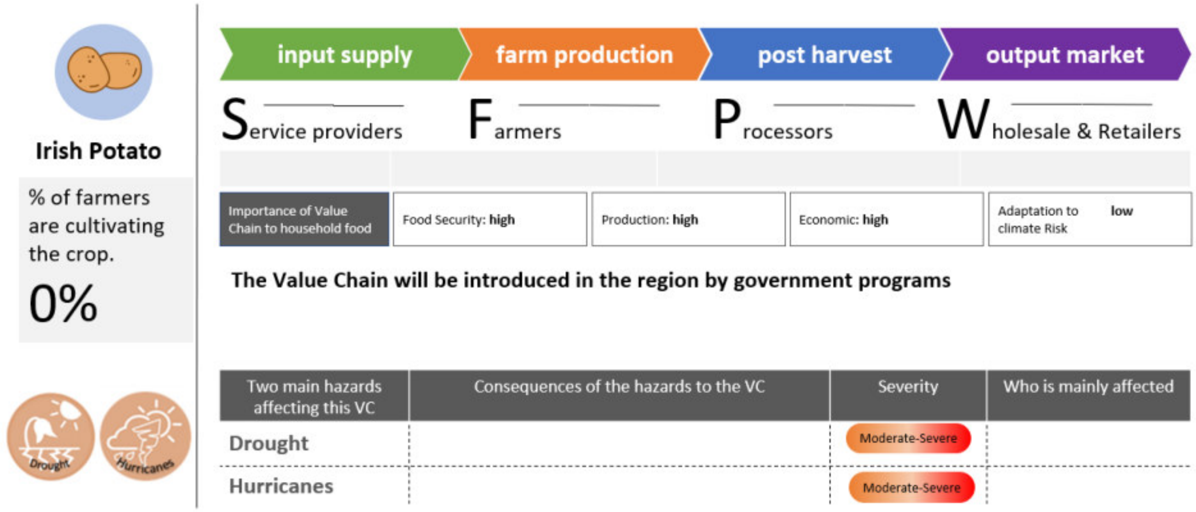


Figure 29. Irish Potato Value Chain in Parnassus.

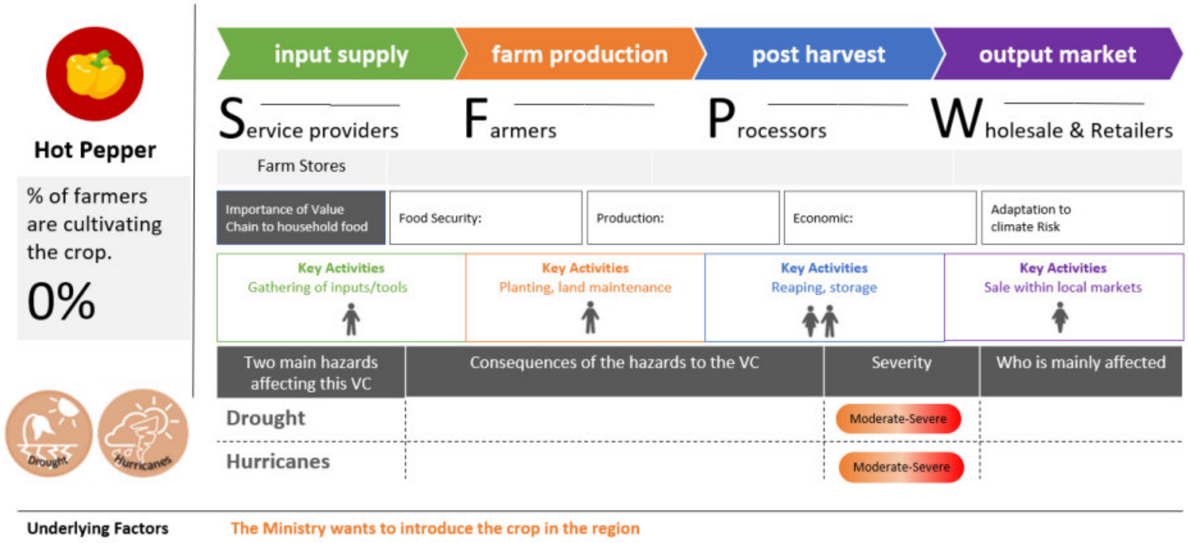
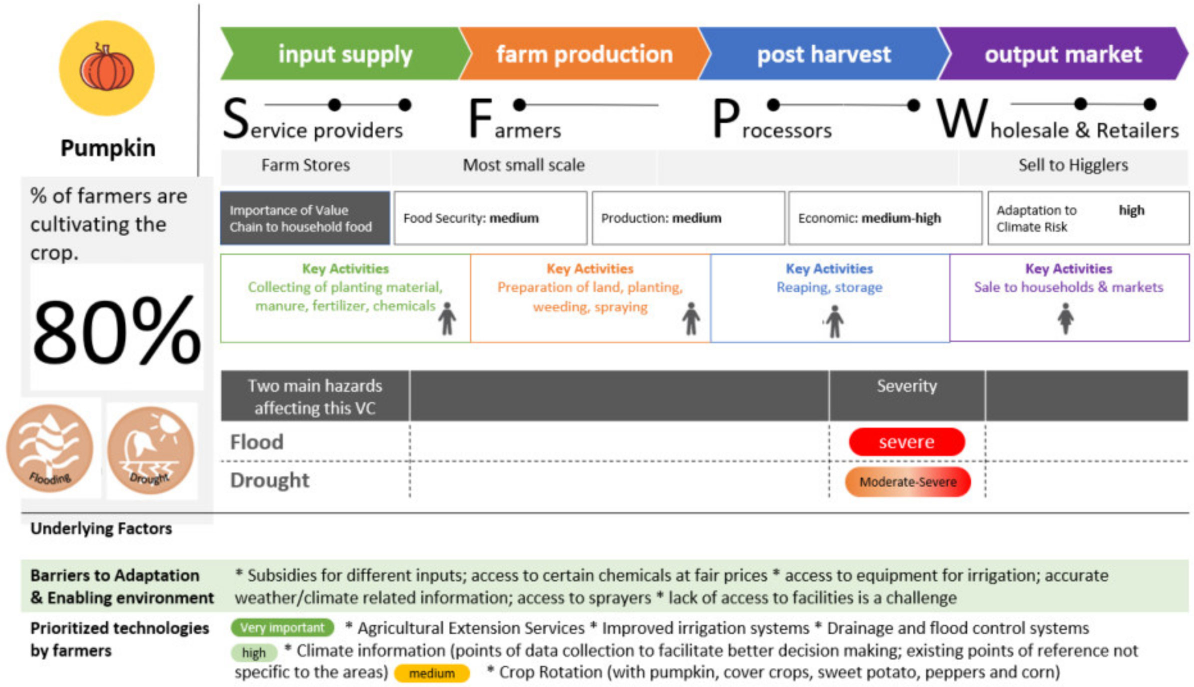


Figure 30. Hot Pepper Value Chain in Parnassus.

For the Agro Park in Amity Hall, we characterized four value chains through interviews with farmers: pumpkin, sweet potato, hot pepper, and watermelon (Figures 31, 32, 33, 34). Most farmers grow on small scale pumpkin (80%) and less farmers grow sweet potato (less than 5%). The other two crops watermelon and hot pepper are not grown by farmers currently, but the Ministry of Agriculture and Fisheries wants to introduce them through new programs. Key activities along the pumpkin value chain are mostly done by men, both women and men are engaged in post-harvest activities in the sweet potato value chain, and like St. Elizabeth and Parnassus, market activities are predominated by women.

Flood hazards affecting the value chains are characterized as severe for pumpkin and moderate for sweet potato, pest & disease impacts, mainly from pests that affect sweet potato production. Droughts can cause moderate to severe issues for pumpkin.

The underlying factors that hinder adaptation of new practices are access to funding or subsidies for tools and inputs, which farmers currently cannot access due to high costs. Further the lack of infrastructure and facilities is another challenge for farmers.



Pumpkin

% of farmers are cultivating the crop.

