Inventory and characterization of food systems on Bonaire

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Increased production of fruits and vegetables on Bonaire may contribute to a better availability of healthy food and employment opportunities. Therefore, possibilities of plant production in the area of Rincon, Bonaire were mapped in this study. The study was based on literature research and online key-informant interviews, complemented with additional analyses. Findings show that increasing year-round fruit and vegetable production in Rincon, and Bonaire in general, is challenged by water availability, an unsupportive business environment, and harsh production circumstances, and may not be possible without support.

Keywords: fruits, vegetables, Bonaire, agriculture, farming, Caribbean, small Islands Development States

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Preface

Wageningen University & Research has a long history in scientific research targeted at the social, economic and environmental aspects of the Caribbean. In recent years, much of this research has taken place as part of the internally funded Knowledge Base program Biodiversity in a Nature Inclusive Society (KB36). The KB36 project Social-ecological **Tr**ansformation for bottom-**UP I**ntegrated **A**pproach in Caribbean **L**andscapes (TRUPIAL) aims to strengthen nature and contributes and links up with small local bottom-up initiatives which could act as 'seeds of change' to support nature inclusive practices.

One of the bottom-up initiatives is a landscape cooperative (in development) in Rincon on Bonaire. In this study we map the possibilities of plant production that contribute to a better availability of healthy food and employment opportunities on Bonaire, and more specifically in Rincon.

A great part of the study is based on online interviews with key-informants, which we would like to thank for the shared information and discussions (in alphabetical order): Maurice Adriaens (LVV), Elsmarie Beukeboom (retired, former Director STINAPA), Arie Boers (Bon Tera), Danilo Christiaan (Mangazina di Rei), Julianka Clarenda (ECHO Bonaire), Bob Janssen (Daily Fresh) and Adolfo Morales (local farmer). The responsibility for the content and any remaining errors remains exclusively with the authors.

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Summary

Increased production of fruits and vegetables may contribute to a better availability of healthy food and employment opportunities on Bonaire. Therefore, possibilities of plant production in the area of Rincon, Bonaire were mapped in this study. The study was based on literature research and online key-informant interviews, complemented with additional analyses. The literature review and the interviews were used to describe Bonaire's food system and to do an analysis of Strengths, Weaknesses, Opportunities and Threats (SWOT) of several production systems. In addition, biophysical conditions were analyzed, and calculations were performed on the land and water requirements for several levels of agricultural production. Findings show that increasing year-round fruit and vegetable production in Rincon, and Bonaire in general, is challenging, and may not be possible without support. The main challenges include limited and irregular water availability, an unsupportive business environment, and harsh production circumstances characterized by pests, diseases and challenging weather conditions. Without sufficient support to increase water availability and local agricultural knowledge and to create a suitable business environment, both capital-intensive and small-scale crop production are unlikely to lead to better availability of healthy food and employment opportunities in Rincon. Support may take the form of increasing the availability and affordability of water, which would be beneficial for several target groups. Additional support that would be required, may differ for entrepreneurs, community gardens and individual home-gardens.

1 Introduction

The Caribbean is a region in Central America with islands and coasts bordering the Caribbean sea. Three island countries are part of the Kingdom of the Netherlands (Aruba, Curaçao and Sint Maarten) and three islands are special Dutch municipalities (Bonaire, Saba and Sint Eustatius among them). Although these islands differ in cultural, economic and environmental diversity they all deal with many of the same socio-economic and environmental issues that small Islands Development States face (UNEP, 2014).

WUR has a long history in scientific research targeted at the social, economic and environmental aspects of the Caribbean. In recent years, much of this research has taken place as part of the internally funded Knowledge Base program. The project Social-ecological **Tr**ansformation for bottom-**UP I**ntegrated **A**pproach in Caribbean **L**andscapes (TRUPIAL) aims to strengthen nature and contributes and links up with small local bottom-up initiatives which could act as 'seeds of change', that strengthen nature inclusive practices. On Bonaire, this is targeted at implementation possibilities that are in line with the nature inclusive vision that was recently developed (Verweij et al., 2022).

One of the bottom-up initiatives is a landscape cooperative (in development) in Rincon on Bonaire. This area is the most fertile and wettest part of Bonaire, located in a valley that was home to enslaved in the 18th and 19th centuries. The current population in Rincon (roughly 2000 residents) is aging because young people are leaving due to a lack of socio-economic prospects. The population and entrepreneurs of Rincon have little voice in the political debate and are not heard when it comes to important policy and investment decisions. The main goal of the landscape cooperative is advocacy towards the municipal council in Kralendijk, the island's capital, for the inhabitants and entrepreneurs of Rincon. A large part of this advocacy will resolve around agriculture, nature and tourism, which constitute the main economic activity in Rincon.

A big challenge for Rincon, and Bonaire in general, is to produce an affordable and healthy diet for the low-income population. Over 60% of the local population is obese or has overweight (Openbaar Lichaam Bonaire, n.d.) and only one third of the population eats daily vegetables, salad or fruit (*id.*). An important reason for the low portion of fruits and vegetables in diets, is their high prices[1]. Most food on Bonaire is imported, which makes food expensive, especially fresh products such as vegetables and fruit. Awareness about the island's vulnerable food system was raised in 2014 when Venezuela closed its border leading to a decrease in the availability of fresh fruits and vegetables on the island. Similar problems happened during the COVID-19 epidemic when (food) trade was hampered, and food prices skyrocketed. The vulnerability of the local food systems was also more recently felt during the Ukraine crises which resulted in global food price hikes. Hence, a sequence of shocks originating from outside Bonaire led to an increased awareness of the vulnerability of Bonaire's current food system. Stimulating local food production contributes to increasing the resilience of Bonaire's food system.

Current high retail prices of fruits and vegetables makes locally produced food potentially competitive. In addition, the tourist industry and associated catering sector are potential clients for locally produced high quality fruits and vegetables. It has been estimated that 99% of the consumed fruits and vegetables are being imported of which 40% could be produced locally (Caribisch Netwerk, 2017)[2]. Apart from contributing to healthier and affordable diets of the local population, agriculture contributes to direct employment (income generation), but also indirectly through employment opportunities in the trade, processing, logistics and sales of food. Finally, a vital agricultural sector contributes to a more-shock-proof local economy, considerably reduces the cost of food imports, and reduces Bonaire's trade deficit, which was million US$ 291 in 2021 (CBS)[3].

[1] One vegetable supplier at Bonaire offers lettuce at US$ 4, while the hourly minimum wage is US$ 7.13 at Bonaire (January 1, 2023).
[2] https://caribischnetwerk.ntr.nl/2017/11/18/bonaire-kan-40-procent-groenten-zelf-produceren/ [visited June 27, 2023].
[3] https://opendata.cbs.nl/#/CBS/nl/dataset/82659NED/table [visited June 27, 2023].

1.1 Problem definition

In the past, various initiatives have been developed to promote agriculture on Bonaire, but in many cases, these have failed or turned out not to be scalable. In addition to two commercial chicken farms and two Dutch entrepreneurs who produce vegetables, the number of agricultural entrepreneurs on Bonaire can be counted on two hands (CBS, 2021)[4]. Animal husbandry in the form of free-roaming goats, and vegetable and fruit production on the scale of vegetable gardens takes place at limited scale on Bonaire and can only produce part of a family's needs; Marketable volumes are small.

Much of the agricultural research so far has identified the availability of freshwater (rainfall and irrigation water) as the biggest bottleneck for farming in Rincon and the rest of Bonaire (Lotz et al., 2020). Annual variation in rainfall is high, but rainfall distribution within the year is unclear to assess the possibilities to grow rainfed short season crops, also in relation to the water holding capacity of the prevailing soils on Bonaire. Irrigation water sources have to be mapped and (dis)advantages made explicit to identify how the scarce water resources can be used most efficiently and cost-effectively. Apart from water availability, little is known about other bottlenecks that hamper agricultural production on Bonaire. Insights in constraints and opportunities of specific production systems on Bonaire are limited. What are these constraints and what are opportunities to deal with them or to solve them? Information and knowledge contributing to answering this type of questions supports the landscape cooperation to develop feasible plans and projects to increase agricultural production in Rincon.

1.2 Objective

Strengthening of the Rincon landscape cooperative (under development) by mapping the possibilities of plant production of Rincon that contribute to a better availability of healthy food and employment opportunities on Bonaire. We focus specifically on plant production as animal production on the island depends on the available feed resources, which are currently to a large extent imported.