80%

input supply	farm production	post harvest	output market
Service providers	Farmers	Processors	Wholesale & Retailers
Farm Stores	Most small scale		Sell to Higglers

Importance of Value Chain to household food	Food Security: **medium**	Production: **medium**	Economic: **medium-high**	Adaptation to Climate Risk **high**

Key Activities	Key Activities	Key Activities	Key Activities
Collecting of planting material, manure, fertilizer, chemicals	Preparation of land, planting, weeding, spraying	Reaping, storage	Sale to households & markets

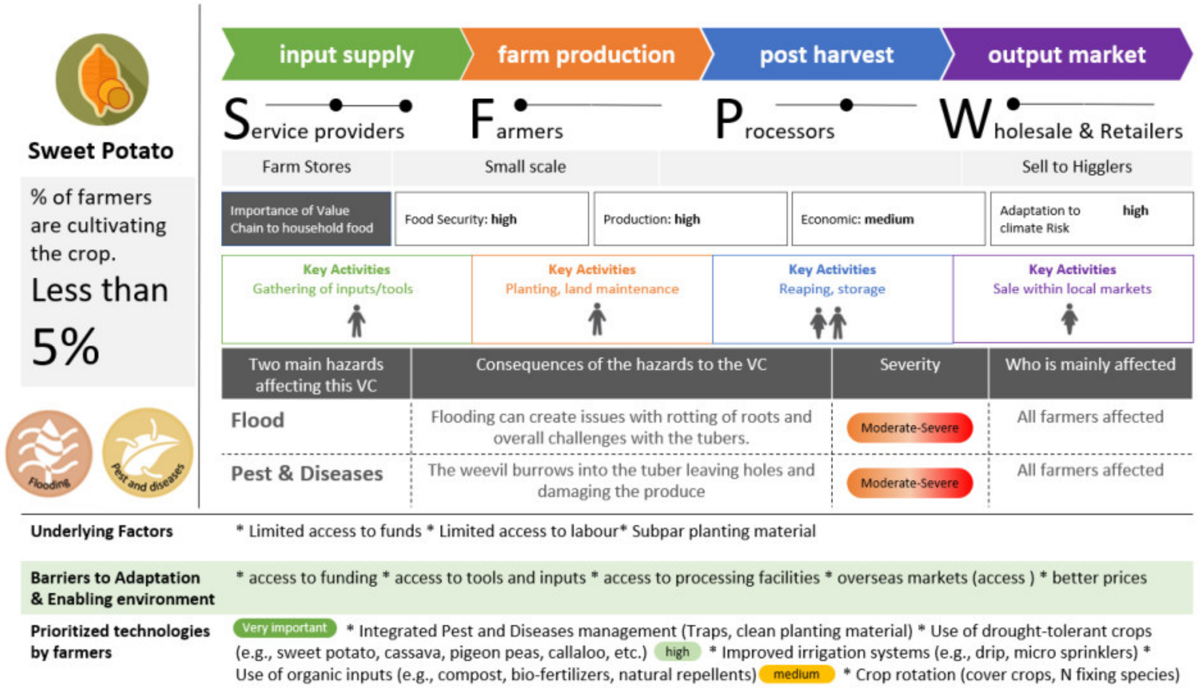
Two main hazards affecting this VC		Severity	
Flood		severe	
Drought		Moderate-Severe	

Underlying Factors

Barriers to Adaptation & Enabling environment * Subsidies for different inputs; access to certain chemicals at fair prices * access to equipment for irrigation; accurate weather/climate related information; access to sprayers * lack of access to facilities is a challenge

Prioritized technologies by farmers Very important * Agricultural Extension Services * Improved irrigation systems * Drainage and flood control systems high * Climate information (points of data collection to facilitate better decision making; existing points of reference not specific to the areas) medium * Crop Rotation (with pumpkin, cover crops, sweet potato, peppers and corn)

Figure 31. Pumpkin Value Chain in Amity Hall.



Sweet Potato

% of farmers are cultivating the crop.

Less than 5%

input supply	farm production	post harvest	output market
Service providers	Farmers	Processors	Wholesale & Retailers
Farm Stores	Small scale		Sell to Higglers

Importance of Value Chain to household food	Food Security: **high**	Production: **high**	Economic: **medium**	Adaptation to climate Risk **high**

Key Activities	Key Activities	Key Activities	Key Activities
Gathering of inputs/tools	Planting, land maintenance	Reaping, storage	Sale within local markets

Two main hazards affecting this VC	Consequences of the hazards to the VC	Severity	Who is mainly affected
Flood	Flooding can create issues with rotting of roots and overall challenges with the tubers.	Moderate-Severe	All farmers affected
Pest & Diseases	The weevil burrows into the tuber leaving holes and damaging the produce	Moderate-Severe	All farmers affected

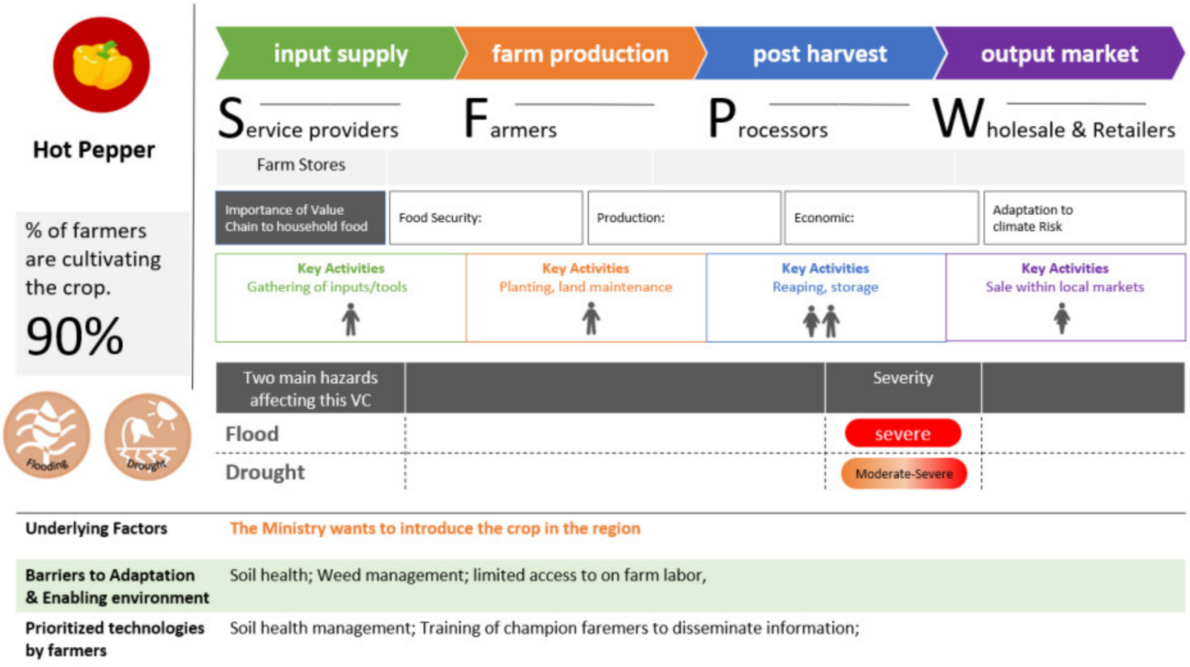
Underlying Factors * Limited access to funds * Limited access to labour* Subpar planting material

Barriers to Adaptation & Enabling environment * access to funding * access to tools and inputs * access to processing facilities * overseas markets (access) * better prices

Prioritized technologies by farmers Very important * Integrated Pest and Diseases management (Traps, clean planting material) * Use of drought-tolerant crops (e.g., sweet potato, cassava, pigeon peas, callaloo, etc.) high * Improved irrigation systems (e.g., drip, micro sprinklers) * Use of organic inputs (e.g., compost, bio-fertilizers, natural repellents) medium * Crop rotation (cover crops, N fixing species)

Figure 32. Sweet Potato Value Chain in Amity Hall.

In Amity Hall, farmers prioritize climate information and extension services high, and also asked for water management like improved irrigation and drainage and flood control systems.



Hot Pepper

% of farmers are cultivating the crop.