We do not consider plant production aimed at non-food products such as aloe vera, wood and coccinelle which were produced in the past on the island (Section 2.1). Non-food production systems may contribute to improved income generation, just as any other employment opportunity, and improve the food accessibility of the local population. However, they do not contribute directly to improved food availability on the island and the resilience of the island's food system. We also do not address fisheries as this sector does not depend on scarce land resources and freshwater availability. However, fisheries is important for providing healthy food (especially proteins) to the inhabitants of the island.

1.3 Approach and methods

This report is based on literature research and online key-informant interviews, complemented with additional analyses. The literature research was mostly based on reports about the situation on Bonaire and other Caribbean islands, and to a lesser extent on scientific literature. Reports were retrieved based on searches with the google search engine, and through snowballing.

Seven key informants were interviewed in six online semi-structured interviews: three agricultural entrepreneurs, one hobby farmer, one representative of the department agriculture, animal production and fisheries (LVV) on Bonaire, and two representatives of NGOs involved in founding the landscape cooperative in Rincon. Questions focused on retrieving information on the current food system and agricultural production on Bonaire, and obstacles for agriculture. Where applicable, the interviews also included specific questions about the enterprises and production practices of the interviewees.

[4] https://www.cbs.nl/nl-nl/cijfers/detail/83169NED [visited June 26, 2023].

The literature review and the interviews were used to describe Bonaire's food system (Chapter 2) and to do an analysis of Strengths, Weaknesses, Opportunities and Threats (SWOT) of several production systems (Chapter 4). In addition, biophysical conditions were analyzed with the help of climate data, and soil and terrain resources were described based on historic maps and data (Chapter 3). Finally, calculations were performed on the land and water requirements for several levels of agricultural production, based on production data of entrepreneurs and data from the literature (Chapter 5).

2 Bonaire's food system

2.1 Agricultural production in the past

Already in 16th century the Spanish conquerors introduced small livestock (goats, sheep, donkeys) on Bonaire. Raising small ruminants using the natural vegetation as feed remained an important agricultural activity since that time because of the harsh conditions for producing other agricultural products. Salted meat and leather have been exported up to the first part of the 20th century. Since the 17th century forest resources of the island have been exploited for wood and the production of charcoal (Gewald et al., 1971). During the time of the Dutch West India Company (1642-1792) most slaves were put to work in the solar salt pans, while a minority raised animals and produced food, mainly sorghum, for food self-sufficiency. However, maize was imported from Curacao as local production was most of the time insufficient to meet even the basic food needs (Hartog, 1957). Various agricultural export products in the mid-19th century were collected from nature, i.e., wood and *dividivi* pulses used for tanning of leather. On plantations, non-food products coccinelle insects (for color pigment) and aloe vera, which was exported till well into the 20th century, were produced. After the period of slavery, plantations were partly sold to rich landowners, and part of the plantations were split into small plots and redistributed among former slaves. These plots are nowadays known as *kunukus* in Papiamento.

According to the literature, major agriculture / crop production on Bonaire has been abandoned some 40 to 50 years ago (Lotz et al., 2020). This was confirmed in several of the interviews, although no documentation has been found allowing to substantiate the extent of agriculture (crop yields, production, area) at that time. Most of the information is anecdotical and indicates that agriculture on *kunukus* consisted mainly of livestock raising, and sorghum production in the rainy season. Vegetables and fruits were produced near water reservoirs, including recessional agriculture or flood retreat agriculture. Possibly small-scale irrigated production was practiced near groundwater wells. A typical rainfed production system in the past consisted of a mixture of maize, climbing beans and pumpkin, locally known as 'three sisters'. Apart from crop production, scavenging goats were an important component of the agricultural system.

Food insecurity in the past

Many travel reports of around 1900 describe the appalling conditions in which the population on the Antilles lived during that time. The situation on Bonaire was worse than on Curacao and Aruba. Hunger and scurvy were common on all islands because of the scarcity of food. One traveller (H. van Kol) visited Bonaire in May 1903 and wrote in his report, for example, '*Waren op de Bovenwindsche eilanden, Sint Eustatius, Saba, en Sint Martin, de economische toestanden minstens "ongunstig" te noemen, op het eerste der drie Benedenwindsche eilanden die ik zou bezoeken, op Bonaire, moet van armoede en ellende worden gesproken'*. He also visited Rincon, with 1700 inhabitants at that time, and he observed the extreme poverty and shortages of freshwater and food. After a bumper crop in 1902 and crop failure in 1903, locally produced food supplies were depleted when he visited Rincon in May 1903. The people needed to wait 10 months till the next (uncertain) harvest. The population till that time lived from imported maize flour from the US and some goat meat.

Source: Soerabaiasch Handelsblad, 24 September 1903.

Nowadays, the *kunukus* are hardly used anymore for agricultural production. By the absence of irrigation water only few *kunukus* are currently used for agriculture by pensionados or part-time farmers. In 1954, still 1000 ha of *kunukus* were ploughed and sown according to a regional newspaper[5]. Between 2004 and 2011 between 51 and 121 hectares were mechanically ploughed each year (Openbaar Lichaam Bonaire, 2014).

[5] Amigoe di Curacao of 25 January 1954.

Currently, most *kunukus* serve as a family resort to stay over during the weekend or are transformed into tourist accommodations.
Based on the literature and interviews, various interrelated factors contributed to the decline in local food production in the 20th century:

- Already in the first half of the 20th century employment opportunities outside the island (Shell refinery on Curacao, shipping companies) were more remunerative than agricultural jobs. This resulted in (temporary) labour migration and an outflow of agricultural labour (Gewald et al., 1971). In the second half of the 20th century the tourism sector on Bonaire became a driver of labour dynamics by offering higher earnings than the agricultural sector. Knowledge about local agricultural production methods was lost, and new agricultural technologies not introduced.
- Dam structures and water reservoirs to capture rainwater and reduce runoff were not maintained. Some reservoirs were designated as wetlands with a nature/biodiversity function (DeFreitas et al., 2006). Overall, water availability for agriculture seems to have decreased.
- In the second half of the 20th century, trade liberalisations facilitated the import of cheap food from countries with a lower cost price of production. Most likely also transport costs of food imports became lower associated with improved overseas logistics.

At the same time various autonomous developments took place that contributed to the increase of food imports:

- Bonaire's population increased from 5800 in 1961 (Verweij et al., 2020) to 10,971 in 2001 (Census, 2001)[6] and to 24,090 in 2023 (CBS)[7] The population growth on the island stimulated the demand for food beyond that what could be supplied by traditional agriculture on the island. The retail sector was in need to find other suppliers, which were found outside Bonaire. Improved transport connections and logistics further facilitated this development.
- The growth in population is for a large part based on migration, in 2021 less than 40% of the population was born on Bonaire, the other part was born on one of the other islands of the Antillean, in the Americas or European Netherlands (CBS[8]). With overseas immigration other dietary preferences were introduced requiring other food items than those produced on Bonaire.
- As in other parts of the world, the average income level of Bonaire's population increased resulting in changed dietary preferences requiring food that was or could not be produced locally.
- A growing tourist sector contributed to the demand for other food items which were not part of the traditional diet and produced locally.

These developments resulted in a higher food demand and a demand for a more diversified food supply beyond what the traditional agricultural system on Bonaire could offer.

2.2 Other food system characteristics

Market channels
There are a limited number of food retailers on Bonaire, with one supermarket group covering the largest part of the market (Osepa & Baaziz, 2014). Other important channels are restaurants and hotels (Lotz et al., 2020). Some wet markets also sell fruits and vegetables.

Waste and recycling
Household waste is currently not collected separately on Bonaire, yet some food waste of hotels and restaurants is used as feed for pigs held by some people. In addition, sewage from the central sewage system and wastewater from sceptic tanks or cesspits is collected for treatment (Briene et al., 2019). The treated, nutrient-rich water is suitable for irrigation, and the sewage sludge can also be used as fertilizer[9].

[6] http://web.archive.org/web/20061001151043/http://www.central-bureau-of-statistics.an/census.asp [visited June 27, 2023].
[7] https://www.cbs.nl/nl-nl/cijfers/detail/84712NED [visited June 27, 2023].
[8] https://longreads.cbs.nl/ticn2021/bonaire/ [visited June 28, 2023].
[9] https://www.webbonaire.com/wastewater/?lang=en [visited June 30, 2023].