90%

input supply	farm production	post harvest	output market
Service providers	Farmers	Processors	Wholesale & Retailers
Farm Stores			

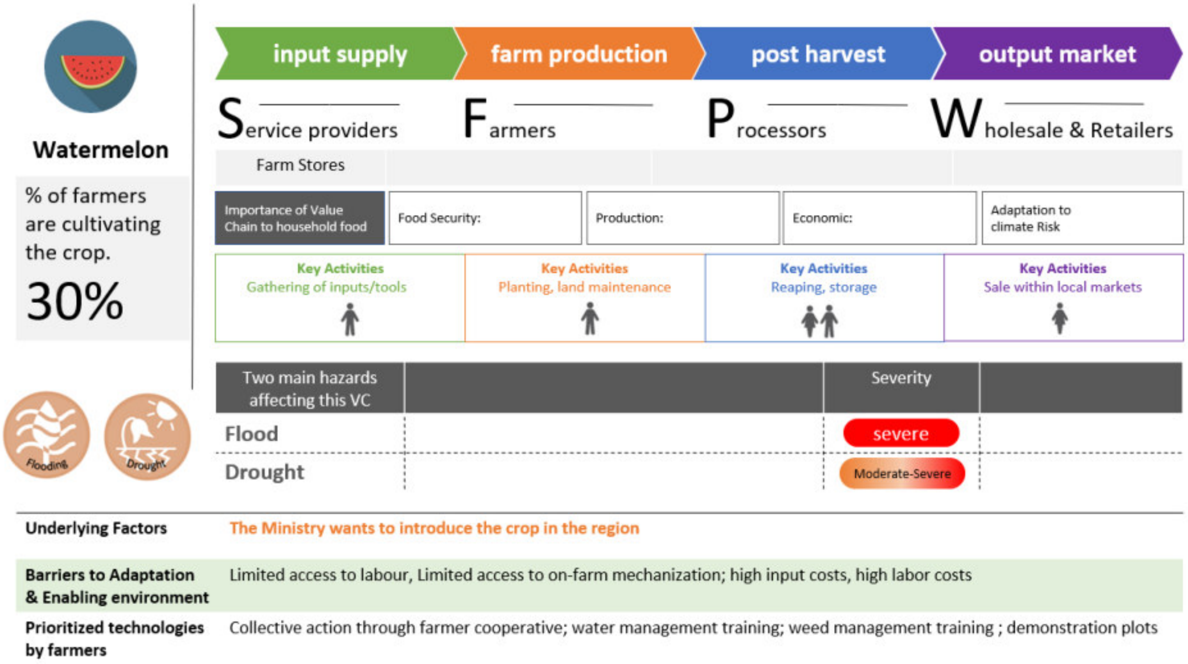
Importance of Value Chain to household food	Food Security:	Production:	Economic:	Adaptation to climate Risk

Key Activities Gathering of inputs/tools	Key Activities Planting, land maintenance	Key Activities Reaping, storage	Key Activities Sale within local markets

Two main hazards affecting this VC		Severity	
Flood		severe	
Drought		Moderate-Severe	

Underlying Factors	The Ministry wants to introduce the crop in the region
Barriers to Adaptation & Enabling environment	Soil health; Weed management; limited access to on farm labor,
Prioritized technologies by farmers	Soil health management; Training of champion faremers to disseminate information;

Figure 3321. Hot Pepper Value Chain in Amity Hall.



Watermelon

% of farmers are cultivating the crop.

30%

input supply	farm production	post harvest	output market
Service providers	Farmers	Processors	Wholesale & Retailers
Farm Stores			

Importance of Value Chain to household food	Food Security:	Production:	Economic:	Adaptation to climate Risk

Key Activities Gathering of inputs/tools	Key Activities Planting, land maintenance	Key Activities Reaping, storage	Key Activities Sale within local markets

Two main hazards affecting this VC		Severity	
Flood		severe	
Drought		Moderate-Severe	

Underlying Factors	The Ministry wants to introduce the crop in the region
Barriers to Adaptation & Enabling environment	Limited access to labour, Limited access to on-farm mechanization; high input costs, high labor costs
Prioritized technologies by farmers	Collective action through farmer cooperative; water management training; weed management training ; demonstration plots

Figure 34. Watermelon Value Chain in Amity Hall.

During the focal group sessions with farmers, we asked them how farming changed over time, what would be needed to maximize the adoption/implementation of the CSA practices, and how it can be ensured that both, women, and men benefit from CSA.

Focal group sessions in the Essex valley (Sea Air, Comma Pen, Lititz)

Farmers in Sea Air were talking about the challenges of accessing water for irrigation and the lack of access to enough land. In the women group discussion, farmers were talking about the challenge of changing weather patterns, like the shift of rain onset from the month of September to October. Farmers get water through government services, but if the drought is extended, some farmers would buy water or switch to alternatives, such as livestock rearing. The additional water come from private trucks and cost 50,000 Jamaican dollars per load. If there would be sufficient access to irrigation, farmers could extend production without causing a glut. The men group was talking about the benefits of mulching with guinea grass. They said it's key to keep the moisture in the soil, without mulching the crop dries out very fast. Farmers are not currently doing tillage or crop rotation. They said that there is no need for rotation since with the mulching they are incorporating enough nutrients into the soil. They decide which crop based on season and market demand. However, some of the farmers mentioned that they are doing crop rotation on sweet potato land, rotating the sweet potato with string beans and cauliform. As reason for rotating, they mentioned having crops planted in between seasons. Regarding what farmers would need to maximize production, they the following needs: Having enough land to produce their own guinea grass to be used as mulch, having access to other varieties for mulching or green cover, understanding the benefit of crop rotation. In case they would have better access to water, they would also need more land.

Focal group session in Parnassus

Farmers in Parnassus are participating in a program initiated by the Ministry of Agriculture and Fisheries to build capacity of farmers. Some farmers have started using drip irrigation, but most farmers still practice furrow irrigation, which requires more water when furrows are set closer. The material cost for drip irrigation is calculated to be about 100,000 Jamaican dollars for 1 acre. Farmers mentioned during the focal group session that funding is needed to set up the infrastructure, including training on how to install and operate the drip irrigation system. Regarding gender differences, the discussion highlighted that woman are more organized with their plans and ideas and would find hep easier by asking than men. Farmers are using tractors for land preparation (tilling), however, they mentioned that the soils remain productive when the seasonal rains are normal and when they use fertilize.

Focal group session in Amity Hall

The government owned land in this area has been used traditionally for sugarcane, but the new Agro-park now helps farmers to expand into vegetables and fruits (papaya, hot pepper, tomato, kale, spinach, dasheen). Farmers are leasing the former sugarcane land, which is a problem for land tenure and investment in larger infrastructure (irrigation). The climate is hot and dry, rainfall patterns changed and are now more intensive, which causes flooding's sometimes. Due to the close distance to the sea, there is also a risk of saltwater intrusion. Farmers are using raised beds and drainage systems to control the flooding, but when farmers train out the water, they also wash out the topsoil. When it rains, there is a problem with water excess because the topography is flat and the soil structure consists of heavy clay in soil, which retains the water too long. While the Agro-park is expanding, they need to investigate market opportunities and value chain diversification. Mechanization is needed to compensate for the hard labor conditions, especially heat conditions. Some farmers have experimented with plastic mulch but recognize that the negative trades offs are higher than the positive ones. Advantages are conservation of moisture, contention of fertilizer nutrients, less compacted soil. Negatives effects of plastic mulch are the heat that reduces microbes and soil life. Farmers recognize that using plant residues for mulching would be more beneficial but is not available. Farmers also know of a degradable plastic that allows the soil to breath - but they are too expensive. Plastic mulch has a positive effect on watermelon production, but the plant distance and pest and disease management are very important for watermelon. On average, farmers grow crops on four to five acres. Growing weeds and related cost for chemicals and manual labor is a major problem for farmers. Manual weeding is two to three times more expensive that tillage using a tractor. One possibility would be shredding the weeds and keep it under a plastic to kill the seeds and then use it for mulch. Crop rotation is practiced on some crops, e.g., sorrel with sweet potato, peas and beans with pumpkin and corn, corn, or pumpkin after hot pepper. One way of lowering a pest infestation would be to agree among farmers to not grow a specific crop for one season.