Agriculture, Livestock and Fisheries service

As part of the overall island strategy to develop Bonaire sustainably while protecting local culture and nature also a related policy strategy for agriculture, livestock and fisheries has been developed (Openbaar Lichaam Bonaire, 2014). Ambitions concerning agriculture and livestock production are self-sufficiency with respect to fresh vegetables and fruit within ecological boundaries and sufficient production of animal feed to enable ecologically and economically sustainable livestock production within dedicated agricultural areas. The agriculture, livestock and fisheries service on the island, in Dutch abbreviated as LVV which stands for *Landbouw, Veeteelt and Visserij,* is coordinating and implementing the policy for agriculture, livestock and fisheries. The LVV terrain has an office and 50 ha land available to support agricultural initiatives and providing services such as insemination services for goats. The LVV terrain has access to part of the treated wastewater from the Water and Energy & Energy company of Bonaire (WEB), 50 m^3 per day (see also Section 3.3). The LVV also acts as knowledge centre for agriculture, livestock and fisheries and supports other agricultural initiatives on the island.

Agricultural inputs

Basically, all agricultural inputs are imported from outside the island from feed concentrates for aquaculture and poultry, pesticides, vegetable seeds to hay for feeding of goats. Imported inputs are from the USA, the Netherlands but also from nearby Venezuela where most of the hay comes from. Inputs are provided on the island by the Kriabon cooperative, especially livestock feed. Once a month Kriabon organizes a market where local agricultural products are sold.

Finance

Although various financial institutions have bank offices on Bonaire, access to agricultural credit, loans and subsidies is limited according to the interviewed stakeholders. This may be related to the status of Bonaire as a special Dutch municipality: The island uses the US dollar as local currency, and because Bonaire is part of the Netherlands it is not eligible for various programs, for example, from the Netherlands Enterprise Agency to stimulate agriculture or agricultural entrepreneurship in international markets.

Environmental impacts

Little information is available about the environmental impacts of the food system of Bonaire. For example, no complete information on greenhouse gas emissions is available for the Dutch Caribbean (Briene et al., 2019). The environmental impacts of agricultural production may be limited because of the overall limited agricultural production. A prevailing problem are free roaming goats, which pose a threat to natural vegetation and coral reefs (Roberts et al., 2017), because their grazing causes soil erosion and sedimentation brings nitrogen to the reef (Openbaar Lichaam Bonaire, 2014). Apart from environmental impacts of agricultural production on the island, most environmental impact is expected to be related to imports from food such as GHG emissions associated with production and transport.

3 Biophysical production conditions

3.1 Climate conditions

Rainfall data from two sources with different temporal resolutions (daily and hourly) have been used to analyse the long-term annual rainfall trend and monthly rainfall distribution at Bonaire. See Annex 1 for the details of the data sources, data handling and how missing data have been dealt with.

The long-term average annual rainfall is 462 mm per year varying between nearly 1100 mm (in 1988) and as low as 200 mm (in 1997 and 1998). Overall, the rainfall trend is positive between 1980 and 2022, but most likely not significant and may be related to the higher number of missing data in the older data sets (Figure 6 in Annex 1). The rainfall trend is different from (Verweij et al., 2022) who looked at the trend till 2009 and included years with > 10% of the daily rainfall data missing.

We do not have information on the spatial variation in rainfall, but (De Freitas et al., 2005) reported rainfall ranging between 217 and 527 mm in 1998 based on four (unknown) locations on the island.

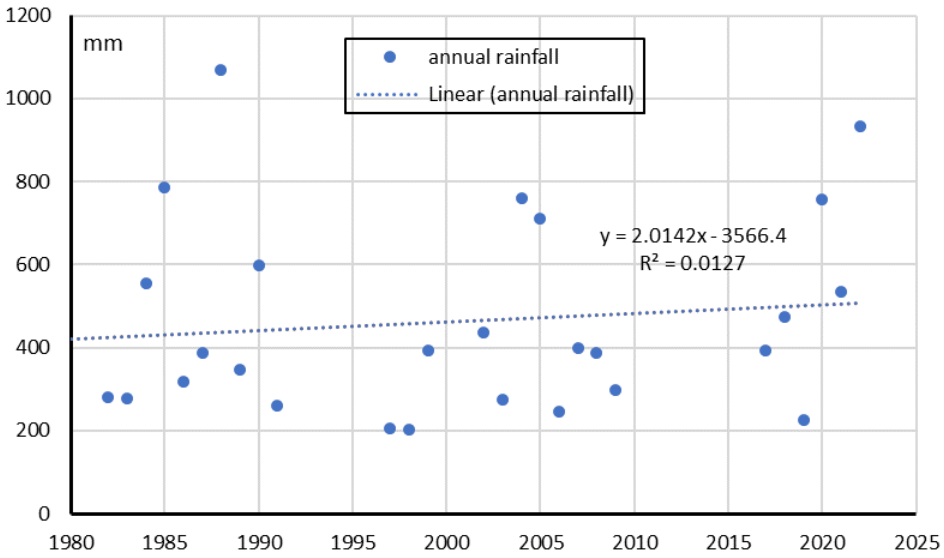

Figure 1 *Annual rainfall at Bonaire (1980-2022). See text and Annex 1 for details. Sources: Kralendijk airport and KNMI.*

Figure 2 shows the long-term monthly rainfall distribution of Bonaire. The wettest period of the year is from October to January, when on average 294 mm precipitates, which is 64% of the annual rainfall. In the remaining part of the year rainfall is less than 40 mm per month.

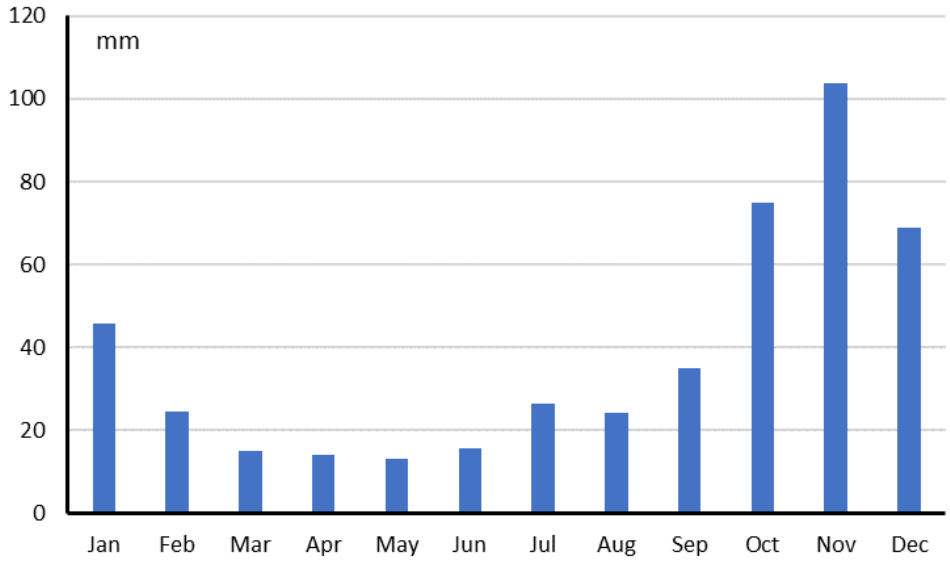

Figure 2 *Long-term monthly distribution of rainfall at Bonaire.*
Sources: Kralendijk airport and KNMI.

Figure 3 shows the average daily minimum and maximum temperatures at Bonaire from 1980 to 2009. Towards the end of this period daily maximum temperatures were > 30°C and minimum temperatures ≈ 26°C. Especially the daily maximum temperatures have increased from 1980 to 2009, much more than the daily minimum temperatures.