Prioritized CSA Portfolios for Jamaica

During the prioritization process, the use of an Excel tool was essential to configure CSA investment portfolios, capturing and weighting the multiple assessments on the prioritization criteria provided by the local stakeholders, which engaged across the different CSA-PF sessions around 59 participants (26 men) and (33 women). Therefore, the recognized CSA portfolios represent a context-specific selection of priority agricultural practices that address socio-environmental issues, seek to maximize farmer´s investment yield and minimize income risks, while seizing synergies and avoiding trade-offs that are particular to each region, value chain/crop and CSA practice. Small- and medium-scale farmers were at the center of the analysis, but the practices recognized can be adapted and extrapolated to large-scale farmers that are also present in the regions.

This process allowed the creation of a dynamic ranking[1] by region of the top two CSA options for each value chain identified, as it is presented in the table below. This ranking serves as a guide for decision-making process presenting the overall performance of a given practice based on the combination of the qualitative and quantitative evaluations from stakeholders and experts on the above-mentioned prioritization criteria. The ranking summarizes and represent a straightforward manner to compare individual practices within a region that will be further analyzed as a whole group of practices in the CSA portfolios' dashboards.

Table 15. Value chain and ranking of prioritized CSA practices by region

		Value Chain and CSA practices	General Weighted Score	Final Ranking
Parnassus	1	Pumpkin _ IPM _Intercropping with marigold, traps, and scouting)	2.2	8
	2	Pumpkin _ Pack houses _Shared facilities: cutting, washing, storage.	2.9	6
	3	Pepper (Scotch Bonnet) _Water efficient irrigation _Drip irrigation	2.2	7
	4	Pepper (Scotch Bonnet) _ Integrated soil management_ Raised beds	3.3	3
	5	Irish potato_ Water efficient irrigation _Drip irrigation	2.9	5
	6	Irish potato_ Integrated soil management _Raised beds	4.2	2
	7	Sweet potato _IPM (traps and clean planting material)	3.2	4
	8	Sweet potato _Crop rotation with cover crops _String bean	5.0	1
Amity Hall	9	Watermelon _Crop rotation with Hot Pepper	3.4	4
	10	Watermelon _Water efficient irrigation _Drip irrigation	4.7	2
	11	Sweet potato _Crop rotation with Pumpkin	3.2	5
	12	Sweet potato _Water efficient irrigation _Drip irrigation	2.8	7
	13	Pumpkin _Crop rotation with Corn	2.7	8
	14	Pumpkin _Water efficient irrigation _Drip irrigation	4.9	1
	15	Pepper (Scotch Bonnet) _Crop rotation with Corn	3.1	6
	16	Pepper (Scotch Bonnet) _Water efficient irrigation _Drip irrigation	4.0	3
Essex Valley	17	Scallion _ Mulching	1.3	5
	18	Scallion _Minimum tillage	-0.1	8
	19	Peanut _Crop Rotation with Sweet potato	2.8	3
	20	Peanut _Use of drought tolerant varieties e.g., Cucurbits	3.4	2
	21	Watermelon _Use of drought tolerant crops	2.4	4
	22	Watermelon _Crop rotation with tomato	1.0	6
	23	Cauliflower _Rainwater harvesting systems	5.3	1
	24	Cauliflower _Minimum tillage	0.0	7

Dynamic ranking refers to the fact that there is no definitive or static ranking of CSA practices, because due to the complex nature of the prioritization process, participants can modify the different values, parameters, and weights at any time to suit their needs and to best adapt to the contextual reality of their territory.

Individual CSA investment portfolios results

The following dash boards are a synthesis of the scores evaluated indicators on each prioritization criteria. Bar graphs and pie charts indicate the average values for: *Benefit/cost ratio, Internal Rate of Return, Payback Period; CSA indicators evaluation; Barriers to implementation difficulty; and Opportunities attainability*. And the sum of: Practices Cost, Net Present Value, amount of Barriers; and amount of Opportunities. This based in an aggregated analysis of selected CSA practices. The grey color scale indicates the most and less favorable values (dark to light grey respectively).

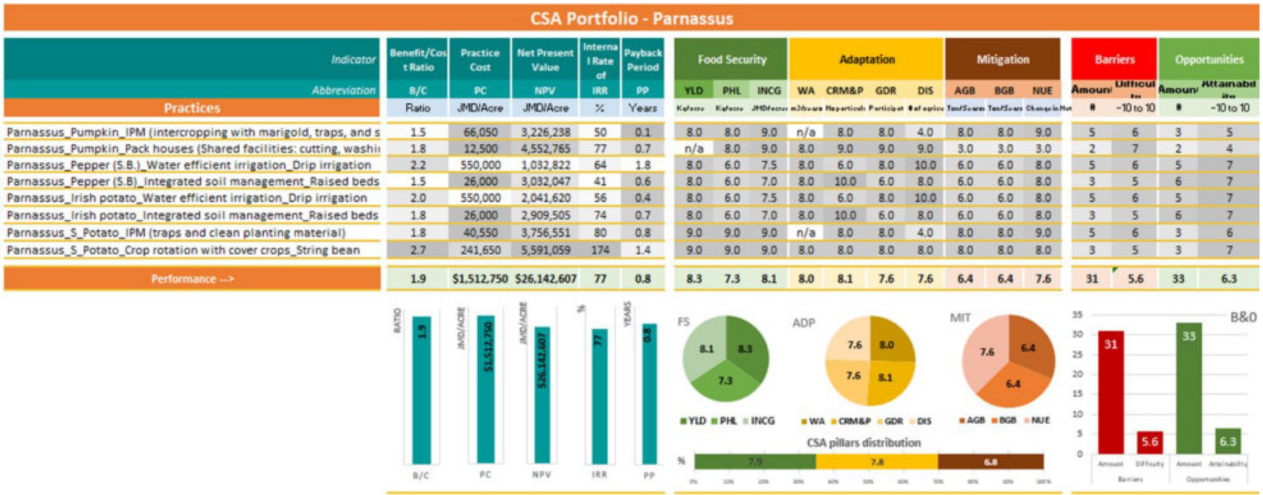
In terms of the Climate smartness, and considering a balanced weighting between criteria (33.3% each), exist a great potential in each portfolio to achieve triple-win benefits in the selected indicators under each CSA pillar, i.e., Food and Nutritional Security: Crop yield [YLD], postharvest loss reduction [PHV] and income generation [INCG], followed by Adaptation: Water availability [WA], water use efficiency [WUE], reduced soil disturbance [SD], climate risk management and prevention [CRM&P], gender [GDR] and diversification of income sources [DIS], and Mitigation: Above-ground biomass [ABG], below-ground biomass [BGB], soil carbon stock [SCS] and nutrient use efficiency [NUE].

Parnassus CSA investment portfolio

Investment portfolio in Parnassus involved CSA options at the on-farm production and postharvest stages in the different value chains. Sustainable soil and water management strategies were prioritized in complement with Integrated Pest and Diseases management practices (IPM). Small-scale pack houses-shared facilities useful for multiple crops was also recognized as a relevant option to strengthen value addition in the region.

Regarding the individual criteria addressed, the portfolio showed the following characteristics:

- *Economic:* Financial indicators such as NPV turn out to be positive (JMD 26,142,607/Acre) with an IRR of 77%, greater than the interest rate used in the analysis (9.46%) and a B/C ratio of 1.9 (>1) indicating that the group of practices in the portfolio are profitable options. The aggregated cost of the portfolio is JMD 1,512,750 /Acre, expecting an average Payback Period of the investment in 0.8 years.
- *Climate smartness*: Based on the CSA indicators evaluated, the portfolio benefits on the CSA pillars tend to contribute in greater proportion to Food and Nutritional Security (35.1%). Closely followed by Adaptation (34.7%) and Mitigation (30.2%). Indicating that most of the practices brings triple-win benefits to the farmers and the agroecosystems in the region.
- *Barriers and Opportunities*: The amount of identified Opportunities for the portfolio (33) was slightly higher than the Barriers (31), a similar pattern was found in the qualitative assessment of the feasibility to attain the Opportunities, showing an average value of 6.3/10 where 10 means that a given opportunity is very easy to overcome. In the case of the Barriers, the average result was 5.6/10 where 10 means that these are very difficult to overcome. This suggests that despite the fact that Barriers and Opportunities are similar in number, the Opportunities recognized by participants are relatively feasible to attain overcoming the difficultness of the barriers found.