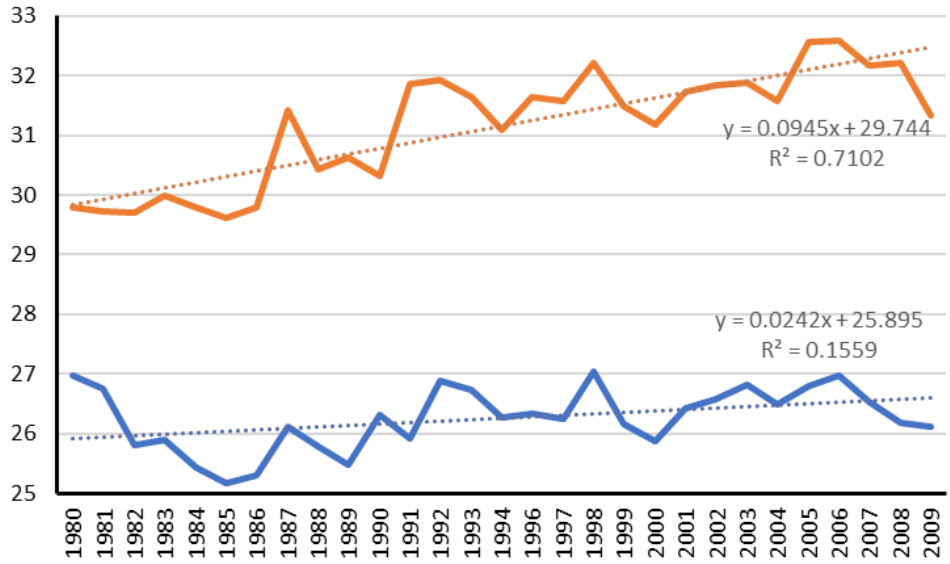

Figure 3 *Average daily minimum and maximum temperatures at Bonaire (1980-2009).*
Source: Kralendijk airport.

3.2 Soil and terrain resources

The map shown in Figure 4, based on a survey in the period from 1956 to 1967, gives a first impression of the suitability of land for agricultural production. The majority of the island consists of eroded land with rocks and stones, especially in the eastern part of the island. This land is less suitable for agriculture.

The area around Rincon consists of shallow and very shallow loamy soils, and partly clayey, partly sandy-loamy, cherty topsoil. The area is surrounded by hilly land. Rincon is the catchment area of the surrounding elevated land and water drains into the reservoir *Boka Onima* before it enters the Caribbean Sea.

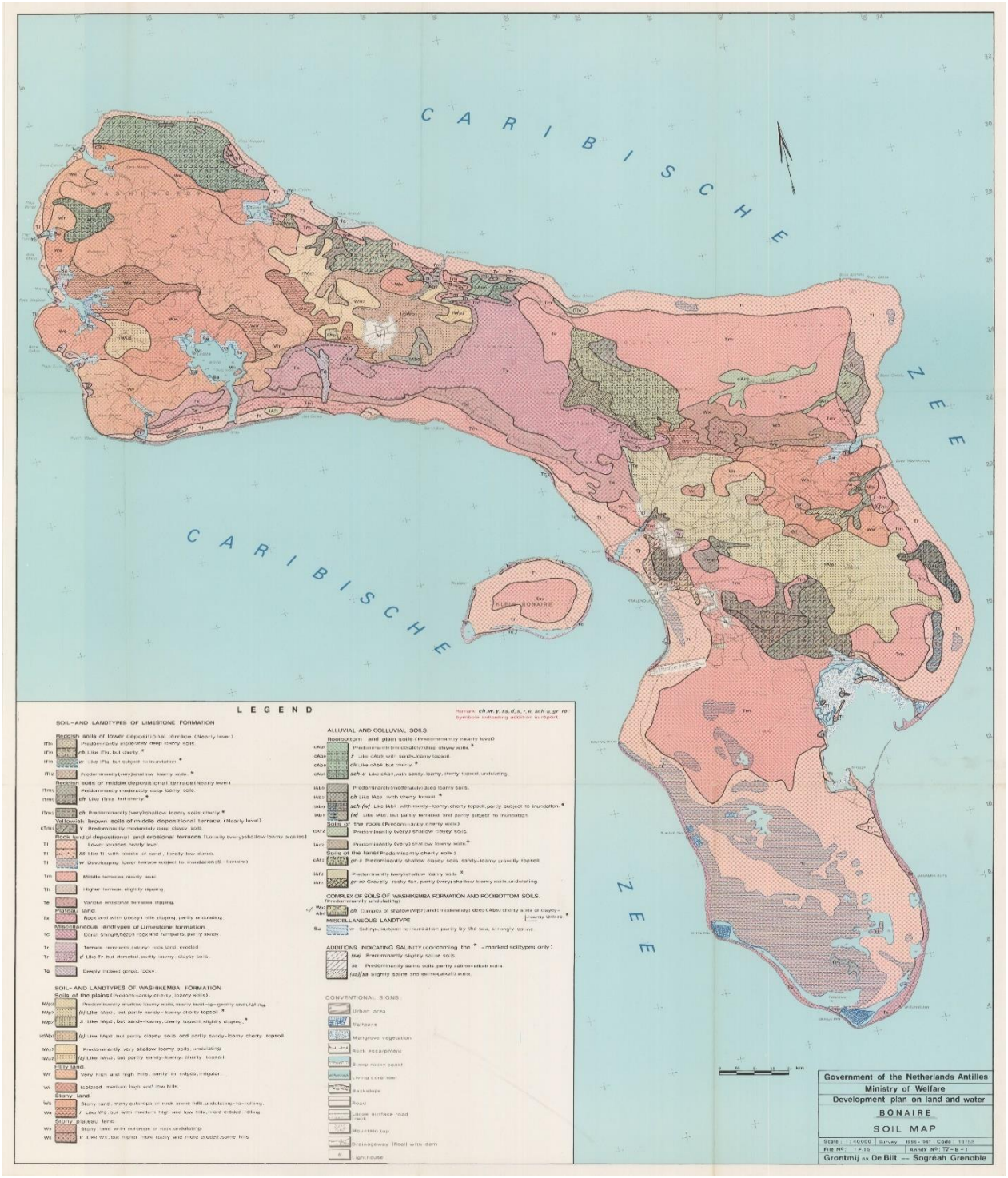

Figure 4 *Soil map of Bonaire.*
Source: Grontmij (1967)[10].

Gewald et al. (1971) estimated the land suitability for agricultural production on Bonaire. The used methodology and data are not very clear and do not disclose, for example, whether the suitability classification also considered the freshwater availability for estimating the area suitable for irrigated crop

[10] https://www.dcbd.nl/document/historical-soil-map-bonaire [visited August 23, 2023].

production. Apart from not being able to fully appreciate the results as the methods and data are unknown, the situation on Bonaire has changed considerably in the last 50 years. Urbanisation has increased but also crop production systems have become available that depend less on soil and terrain characteristics such a protected systems (drip irrigation systems, hydroponics, etc.). The results do highlight the intrinsic unfavourable production conditions for soil-based agriculture, especially for crop production. Only 406 ha is considered suitable for irrigated crop production and about 3,000 ha for rainfed crop production, in total about 11.7% of the island. Most of the land (63.5%) is not considered suitable for crop production nor livestock grazing (Table 1).

Table 1 *Classification of soil suitability.*

Suitable for:	Soil depth (cm)	Slope (%)	Salinity	Area (ha)	% (of total)
Irrigated crop production	> 40-50	< 3	Not saline	406	1.4
Rainfed crop production	> 20-30	< 8	Not saline	2,774	9.9
Grazing land	> 20-30	< 12	Alkali	1,720	6.1
Limited grazing / forestry	> 20-30	< 20	Not saline	3,103	11.0
Combination crop and grazing	> 20-30	< 20	Not saline	110	0.4
Not suitable for crops & grazing	Shallow	Steep	Sometimes saline	17,811	63.5
Limited suitability for grazing	Shallow	Steep	Sometimes saline	1,720	6.1
Roads and urban areas					1.6
Total				28,100	100

Source: Gewald et al. (1971).

3.3 Water resources and water resources management

Figure 5 illustrates the components of the islands' hydrology from an agricultural point of view.

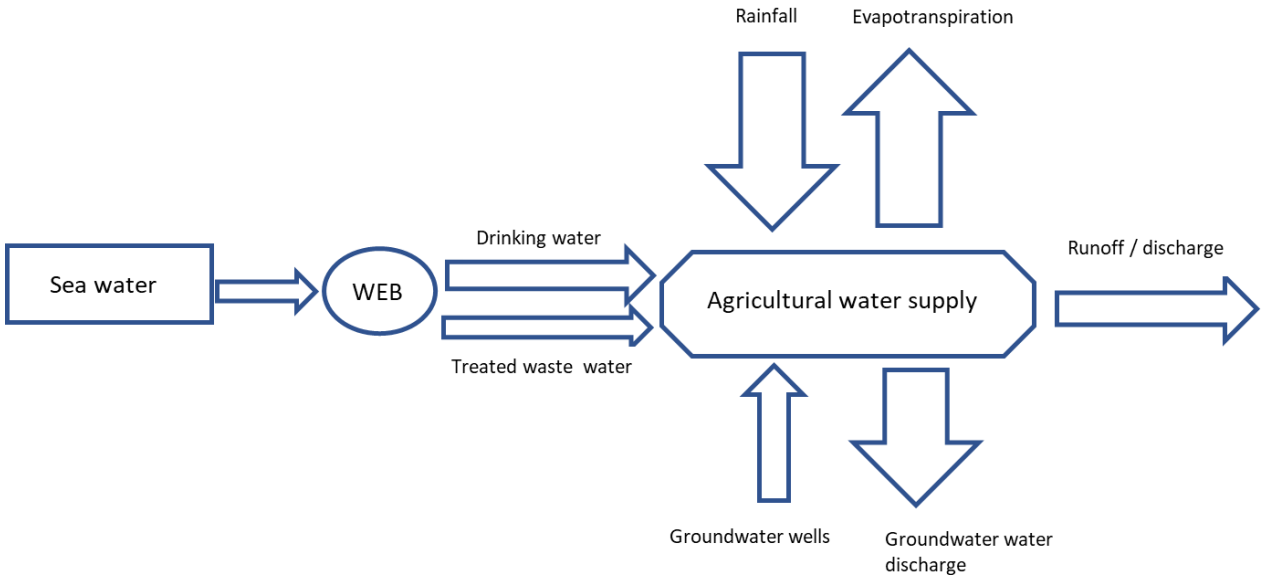

Figure 5 *Simplified water cycle of Bonaire.*

Water availability for agriculture is determined by various inflows and outflows of water.

The **water inflows** are:

- Rainfall: As described in Section 3.1, the annual rainfall is about 462 mm per year. Based on Bonaire's land area of 288 km^2 a volume of about 133 million m^3 rainwater precipitates annually on the island. However, annual rainfall is highly erratic (Figure 1) and unevenly distributed over the year (Figure 2).
- Drinking water: The Water and Energy & Energy company of Bonaire (WEB) produces drinking water from sea water using reverse osmosis. In 2021, 2.1 million m^3 drinking water was produced (WEB, 2022). Although this water is expensive to produce, drinking water is being used by agriculture as it is a reliable source with a guaranteed quality.
- Treated wastewater: WEB is also responsible for wastewater treatment, and since 2014 WEB offers through a biological sanitation process treated wastewater as irrigation water. In 2021, about 0.28 million m^3 treated wastewater was produced (WEB, 2022). The LVV has access to about 18,250 m^3 per year, about 7% of the total available treated wastewater on the island.
- Ground water wells: Some of the rainwater will recharge the groundwater, which can be abstracted for agriculture. However, saltwater intrusion is widespread on Bonaire because of the small size of the island. In wells, a lens of fresh groundwater will float above the denser saltwater groundwater. Bonaire contains an unknown number of groundwater wells of which several are used to provide drinking water to goats and other animals. Especially during the dry season when freshwater is being extracted from these wells, the lens of freshwater decreases, and the abstracted water from the wells is becoming increasingly saltier. The total amount of water extracted from these wells is unknown, as part of the water is extracted illegally, but most likely limited while its quality limits the use for crop production.

The **water outflows** are:

- Evapotranspiration: Most of the rainfall on Bonaire will evaporate and transpire. The actual evapotranspiration (ETa) is difficult to quantify as it depends on factors such as crop characteristics, atmospheric conditions and the soil water holding capacity. The climate data from Kralendijk airport (1980-2009) also provide information on the daily reference evapotranspiration (ETref), which represents the evapotranspiration rate from a hypothetical grass reference with specific characteristics and not short of water (Allen et al., 1998). Hence, ETref assumes no water limitation and is only based on meteorological data only, including temperature, humidity, wind speed, and solar radiation. Therefore, ETa is always less than ETref. In the rainy season (October-January), the long-term average ETref was 5.8 mm per day. Total ETref in the rainy season is approximately 696 mm (= 5.8 mm * 120 days), which is much more that the total rainfall during an average wet season, 294 mm (Section 3.1).
- Discharge to the ground water: Recharge of groundwater resources only happens when soils are saturated. Under the low rainfall conditions of Bonaire recharge of groundwater resources will be limited especially in dry years.
- Runoff: surface runoff happens when soils are saturated and during heavy showers when soil water infiltration rate is too low, and rainwater runs off over the soil surface. In addition, the slope of the terrain and vegetation matter: a hillier landscape, the higher the surface runoff; less vegetation means less rainfall interception and more runoff. (Gewald et al., 1971) estimate that on average about 11% of the total annual rainfall is lost as runoff, with somewhat higher runoff (up to 18%) in wet years and lower runoff in dry years (3%). This would mean that on average 14.6 million m3 (= 11% * 133 million m^3) is lost as surface runoff.

4 Production systems

In this Chapter we describe the current agricultural production systems on Bonaire. We have grouped them into broad categories according to capital and scalability, i.e., the ability to adapt and expand to meet changing food demands and accommodate growth.

4.1 Capital-intensive plant-based production

4.1.1 Protected cultivation using aquaponics

Currently, there is one aquaponics system on Bonaire, i.e., Bonaire Daily Fresh, an integrated system that combines aquaculture (fish farming) and hydroponics (soil-less crop cultivation). The system produces about 100,000 pieces of leafy vegetables annually, of which about 75% is lettuce (four varieties) and the rest is spinach and paksoi. In addition, it produces 4,000 fish (Tilapia) per year. Experiments with producing herbs are currently being conducted. Production is based on biological principles, i.e., without the use of chemical pesticides. Because of the required water quality for fish production used water in the system is based on reversed osmosis.

Strengths:
- The system is largely independent of environmental factors as it is a closed system.
- High water use efficiency.
- Year-round production.

Weaknesses:
- Price of products is relatively high.
- High dependency on imported inputs (seed, nutrients, fish concentrate, etc.).
- Much capital is required to start the system.
- High energy input because water needs to be cooled for the fish production.
- Much knowledge is required.
- High maintenance costs of materials because of corrosion.
- No organic certification of vegetables possible, but organic practices for growing the vegetables are needed otherwise the fish will not survive.

Opportunities:
- High import prices of competing products counter relatively high product price.
- Sufficient market potential.
- Once operational easy to scale up because little land is needed, and inputs are imported.

Threats:
- Leavy vegetables are not part of the local diet. Challenge to produce other vegetables in aquaponics.
- Dependency on imported inputs.
- Pests and diseases.
- High turnover of staff.

4.1.2 Protected cultivation using substrate

Currently one farmer practices substrate-cultivation on a commercial scale, Bon Tera. The farmer produces under nets on about 0.5 ha and uses coconut-fiber substrate, but also produces some crops in the soil. Crops produced are tropical spinach, some varieties of lettuce, herbs (mint and basil), cucumbers, snack-cucumbers, asparagus bean, microgreens, and watermelons. The annual production is about 12 t of common and snack cucumbers, 4 t of spinach, 0.5 t of different varieties of lettuces, 2 t of melons, 1.2 t asparagus bean next to about 1 t of herbs. About 300 m^3 tap-water is used per month. The farm has five employees.

Strengths:
- Production is commercially viable.
- Pioneering stage in which many crops have been tested is over and suitable crops have been selected for which there is market demand.

Weaknesses:
- High dependency on imported inputs (fertiliser, pesticides, and other inputs).
- Only a limited number of crops are technically feasible. One reason is the high night temperature, hampering the pollination of fruit vegetables and, thus, the production of fruits.
- Considerable capital is required to start the system.
- No use of biological control because import of natural enemies including micro-organisms is not allowed.

Opportunities:
- Market demand for currently produced crops is not yet satisfied.
- Local production and associated lower carbon-footprint may be used as marketing instrument in the future.
- Cooling of irrigation water would improve production.

Threats:
- Dependency on expensive imported production inputs.
- Uncertainty about the price of tap water.