CSA Portfolio - Parnassus

	Indicator	Benefit/Cost Ratio	Practice Cost	Net Present Value	Internal Rate of	Payback Period	Food Security			Adaptation				Mitigation			Barriers		Opportunities	
	Abbreviation	B/C	PC	NPV	IRR	PP	YLD	PHL	INCG	WA	CRM&P	GDR	DIS	AGB	BGB	NUE	Amoun	Difficul	Amoun	Attainabil
	Practices	Ratio	JMD/Acre	JMD/Acre	%	Years	Kg/acre	Kg/acre	JMD/acre	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	#	-10 to 10	#	-10 to 10
1	Parnassus_Pumpkin_IPM (intercropping with marigold, traps, and s	1.5	66,050	3,226,238	50	0.1	8.0	8.0	9.0	n/a	8.0	8.0	4.0	8.0	8.0	9.0	5	6	3	5
2	Parnassus_Pumpkin_Pack houses (Shared facilities: cutting, washi	1.8	12,500	4,552,765	77	0.7	n/a	8.0	9.0	8.0	9.0	9.0	9.0	3.0	3.0	3.0	2	7	2	4
3	Parnassus_Pepper (S.B.)_Water efficient irrigation_Drip irrigation	2.2	550,000	1,032,822	64	1.8	8.0	6.0	7.5	8.0	6.0	8.0	10.0	6.0	6.0	8.0	5	6	5	7
4	Parnassus_Pepper (S.B)_Integrated soil management_Raised beds	1.5	26,000	3,032,047	41	0.6	8.0	6.0	7.0	8.0	10.0	6.0	8.0	6.0	6.0	8.0	3	5	6	7
5	Parnassus_Irish potato_Water efficient irrigation_Drip irrigation	2.0	550,000	2,041,620	56	0.4	8.0	6.0	7.5	8.0	6.0	8.0	10.0	6.0	6.0	8.0	5	6	5	7
6	Parnassus_Irish potato_Integrated soil management_Raised beds	1.8	26,000	2,909,505	74	0.7	8.0	6.0	7.0	8.0	10.0	6.0	8.0	6.0	6.0	8.0	3	5	6	7
7	Parnassus_S_Potato_IPM (traps and clean planting material)	1.8	40,550	3,756,551	80	0.8	9.0	9.0	9.0	n/a	8.0	8.0	4.0	8.0	8.0	9.0	5	6	3	6
8	Parnassus_S_Potato_Crop rotation with cover crops_String bean	2.7	241,650	5,591,059	174	1.4	9.0	9.0	9.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	3	5	3	7
	Performance -->	1.9	$1,512,750	$26,142,607	77	0.8	8.3	7.3	8.1	8.0	8.1	7.6	7.6	6.4	6.4	7.6	31	5.6	33	6.3

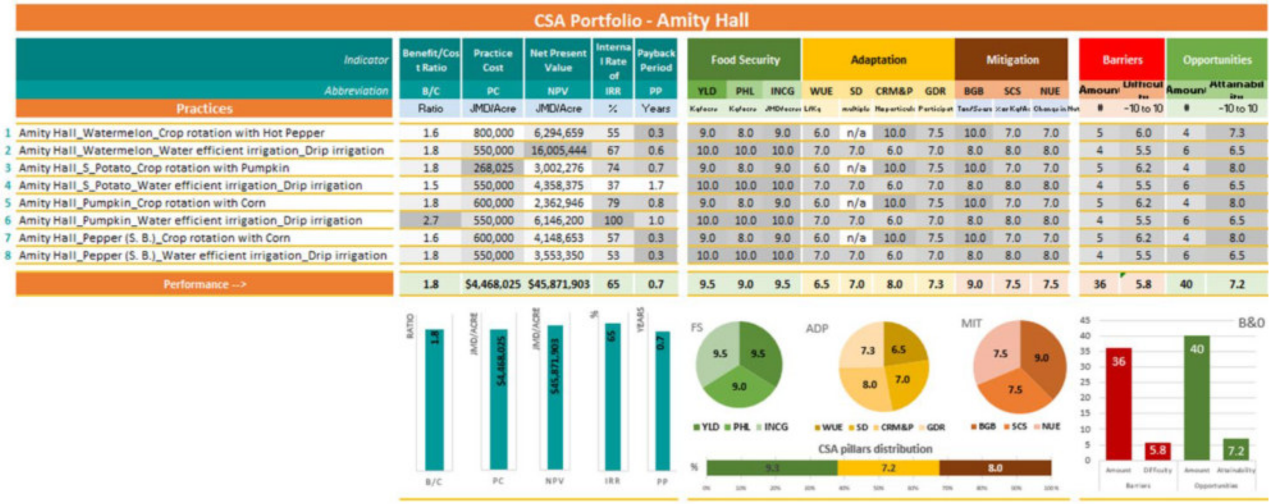
Figure 35. CSA investment portfolio dashboard for Parnassus

Amity Hall CSA investment portfolio

Investment portfolio for Amity Hall involved two key CSA options relevant at the on-farm production stage across the different value chains. Water efficient irrigation systems e.g. drip irrigation and crop rotation with different species, were prioritized as crosscutting strategies as sustainable water management strategies and the later, due to the importance to move towards diversification of agricultural products to avoid market constraints related, for example, to low sale prices linked in turn to excess supply of agricultural products during harvest seasons.

Regarding the individual criteria addressed, the portfolio showed the following characteristics:

- Economic: Financial indicators such as NPV turn out to be positive (JMD 45,871,903/Acre) with an IRR of 65%, greater than the interest rate used in the analysis (9.46%) and a B/C ratio of 1.6 (>1) indicating that the group of practices in the portfolio are profitable options. The aggregated cost of the portfolio is JMD 4,468,025 /Acre, expecting an average Payback Period of the investment in 0.7 years.
- CSA: Based on the CSA indicators evaluated, the portfolio benefits on the CSA pillars tend to contribute in greater proportion to Food and Nutritional Security (37.9%), followed by Mitigation (32.7%) and Adaptation (29.4%). Indicating that most of the practices brings triple-win benefits to the farmers and the agroecosystems in the region.
- Barriers and Opportunities: The amount of identified Opportunities for the portfolio (40) was higher than the Barriers (36), a similar pattern was found in the qualitative assessment of the feasibility to attain the Opportunities, showing an average value of 7.2/10, where 10 means that a given opportunity is very easy to overcome. In the case of the Barriers, the average result was 5.8/10, where 10 means that these are very difficult to overcome. This suggest an optimistic scenario considering that the Opportunities are relatively higher in number, and the assessment of the Opportunities recognized by participants indicate greater chances to attain them vs. the difficultness to overcome the barriers found.