4.2 Small-scale plant-based production

Small-scale plant-based production is practiced, though at limited scale, in several forms in Bonaire. Usually, it consists of a mix of perennials and annual crops, in some cases under nets. There is a range of different systems that would fall under this type of system. Here the systems are distinguished based on the setting in which they occur.

4.2.1 Home-garden setting

Production around homes with often a mix of annual crops and perennials occur in Bonaire, sometimes including animals. Production is often directed at home consumption, with any surplus being given to friends and relatives, sold on local markets or grocery stores. The water source for this production may be from wells, rooftop-harvested rainwater but can also be supplied by tap water that is delivered by truck. Actual supply to the crops is commonly done through drip irrigation systems.

Strengths:
- Home production gives home growers control over what they eat.
- Social gains: increased self-esteem if home grower manages to produce own food and can share with friends or sell.

Weaknesses:
- Expensive as it requires costly irrigation infrastructure, i.e., water storage, drip irrigation system, netting and other inputs.
- Not all households have suitable (land) space around the house for home gardening.
- As home gardening requires daily attention, this system is less suitable for the *kunukus* because most people do not live permanently there.
- Requires a lot of knowledge and time, while many people have already several jobs limiting the available time to learn and work in the home garden.
- Home growers lack a network for knowledge and advice in case of questions and setbacks.

Opportunities:
- Reuse of rainwater from house roofs.
- In *kunukus* setting, home gardens may provide an incentive to rebuild dams that on the one hand protect low lying areas against floods and on the other hand provide the irrigation water needed for home gardens.
- Improved availability of healthy food at household level.
- Possibility for households to try out new fruits and vegetables.
- Over-production may be used to sell (earn income) or give away to friends and relatives strengthening social ties.

Threats:
- Pests and diseases, birds, lizards and rats.
- Risk of pesticides misuse.
- When home growers are insufficiently supported with advice and knowledge, they can easily become disappointed in case of crop failure and abandon the system.

4.2.2 Community-garden setting

There are a few settings on Bonaire that may be regarded as a community-garden setting. Recently, a pilot has been implemented on the LVV-terrain (Van De Velde, 2022), while there are opportunities for starting a pilot on the terrain of *Mangazina di Rei* in Rincon, which now hosts a small syntropics[11] plot that is being maintained by the NGO since November 2022. The community garden has much in common with the home garden setting, but it is a group of people that cultivates and manages crops together on the same land, or a group that works on the same land that is divided into individual plots. In contrast, the home garden setting is an individual household effort, but many of the SWOTs have similarities.

Strengths:
- Growers have control over what they eat.
- Shared infrastructure allows to have more economies of scale (compared to home-garden setting).
- Working in a social network allows to share and overcome problems jointly and cherish successes together.

Weaknesses:
- Participants may have different ambitions ranging from setting up a business to socialising, which may result in tensions related to the implementation among the community participants (Van De Velde, 2022).
- Related to the previous point, participation requires knowledge and more coordination time compared to home-garden setting, while many people on Bonaire have several jobs limiting the available time to learn and work in a community garden (Van De Velde, 2022).
- Growers lack a network for knowledge and advice in case of questions and setbacks.
- Because community gardens require space, it may not be possible to organise them near living areas. Instead, they may need to be located more remote with less possibilities to monitor and control the garden, introducing all kinds of practical issues ranging from the risk of theft, risk of animals feeding on the crops, to the travel time of participants' homesteads to the community-garden (Van De Velde, 2022).

[11] No widely accepted definition of syntropic farming exists but it can be best described as a set of principles and practices to integrate food crops with the natural conservation of perennial crops and the production of biomass for soil cover (Andrade et al., 2020).

Opportunities:
- Strengthening social ties in the community.
- Improved availability of healthy food at household level.
- Possibility for households to try out new fruits and vegetables.
- Over-production may be used to sell (earn income) or give away to friends and relatives strengthening social ties.

Threats:
- Requires joint ownership and leadership; if lacking risks of failure are large (Van De Velde, 2022).
- Pests and diseases, birds, lizards and rats.
- Risk of pesticides misuse.
- When community growers are insufficiently supported with advice and knowledge, they can easily become disappointed in case of crop failure and abandon the system.

4.2.3 *Kunukus* systems

Kunukus, the traditional private estates on Bonaire, are currently mainly used as leisure retreat, but limited production does still take place. In Rincon, there are about 30, generally retired, farmers that to some extent produce on their *kunukus* plot. Sorghum-production during the rainy season, and keeping goats are the main activities. Traditional practices in the form of flood-retreat cultivation around artificially constructed dam-systems, and "three sisters" cultivation (growing corn, beans and squash together) disappeared. No exact yield figures were obtained, but narratives of regular failed harvests of rainfed production prevail.

Strengths:
- Low costs, i.e., the cultivation depends on prevailing rainfall and only in few cases on expensive irrigation.

Weaknesses:
- High risk for crop failure because of high rainfall variability among the years.
- Scarcity of machinery to till and manage the land.
- Water access is usually only through trucks, which is costly and still requires investments in infrastructure.

Opportunities:
- Many *kunukus* are currently underutilized.
- Revitalizing the *kunukus* system may provide an incentive to rebuild dams that on the one hand protect low lying areas against floods and on the other hand provide the irrigation water for production on the *kunukus*.

Threats:
- Alternative use of *kunukus* for leisure and tourism.
- Loss of traditional agricultural knowledge by new generations.

4.3 Livestock production

4.3.1 Goat production

Through the ages, livestock production has fluctuated with the feed availability on Bonaire which was determined by the amount of rainfall (Hartog, 1957). Currently about 200 livestock owners raise goats and sheep that feed in the *kunukus* and public areas, including the National Park Washington Slagbaai (Openbaar Lichaam Bonaire, 2014). There are plans to intensify goat production using stable feeding methods on the LVV compound. Köster (2017) showed that it is technically feasible to produce large amounts of elephant grass under irrigated conditions. The in 2015 estimated number of goats on Bonaire is 32,500 (95% confidence interval: 19,800-52,600) of which 62% graze in a closed *kunukus* (Lagerveld et al., 2014). The annual number of goats slaughtered in the slaughterhouse lies around 1500 (Lotz et al., 2020; Openbaar Lichaam Bonaire, 2014).

Strengths:
- Raising goats and sheep requires little labour and can be done part-time.

Weaknesses:
- Free ranging cattle damages the natural vegetation.
- Dependency on expensive imported concentrates, hay and other roughages.
- Ownership of free ranging small ruminants is not always clear.

Opportunities:
- Production intensification using stable feeding.

Threats:
- Locally produced roughages to feed animals during the dry season is scarce.
- Economic viability of locally produced hay using irrigation water uncertain.

4.3.2 Chicken production

Two chicken farms are active on Bonaire, one of which is in Rincon. The farms produce sufficient eggs for the demand on the island (Lotz et al., 2020; Openbaar Lichaam Bonaire, 2014).

Strengths:
- Egg demand of island is fulfilled.

Weaknesses:
- Production is dependent on feed import.

Opportunities:
- Chicken manure can be used as fertiliser to produce crops but is currently discarded.
- Currently, research is being conducted on the possibilities to grow black-soldier fly larvae as a source of feed.

4.3.3 Pig production

Five to six small enterprises raise pigs on Bonaire. They partly use swill from hotels and restaurants as pig feed. The annual number of pigs slaughtered lies between 100 and 200 (Lotz et al., 2020; Openbaar Lichaam Bonaire, 2014).

Strengths:
- Upgrade swill as feed.

Weaknesses:
- Dependent on imported feed.

Opportunities:
- Separated waste collection increases the availability of swill for feed.

5 Fruit and vegetable demand in context

Because of the high prevalence of obesity, the low portion of vegetables and fruits in diets and the high prices for fruits and vegetables on Bonaire, the focus in this section is to put the possibilities of fruit and vegetable production in Bonaire in context. A focus on fruits and vegetables is in line with island's strategy to become self-sufficient in fruits and vegetables (Openbaar Lichaam Bonaire, 2014).

Current intake of fruits and vegetables on Bonaire is lower than international recommendations for a healthy diet. Precise numbers of fruit and vegetable intake are not available, but intake has been estimated at 100 g per capita per day (Van Der Geest & Slijkerman, 2019). This is much lower than in the rest of the Netherlands which consumes on average 165 g vegetables per capita per day and 130 g fruits per capita per day (RIVM[12]), while the national consumption guideline is to eat daily 200 g of fruits and 200 g of vegetables, which is in line with the guideline to eat daily 400 g fruits and vegetables by the World Health Organisation (WHO[13]).