CSA Portfolio - Amity Hall

	Indicator	Benefit/Cost Ratio	Practice Cost	Net Present Value	Internal Rate of	Payback Period	Food Security			Adaptation				Mitigation			Barriers		Opportunities	
	Abbreviation	B/C	PC	NPV	IRR	PP	YLD	PHL	INCG	WUE	SD	CRM&P	GDR	BGB	SCS	NUE	Amoun	Difficulty	Amoun	Attainability
	Practices	Ratio	JMD/Acre	JMD/Acre	%	Years	Kg/acre	Kg/acre	JMD/acre	L/Kg	multiple	[illegible]	Participat	[illegible]	[illegible]	Change in Nut	#	-10 to 10	#	-10 to 10
1	Amity Hall_Watermelon_Crop rotation with Hot Pepper	1.6	800,000	6,294,659	55	0.3	9.0	8.0	9.0	6.0	n/a	10.0	7.5	10.0	7.0	7.0	5	6.0	4	7.3
2	Amity Hall_Watermelon_Water efficient irrigation_Drip irrigation	1.8	550,000	16,005,444	67	0.6	10.0	10.0	10.0	7.0	7.0	6.0	7.0	8.0	8.0	8.0	4	5.5	6	6.5
3	Amity Hall_S_Potato_Crop rotation with Pumpkin	1.8	268,025	3,002,276	74	0.7	9.0	8.0	9.0	6.0	n/a	10.0	7.5	10.0	7.0	7.0	5	6.2	4	8.0
4	Amity Hall_S_Potato_Water efficient irrigation_Drip irrigation	1.5	550,000	4,358,375	37	1.7	10.0	10.0	10.0	7.0	7.0	6.0	7.0	8.0	8.0	8.0	4	5.5	6	6.5
5	Amity Hall_Pumpkin_Crop rotation with Corn	1.8	600,000	2,362,946	79	0.8	9.0	8.0	9.0	6.0	n/a	10.0	7.5	10.0	7.0	7.0	5	6.2	4	8.0
6	Amity Hall_Pumpkin_Water efficient irrigation_Drip irrigation	2.7	550,000	6,146,200	100	1.0	10.0	10.0	10.0	7.0	7.0	6.0	7.0	8.0	8.0	8.0	4	5.5	6	6.5
7	Amity Hall_Pepper (S. B.)_Crop rotation with Corn	1.6	600,000	4,148,653	57	0.3	9.0	8.0	9.0	6.0	n/a	10.0	7.5	10.0	7.0	7.0	5	6.2	4	8.0
8	Amity Hall_Pepper (S. B.)_Water efficient irrigation_Drip irrigation	1.8	550,000	3,553,350	53	0.3	10.0	10.0	10.0	7.0	7.0	6.0	7.0	8.0	8.0	8.0	4	5.5	6	6.5
	Performance -->	1.8	$4,468,025	$45,871,903	65	0.7	9.5	9.0	9.5	6.5	7.0	8.0	7.3	9.0	7.5	7.5	36	5.8	40	7.2

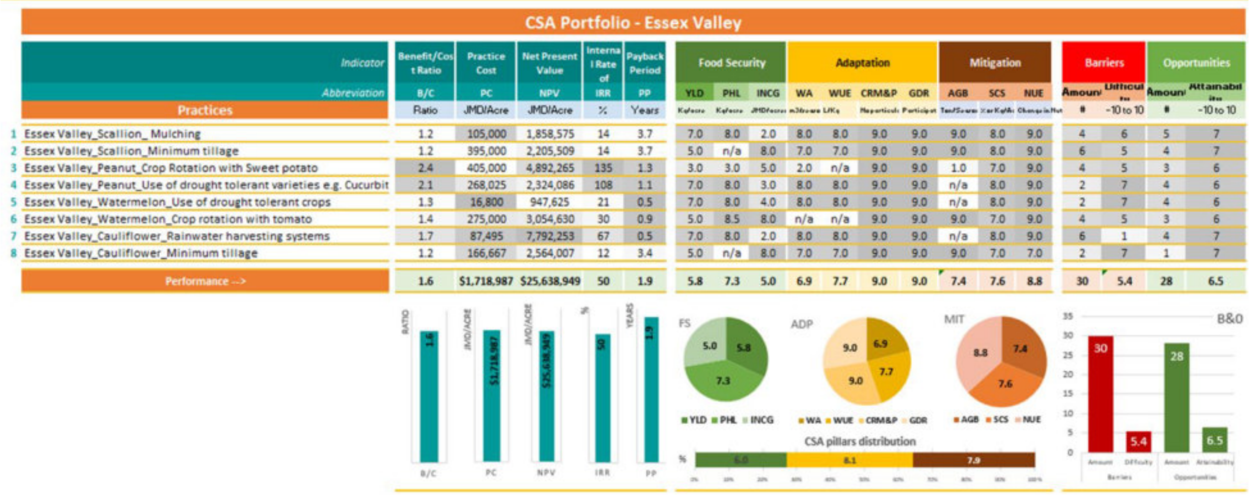
Figure 36. CSA investment portfolio dashboard for Amity Hall

Essex Valley CSA investment portfolio

Investment portfolio in Essex Valley involved CSA options mostly related to on-farm production stage in the different value chains. Sustainable soil and water management strategies were prioritized. Conservation of soil´s health and fertility through the use of mulching, minimum tillage and crop rotation, was complemented with the use of drought-tolerant crops and varieties and the introduction of rainwater harvesting systems that contribute to efficient use of water for agricultural activities.

Regarding the individual criteria addressed, the portfolio showed the following characteristics:

- Economic: Financial indicators such as NPV turn out to be positive (JMD 25,638,949/Acre) with an IRR of 50%, greater than the interest rate used in the analysis (9.46%) and a B/C ratio of 1.6 (>1) indicating that the group of practices in the portfolio are profitable options. The aggregated cost of the portfolio is JMD 1,718,987 /Acre, expecting an average Payback Period of the investment in 1.9 years.
- CSA: Based on the CSA indicators evaluated, the portfolio benefits on the CSA pillars tend to contribute in greater proportion to Adaptation (36.8%). Closely followed by Mitigation (35.9%) and to a lesser extent to Food and Nutritional Security (27.3%). Indicating that most of the practices brings triple-win benefits to the farmers and the agroecosystems in the region.
- Barriers and Opportunities: The amount of identified Barriers for the portfolio (30) was slightly higher than the Opportunities (28). In contrast, the qualitative assessment of the feasibility to attain the Opportunities showed an average value of 6.5/10 where 10 means that a given opportunity is very easy to overcome, whereas in the case of the Barriers, the average result was 5.4/10 where 10 means that these are very difficult to overcome. This suggest that although the number of Barriers exceeds the number of Opportunities, the Opportunities recognized by participants are relatively feasible to attain compared to the level of difficultness of the barriers found.



CSA Portfolio - Essex Valley

	Indicator	Benefit/Cost Ratio	Practice Cost	Net Present Value	Internal Rate of	Payback Period	Food Security			Adaptation				Mitigation			Barriers		Opportunities	
	Abbreviation	B/C	PC	NPV	IRR	PP	YLD	PHL	INCG	WA	WUE	CRM&P	GDR	AGB	SCS	NUE	Amoun	Difficul	Amoun	Attainabil
	Practices	Ratio	JMD/Acre	JMD/Acre	%	Years	Kg/acre	Kg/acre	JMD/acre	m3/acre	L/Kg	[illegible]	Participat	[illegible]	[illegible]	[illegible]	#	-10 to 10	#	-10 to 10
1	Essex Valley_Scallion_ Mulching	1.2	105,000	1,858,575	14	3.7	7.0	8.0	2.0	8.0	8.0	9.0	9.0	9.0	8.0	9.0	4	6	5	7
2	Essex Valley_Scallion_Minimum tillage	1.2	395,000	2,205,509	14	3.7	5.0	n/a	8.0	7.0	7.0	9.0	9.0	9.0	8.0	9.0	6	5	4	7
3	Essex Valley_Peanut_Crop Rotation with Sweet potato	2.4	405,000	4,892,265	135	1.3	3.0	3.0	5.0	2.0	n/a	9.0	9.0	1.0	7.0	9.0	4	5	3	6
4	Essex Valley_Peanut_Use of drought tolerant varieties e.g. Cucurbit	2.1	268,025	2,324,086	108	1.1	7.0	8.0	3.0	8.0	8.0	9.0	9.0	n/a	8.0	9.0	2	7	4	6
5	Essex Valley_Watermelon_Use of drought tolerant crops	1.3	16,800	947,625	21	0.5	7.0	8.0	4.0	8.0	8.0	9.0	9.0	n/a	8.0	9.0	2	7	4	6
6	Essex Valley_Watermelon_Crop rotation with tomato	1.4	275,000	3,054,630	30	0.9	5.0	8.5	8.0	n/a	n/a	9.0	9.0	9.0	7.0	9.0	4	5	3	6
7	Essex Valley_Cauliflower_Rainwater harvesting systems	1.7	87,495	7,792,253	67	0.5	7.0	8.0	2.0	8.0	8.0	9.0	9.0	n/a	8.0	9.0	6	1	4	7
8	Essex Valley_Cauliflower_Minimum tillage	1.2	166,667	2,564,007	12	3.4	5.0	n/a	8.0	7.0	7.0	9.0	9.0	9.0	7.0	7.0	2	7	1	7
	Performance -->	1.6	$1,718,987	$25,638,949	50	1.9	5.8	7.3	5.0	6.9	7.7	9.0	9.0	7.4	7.6	8.8	30	5.4	28	6.5