Currently, less than 5% of the current intake of fruits and vegetables is estimated to be commercially produced on Bonaire. This estimate is based on the production of the two main commercial vegetable enterprises on Bonaire, which together produce about 45 t per year, and assuming that the remaining non-commercial fruit and vegetable production on the island is only a fraction of this. The two commercial enterprises do not solely supply the local population as they also deliver to the catering industry for tourists. Therefore, the commercial production of fruits and vegetables produced on Bonaire is expected to be less than 5% of the estimated current total fruit and vegetable intake of 879 ton per year (Table 2), based on the estimated per capita consumption and a population of 24,090 (Section 2.1).

An important biophysical limitation for increasing especially the amount of fruit vegetables is the high daytime and night-time temperatures, affecting pollination and fruit setting negatively under such conditions (e.g., Abdalla & Verkerk, 1968; Rudich et al., 1977). This means that it may be difficult to produce such vegetables economically on Bonaire. Estimates suggest that between 25 and 40% of the current annual fruit and vegetable consumption (879 ton, see before) can be produced locally (Van Der Geest & Slijkerman, 2019). This would mean that an annual production is needed between 220 and 352 t per year to meet current intake levels (Table 2). This means a year-round supply between 602 and 963 kg on daily basis.

Table 2 gives an impression of the land and water requirements to produce fruits and vegetables under different consumption scenarios ranging from a situation in which 25% of the current intake of fruits and vegetables is produced on the island to a situation in which sufficient fruits and vegetables are produced to provide a healthy intake for Bonaire's population (400 g/capita/day). Both scenarios represent two extremes: The first scenario represents the minimum land and water requirements to substitute 25% of the current fruit and vegetable import, and the second scenario the theoretical upper limit of land and water needed to make Bonaire self-sufficient in fruit and vegetable production needed to provide a healthy intake of fruits and vegetables for all. The estimated land and water requirements in the scenarios indicate orders of magnitude, and allow to compare scenarios but should not be interpreted as future predictions.

Using two production estimates, 10 and 40 t/ha/year, the required area for producing sufficient vegetables for a healthy diet would be lower than the area considered suitable for irrigated crop production (406 ha, Table 1). Even using the most pessimistic case, the low production estimate of 10 t/ha/year and ignoring the temporal availability of fruits and vegetables throughout the year, 352 ha would be sufficient to provide sufficient fruits and vegetables supply needed for a healthy diet of the entire population. To produce 25% of the current intake and using the optimistic production situation, 40 t/ha/year, only less than 6 ha of fruit and vegetable production would be needed.

[12] https://www.wateetnederland.nl/ [visited June 28, 2023].
[13] https://www.who.int/news-room/fact-sheets/detail/healthy-diet [visited June 28, 2023].

Minimum and maximum water requirements are based on conservative water use efficiencies for tomato production under open field conditions and greenhouse conditions, i.e., 0.5 and 0.1 m^3/kg, respectively (Nederhoff & Stanghellini, 2010). On Bonaire, to create greenhouse conditions allowing to realize such water efficient vegetable systems may be difficult in practice as it will require extensive greenhouse cooling. Therefore, the minimum water use efficiency should be considered as a theoretical lower limit. It is further noted that water use efficiencies among vegetables may differ depending on the harvest index, dry matter content, and whether they belong to C3 and C4 crop species[14], with the latter having more favourable water use efficiencies (Stanghellini, 2014). Some of these traits may counteract each other, for example, a C4 crop with a low harvest index may perform the same in terms of water use efficiency as a C3 crop with high harvest index. It is beyond the scope of this report to detail the water use efficiencies of all possible fruits and vegetables that can be grown on Bonaire. Rather we use the water use efficiency of tomato as an indicator to illustrate the order of magnitude of water consumption and its variation for different vegetable and fruit consumption scenarios and crop management practices (open field and greenhouse conditions).

Table 2 *Water and land requirements for different fruit and vegetable consumption scenarios based on Bonaire's population of 24,090.*

	Fruit/vegetable per capita per day (g)	Required Fruit/vegetable production per year (ton)	Required area with high yield estimate [a] (ha)	Required area with low yield estimate [b] (ha)	Minimum water requirements [c] (m3/year)	Maximum water requirements [d] (m3/year)
25% current consumption	25	220	5.5	22.0	22,000	110,000
40% current consumption	40	352	8.8	35.2	35,200	176,000
current consumption	100	879	22.0	87.9	87,900	439,500
Dutch diet	295	2594	64.8	259.4	259,400	1,297,000
healthy diet	400	3517	87.9	351.7	351,700	1,758,500

[a] Assumed 40 ton/ha/year; [b] Assumed 10 ton/ha/year; [c] Assumed water use efficiency of 0.1 m^3/kg; [d] Assumed water use efficiency of 0.5 m^3/kg.

The water demand in the different scenarios can be compared with the current treated wastewater production (0.28 million m^3), the current drinking water production (2.1 million m^3) and the annual rainfall on Bonaire (133 million m^3). This shows that the water required for producing 25-40% of vegetables and fruits would consume 8-63% of current treated wastewater production and 1-8% of current drinking water production. It is emphasized that only 18,250 m^3 treated wastewater is currently available at the LVV terrain for agricultural purposes and that the two commercial vegetable production systems on Bonaire use drinking water to irrigate their vegetables, partly because of quality concerns about the wastewater. Even if this concern can be taken away, the currently available amount of treated wastewater is insufficient to produce 25% of the current fruits and vegetable intake. The annual rainfall provides a larger theoretical potential but would require large investments to store enormous water volumes to get through the dry months.

The numbers in Table 2 show the indicative range of land and water requirements needed for different consumption scenarios and technologies (resource use efficiencies). Land seems less restrictive, even for producing a healthy diet (400 g fruits and vegetables/cap/day) sufficient land is available. Water availability becomes quite rapidly restrictive given the current small amounts of treated wastewater available for agriculture. The share of fruits and vegetables that can be produced locally on Bonaire could be increased, but the potential is expected to be limited.

Finally, these calculations give lower thresholds of land and water requirements for different situations because the consumption of fruits and vegetables by tourists, almost 175,000 airline passengers in 2022 (CBS[15]), is difficult to estimate and not included.

[14] C3 and C4 refer to different pathways of photosyntheses that exist in nature and affect the water use efficiency of plants.
[15] https://opendata.cbs.nl/#/CBS/nl/dataset/83104NED/table [visited June 28, 2023].

6 Discussion

Bonaire has a harsh production environment with on average low and highly fluctuating annual rainfall which is concentrated in a limited period of the year. The high daily temperatures and strong winds fuel crop evapotranspiration. Therefore, both commercial vegetable farms on Bonaire use shade nets to reduce wind, lower temperature and avoid sunburn. In addition, pest and disease pressure is high, while various stakeholders mentioned the problem of rats, birds and lizards that feed on maturing fruits and vegetables. The combination of these factors makes agriculture complex and, as some stakeholders indicated, a frustrating and time-consuming activity. Despite these difficulties, a few entrepreneurs have managed to set up viable businesses, but this has required personal investments, perseverance and creativity.

Year-round supply of agricultural products is only possible with irrigation water, while ground and surface freshwater resources are scarce, and other water sources costly. Most of the ground water resources are to some extent saline. During the dry season salinity levels of ground water increase. Surface water availability is also scarce as the infrastructure to collect runoff in basins is absent or degraded. The drinking water supply on Bonaire is based on reversed osmosis, a capital-intensive process making this water too expensive for most agricultural applications (starting from US$ 3.91 / m^3)[16]. Treated wastewater in Kralendijk is cheaper and currently available at US$ 1.50 / m^3. The current supply is 50 m^3/day but could potentially be scaled up to 150 m3/day. Due to the absence of wastewater transport infrastructure, application of treated wastewater is limited to the LVV terrain.

Because of these challenges in water availability, business environment and production circumstances, possibilities for plant production in Rincon seem limited currently. Without sufficient support to increase water availability and local agricultural knowledge and to create a suitable business environment, both capital-intensive and small-scale crop production are unlikely to lead to better availability of healthy food and employment opportunities in Rincon. With capital-intensive, commercial food and vegetable production systems such as developed by Bon Tera and Bonaire Daily Fresh, year-round production is possible for a range of (mainly leafy) vegetables and herbs. While such systems can improve the availability of fresh vegetables on Bonaire, product prices will remain relatively high as the costs of inputs are high. Most inputs need to be imported, which is costly, while the used irrigation water based on reverse osmosis is extremely expensive. Unless production costs such as water are subsidized product prices will not go down. In home-production or community-garden production, costly water resources are required as well, unless only seasonal production is performed during the rainy season. Even if sufficient rainwater is available, the harsh production environment requires knowledge, skills and dedication of the people involved. Output subsidies to lower product prices and to make fruits and vegetables more accessible for low-income groups on Bonaire seem less effective to stimulate agricultural development as current production is already not able to satisfy current demand.

Because of the challenges in creating economically viable initiatives that contribute to affordable production of local fruits and vegetables, support of serious creative initiatives that can increase the affordability of locally produced fruits and vegetables is warranted. Support may take different forms from subsidies on irrigation water, investments in water infrastructure (or rainwater-harvesting infrastructure), training/support in knowledge and skills to support in setting up businesses. The type of support will differ for the various target groups:

- **Entrepreneurs** (from Bonaire or from abroad):
  - Support in setting op business, especially the financing of agricultural activities appears difficult on Bonaire.
  - Input subsidies (e.g., water, personnel, imported inputs) if affordable fruit and vegetable production is the aim.

[16] https://www.webbonaire.com/tarieven-en-voorwaarden/ [visited August 18, 2023].

- **Community-garden production:**
  - Support for facilitators, who help communities to set up production systems.
  - Input subsidies (e.g., water, shade nets, tools).
- **Individual home production:**
  - Training (teaching what vegetable and fruit production entails in terms of dedication).
  - Input subsidies (e.g., water, fertilizer, shade nets, tools).

For all target groups, support in increasing the water availability would be helpful. Possibilities for increasing the water availability for agricultural production in and near Rincon include:

- **Decentralized rainwater harvesting**
  This option is expensive but could provide supplementary irrigation for home gardens and community gardens during the rainy season or to extend the growing period after the rainy season. The amount of water that can be harvested from roofs, roads, etc. and stored is small in relation to the crop water requirements during the dry season. Therefore, rainwater harvesting is no solution for crop cultivation during the dry season.
- **Upstream rainwater harvesting at catchment level**
  Upstream water-harvesting through the construction of dams and central reservoirs could contribute to reduced flood risks downstream, increased freshwater infiltration in the soils, and nature development. Its potential depends on location-specific condition such as soil and terrain characteristics and therefore, requires a feasibility study, that also considers the possible risk of increased water borne diseases in reservoirs and the reservoir capacity in relation to the needs for agriculture.
- **Centralized waste-water treatment at village level**
  Central waste-water treatment could contribute to improved hygiene in Rincon village, while the wastewater could be used for agricultural purposes as is now being done at the LVV terrain. Alternatively, wastewater could be transported from Kralendijk to Rincon with investments in infrastructure that would then be required. The willingness to use treated wastewater for agriculture should be determined, as there are prejudices regarding the use of this water.
- **Increased drinking water production and supply to agriculture under subsidies**
  Increasing drinking water production through upscaling the available reversed osmosis facilities can increase the water availability for irrigation in agriculture. This requires investments and this water is expensive, so without subsidizing the water supply to agricultural producers, this option will not reduce the production costs.

7 Conclusions

Increasing year-round fruit and vegetable production in Rincon, and Bonaire in general, is challenging, and may not be possible without support. The main challenges include water availability, business environment and production circumstances (biotic and abiotic stresses). Without sufficient support to increase water availability and local agricultural knowledge and to create a suitable business environment, both capital-intensive and small-scale crop production are unlikely to lead to better availability of healthy food and employment opportunities in Rincon. Support may take the form of increasing the availability and affordability of water, which would be beneficial for several target groups. Additional support that would be required, may differ for entrepreneurs, community gardens and individual home-gardens.

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Annex 1 Annex Climate data

We have used two data sources, i.e., daily data from Kralendijk airport (1980-2009) and hourly data from the KNMI (2017-2022)[17]. The Kralendijk series contained data on radiation, minimum and maximum temperature, rainfall, humidity, wind speed and reference Evapotranspiration (ETref), which is a calculated climate characteristic. The KNMI series contained more climate data, but we only analyzed rainfall and temperature data. The hourly rainfall data from KNMI have been aggregated to daily values to allow comparison with the Kralendijk series. We also analyzed temperature data from KNMI using the minimum and maximum **hourly** temperature data of each day in the year to represent the **daily** minimum and maximum temperature. However, the analyses showed that this method resulted in suspicious low average daily minimum and maximum temperatures compared to the Kralendijk series. All KNMI average daily minimum and maximum temperatures were below the long-term average daily minimum and maximum temperature from the Kralendijk series. Reasons for the difference are unclear but may be related to the method to calculate daily minimum and maximum temperature, the moment of the day that minimum and maximum temperature are determined, differences in measurement instruments, etc. We did not further investigate these differences but decided to use only the rainfall data from the KNMI series.

The rainfall data series from KNMI was more complete than the Kralendijk rainfall data, which appeared to have quite some missing data. For both data sets we set a use criterion of < 10% daily rainfall values missing (Figure 6). This means that the rainfall data sets from 1980, 1981, 1992, 1993, 1994, 1995, 1996, 2000, and 2001 were not used in the rainfall analyses, i.e., out of the 36 available annual rainfall data sets 27 have been used. Many of them also missed data, but less than 10% of the total data. This may mean that the rainfall is underestimated, but missing data also happened in the dry season with little to no rainfall.

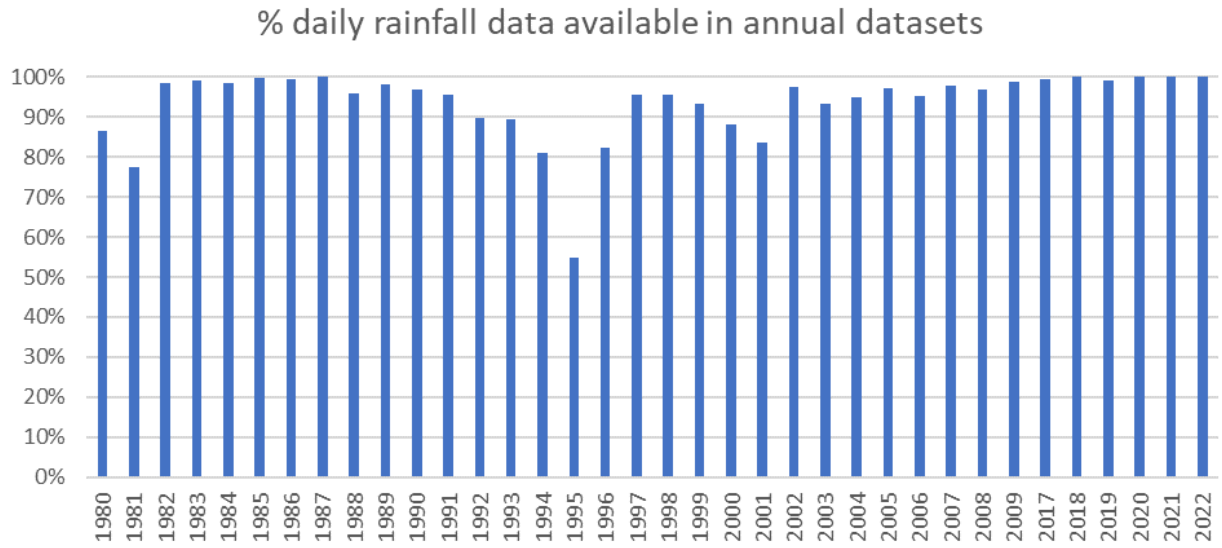

Figure 6 *Available daily rainfall data in annual data sets from Kralendijk airport and KNMI, see text for explanation.*

The temperature data (Kralendijk, 1980-2009) had less missing values than the rainfall data. In addition, missing temperature data are less important as the temperature is quite constant year-round. We used a criterion of < 20% missing values for data years to be included in the analysis. This implied that only 1995 dropped out because of too many missing value.

[17] https://www.knmi.nl/nederland-nu/klimatologie/uurgegevens_Caribisch_gebied [visited June 26, 2023].

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