Figure 37. CSA investment portfolio dashboard for Essex Valley

Comparison between regions

In perspective, from the different criteria evaluated, the CSA investment portfolio for Amity Hall (AH) demonstrated a better performance gathering 6 out of the 12 parameters evaluated. Followed by Essex Valley (EV) and Parnassus (P) with 4 and 3 respectively. From the economic point of view, AH showed higher total NPV, almost duplicating the expected net benefits compared to the other two regions, coupled with a lower projected average time to recover the investment (0.7 years). Nevertheless, the Parnassus´ portfolio, having a lower total cost in the implementation of the CSA practices and a relatively good financial performance (NPV), it showed the best benefit-cost ratio (B/C), not far from those found for the other two regions. Results that are aligned with the highest Internal Rate of Return of the three regions (77%). Under the assumptions of the analysis, the total aggregated* and average** values for each economic indicator considering all regions of the study, reveals that priority CSA portfolios and their practices are attractive alternatives in economic terms. Showing a total cost of JMD 7,699,762 /Acre, with and NPV of JMD 97,653,460 /Acre, an IRR of 64%, a B/C ratio of 1.8, and an IRR of 64% in an average period of 1.1 years.

Greater climate-smart benefits on Food and Nutritional Security and Mitigation are projected to be perceived in the AH portfolio, while Adaptation benefits are expected to be higher in the EV portfolio. Qualitative assessment of CSA indicators was predominantly positive in all portfolios, indicating that there are several opportunities to increase resilience capacity not only in the household sphere but also at the ecosystem level, driven by an adequate and successful process of education and subsequent implementation and adoption of the priority CSA practices. Worth to mention that weighting assigned to the CSA criterion, remained similar to that used in the overall criteria of the analysis (33.3%).

In terms of the aggregated analysis of Opportunities and Barriers to adoption of the CSA practices/portfolios, average scores indicate that EV has the least number and degree of difficulty in overcoming the barriers to implementation. For its part, AH is perceived as the region with the greatest number of opportunities and, in turn, the greatest possibility to attain them along with EV. It is important to mention that both the amount and difficulty/attainability assessment did not differ significantly between regions, covering a wide range of multidimensional aspects (social, economic, environmental etc.).

C. DEVELOPMENT OF CSA TRAINING PROGRAM

Methods

Approach to Manual development

A consultative approach was taken in developing this manual, engaging a wide variety of agricultural stakeholders who are knowledgeable about the area, including agricultural extension officers, farmers, academic researchers, and other agricultural stakeholders. This multi-stakeholder approach enriches the perspectives presented in this manual, as it incorporates technical, academic, experiential, and cultural outlooks on climate-smart agricultural practices directly relevant to the community of interest. Key questions of consideration in the information gathering stages included:

- What key pieces of information do farmers need?
- What are the best methods to convey such information?

In response to these questions, the key gaps outlined by farmers were highlighted and compiled in this manual. Special emphasis was placed on devising methods that are useful for sharing such information, based on farmers' preferences in the region. Emerging from workshops and consultations with the agricultural stakeholders and experts in Amity Hall, four key crops were identified as especially important in the region: Pumpkin, sweet potato, Scotch Bonnet peppers, and watermelon.

In response to these questions, the key gaps outlined by farmers were highlighted and compiled in this manual. Special emphasis was placed on devising methods that are useful for sharing such information, based on farmers' preferences in the region. Productive, nutritional, and socio-cultural and economic criteria were analyzed and discussed to prioritize the crops, further considering current and viable options that included major crop categories: vegetables, legumes, condiments, fruits, and tubers.

Perspectives on climate-smart practices were then solicited from farmers, extension agents and academics for each of these crops, and the importance of each practice was then ranked based on qualitative and quantitative assessments by stakeholders for different indicators related to food and nutritional security, adaptation and resilience, and mitigation. Likewise, discussions on multidimensional barriers to adoption and opportunities to overcome these were held to inform the prioritization and decision-making process. Supplementary perspectives on these practices were also drawn from secondary sources to obtain a global standpoint of reference, by consulting standard agricultural documentation of agricultural practices in the country.

In addition to the social and environmental considerations of the crops and practices, an ex-ante cost-benefit analysis was carried out to gauge the economic potential of farmers' implementation of the priority CSA practices described herein for each crop. Input data from Focus Group Discussions (FGDs) and consultations with local experts was essential to calculate the profitability of the practices through financial indicators such as Net Present Value (NPV), Internal Rate of Return (IRR), Cost-Benefit ratio (C/B) and Payback Period (PP), including the quantification of positive environmental externalities of practices adoption (Sain et al., 2017).

Co-Creation of Training Manuals

The co-creation workshops were undertaken in each of the three regions and sought to engage farmers in the development of outlines for locally specific Climate Smart Agriculture (CSA) training programs. The sessions across the different regions were geared towards sensitizing farmers about the program and its intent; introducing them to the crops and practices selected during the prioritization workshops; exploring potential opportunities and challenges in the implementation of the specified practices; identifying appropriate mediums for information dissemination and assessing the differences in activities undertaken and challenges experienced by male and female farmers.

Trainings program and Knowledge Transfer

The Training of Trainers (TOT) will be undertaken in January where technical experts will be introduced to the training manuals and sensitized on how to effectively disseminate the information across the different areas. They will also be introduced to Geo-farmer, as a platform that can facilitate increased engagement with farmers.

GeoFarmer

GeoFarmer is an app designed to support experience exchanges between farmers – be they positive or negative – so that they can learn from each other by asking questions and by sharing suggestions on how their crop, animal and farm management can be improved. Extensionists can also use it to share information and obtain continuous feedback and follow up with farmers during support. GeoFarmer helps to democratize extension services and provide an alternative to the often-one-way top-down traditional extension services (Eitzinger et al., 2019; Eitzinger et al., 2020).

On a GeoFarmer channel, social media like functionalities allow users to easily provide specific input and best practice cases to their communities and ask others for feedback in certain fields of interest, building a common knowledge base. Farmers – user role – can ask a question to the channel community, and other users can provide answers. Experts can share step-by-step instructions on how to implement agricultural practices, and other channel subscribers can rate and comment on the best practice.

Expected Outcomes

The manuals and published content on GeoFarmer channels aim to achieve the following objectives:

- To enable agricultural extension officers to provide more targeted training to farmers in the area, based on the priority needs identified
- To build farmers' knowledge capacity in adequately responding to key climate-related hazards to their agricultural production systems.
- To promote broader adoption of climate-smart practices in the area.

Results and Findings

The co-creation workshops were held between August and November 2021 and explored farmers' experiences with the prioritized crops and practices. They further sought to engage farmers in discussions on training needs and mediums for information dissemination. No major differences were seen in the activities done/challenges faced by male and female farmers across the three regions.

Essex Valley

Scallion and watermelon were considered key crops in Comma pen. Cauliflower and peanut were more popular in other communities within the valley. Scallion was considered a popular crop that farmers cultivate for a variety of reasons. It thrives well in the area and there is a constant demand particularly from factories, hotels, restaurants, and jerk centers, creating a high demand. For watermelon, when it is in abundance, it is sometimes difficult to get a sale. Demand however increases during the summer months (July-September).

Farmers expressed that their current information needs include knowing when to plant (would be based on community specific climate information); having adequate information on markets and crop availability (would help to reduce spoilage) and the selection and introduction of new varieties. They further discussed that demonstration plots would prove useful especially for young farmers. Audio-visual content was also deemed critical.

Amity Hall

The four (4) crops selected for the area were watermelon, scotch bonnet, sweet potato and pumpkin. Sweet pepper and sweet corn were also considered among the most robust crops in the area. Farmers provided detailed information for all crops except watermelon as it was not being extensively cultivated.

Pumpkin was considered popular among farmers in the park despite its low yields in comparison to that seen within other Agroparks. The low yields were attributed to existing fungal diseases and poor soil health, evident throughout the park. Due to problems of infestation and the clay soil in the area, farmers were cultivating fewer sweet potatoes. The crop was seen as being better suited for soils with greater concentrations of sand/silt. Farmers involved in the cultivation of scotch bonnet pepper were normally affected more than other farmers during periods of water shortages. The high incidence of disease, partly attributable to the contaminated water in the area, was one of the biggest challenges farmers have had to address daily.

Farmers highlighted varying areas where training was needed. They discussed that training in relation to soil health was necessary as the current information being provided was considered too simplistic. Pest management was also of importance given the proximity of farms to each other. Improved knowledge on water treatment was also necessary as a water test was done on site last year which indicated Fusarium, a fungal disease, was present which drastically affected not only crop yields but also the overall operational costs.

Parnassus

The main crops cultivated by farmers included corn, pumpkin, onion, callaloo, pepper, papaya, banana, sorrel, tobacco, and peanut. Pumpkin is the most popular crop as it able to withstand dry conditions and the limited access to water that is evident in the community. Cassava is another popular crop for similar reasons. While most farmers cultivate the regular strain of pumpkin, there is another variety, ‘the Bodles Pumpkin’ that is not very popular as it requires more inputs (chemicals and water). Within the space, male and female farmers alike, cultivate similar crops. There are also young farmers that are actively engaged in the cultivation of different crops, especially pumpkin.

Most farmers currently rely on indigenous knowledge, trial and error, farmer’s almanac, information from peers, smart devices, clouds, observing animals and the sky. They are also interested in having demonstration plots, FFS and learn by doing approaches to effectively disseminate information.

Location specific weather/climate data is an area of interest that can assist in farm management and overall decision making. Such information has been considered important as weather is no longer predictable with cyclical changes being seen. Other needs expressed by the farmers include irrigation access; storage; better markets and higher prices for their produce; lower input costs; opportunities for value added agriculture and the strengthening of linkages with local producers. A farmers' group has been revived in the community and its value is well recognized especially in being able to attain some of these needs.

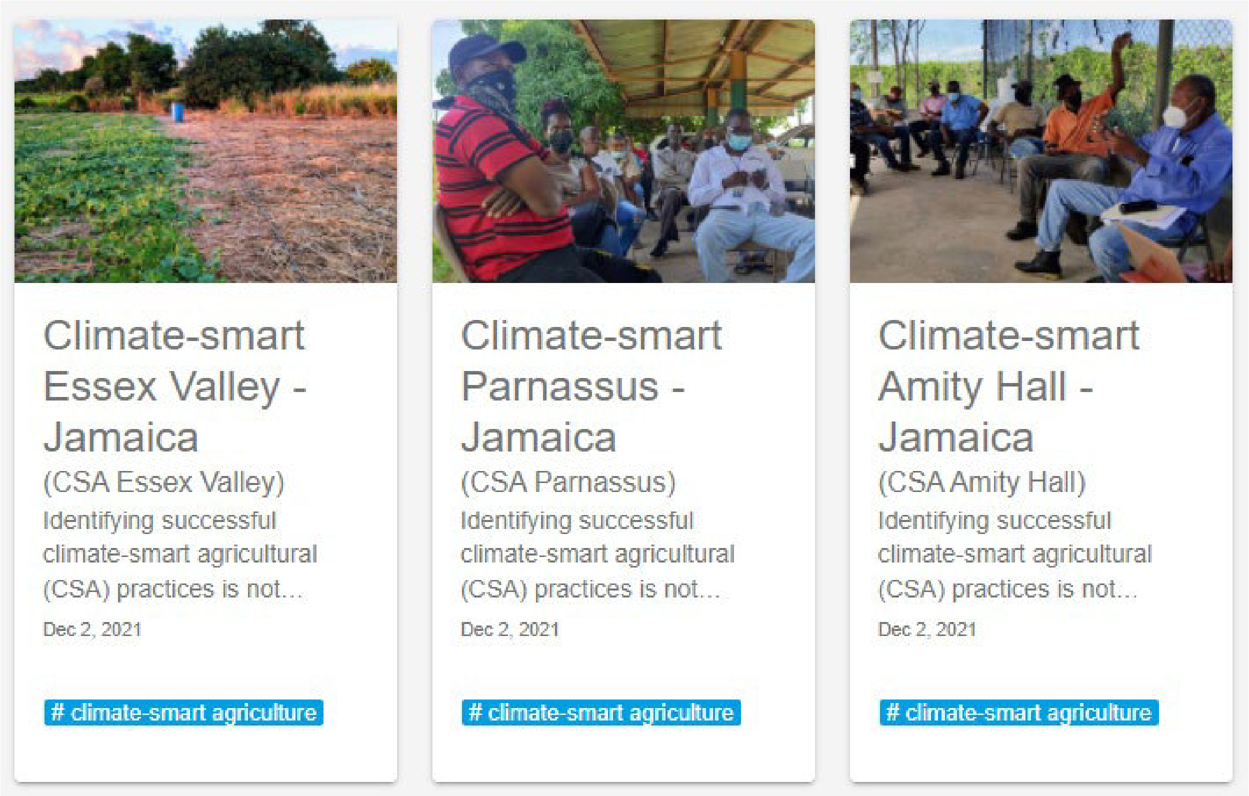
Climate-Smart Agriculture Extension Service Manuals

The CSA Extension Services Manual aims to provide agricultural extension staff in the region with ready-to-use guidelines for climate-smart practices. It incorporates the local experiences of farmers as well as the expertise of local and international adaptation researchers. A key feature of this manual is an assessment of the costs and benefits associated with implementing targeted CSA practices, with direct reference to local economic conditions. The manuals are:

- INTEGRATIVE: Provides both technical information and incorporates the voices of farmers in the community of interest for improved integrated crop management.
- CULTURALLY SENSITIVE: Gives special consideration of cultural and traditional practices in the area
- CROP-SPECIFIC: Focuses on major crops that are important to the economy and culture of communities, instead of presenting generic guidelines.
- ECONOMICALLY RELEVANT: Enables improved decision-making for the farmer and agricultural stakeholders who desires to understand the long-term benefits of their investment options, optimizing their farm practices by presenting cost-benefit analyses for each prioritized option.
- ACTION ORIENTED: Highlights farmers' own perspectives and recommendations to attain opportunities to overcome current and potential barriers to adoption of CSA practices in the regional context.

Target Audience

Agricultural extension services aim to provide technical support to producers at the farm- and community levels. Extension services have been found to improve farmer accessibility and use of climate information services, including in the Jamaican context (Buckland and Campbell, 2021). A knowledgeable and strategic extension service at the local level has great potential to have significant national impact on increasing agricultural productivity sustainably, enhancing food and nutritional security, improving, and diversifying rural livelihoods, and promoting agriculture as an engine of socio-economic growth.



Climate-smart Essex Valley - Jamaica

(CSA Essex Valley)

Identifying successful climate-smart agricultural (CSA) practices is not…

Dec 2, 2021

climate-smart agriculture

Climate-smart Parnassus - Jamaica

(CSA Parnassus)

Identifying successful climate-smart agricultural (CSA) practices is not…

Dec 2, 2021

climate-smart agriculture

Climate-smart Amity Hall - Jamaica

(CSA Amity Hall)

Identifying successful climate-smart agricultural (CSA) practices is not…

Dec 2, 2021

climate-smart agriculture

Figure 229. GeoFarmer Channels for promoting the Training manuals.

The developed training manuals can be found on the GeoFarmer channels (Figure 39):

https://geofarmer.org/csa-essex-valley

https://geofarmer.org/csa-parnassus

https://geofarmer.org/csa-amity-hall

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