

## Production optimization for sustainable agriculture and efficient contract farming in the Republic of Maldives

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### Abstract

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This research study is carried out to identify the efficiency of farms in crop production from three different regions of Maldives, which have started the contracting farming in 2021 to improve their sustainability and farm management. The research question concerns about crop efficiency evaluation, to identify how the production of crops can be distributed among 3 regions of Maldives to optimize farming under conditions of soil limits and climate changes. A total of 13 islands were visited and data from 700 farmers were collected. In addition to this, more than 1200 farmers were directly intervened to understand the nature of their farming and understanding the situation of agriculture in the Maldives. Atolls were divided into 3 major regions and data were analyzed using tool Solver built in the spreadsheet MS Excel. It shows that region 3 can reduce its input cost by 7%, and in region 2 by 43% by incorporating these criteria. It also suggests that following these criteria it would increase total farmers income by 59% about its initial value, thus enhancing Maldivian food security and improving welfare of the local farmers. The study reveals that different regions must focus on certain area related crops and should redistribute and relocate land area for specific crops to decrease production expenditures

*Keywords:* Contract farming; resource management; optimization model; regional agriculture

### Introduction

The Republic of Maldives is known as one, whose economy solely depends on Tourism and Fishing. In the last 5 years, economic growth has averaged 4.5% per year, mainly on account of mentioned sectors, but also supported by transport, communications, and construction (MoFA, 2019 & MPF, 2019). Continued growth, however, needs to be more inclusive and balanced. Agricultural sector being neglected and considered as the minimum contribution to the economic growth of the country is given less attention by the government and by the people of Maldives. However, farmers are actively doing agriculture on 582 hectares of land (MPF, 2019). According to the Ministry of Fisheries

and Agriculture (MoFA), 2018 report there are 8000 registered farmers and whereby the sector contributes, <5% to the national GDP (MoFA, 2019 & FAO, 2012). Farming has been and is prominent in the livelihoods of the rural population of Maldives. The agricultural small and medium sized enterprises (SMEs) play an important role in food and nutrition security, especially for those who are residing in the rural areas, creating job opportunities economic growth, and contributing to a stable social environment.

Local communities have long been practicing the traditional way of farming methods with a recent introduction of different types of chemicals, fertilizers, and pesticides to their farming methods. The agricultural production of crops such as yam, sweet potato, breadfruit, banana, cassa-

va, brinjal, watermelon, coconut, pumpkin, papaya, chillies, etc. provided nutrients and food supply to the communities. Other non-food items produced such as timber, betel leaf, and cordage provided as a means of building shelter and medicine. The surplus food they produced and things such as cordage were sold as a way of earning income (MoFA, 2019). However, the population has doubled over the past years, putting more demand for food and nutrition. As a result, the country shifted towards importing all the food products and depended on imported foods (UNDP, 2020). Farming local food products slowly diminished among communities depending completely on the imported food products. Being a country, whose economy is based on fishing and tourism, it drove the country towards an import-oriented country where the production decreased. This has placed the country in risky position as the country completely depends on another country for food security.

In the Maldives, given the limited economic base, it is important to invest and develop the agricultural sector for the sustainable development of the country. The country has attained its status as an upper middle-income country where 3.6% of the population is recorded as below the poverty line. A country that heavily depends on external imports it is highly vulnerable to external shocks such as natural disasters and global shocks. This was clear in the sudden outbreak of COVID-19 forcing to lock down borders. The poor economic growth was further worsened by the situation and the economic activity decreased by 1.4% in 2020 (MIRA, 2019). The tourism sector which was the main source of income for many households decreased by 28% leaving many jobless without any income. Food prices increased by 3% worsening the situation. At this point, many people picked up on farming activities to sustain their livelihoods. Especially among rural communities whose daily lives were adversely impacted by the COVID-19 situation, farming activities became as a means of earning a viable income as well as a source of food and nutrition (MIRA, 2019).

Despite all these challenges, some agriculturists are doing exceptionally very successfully in the country. According to Maldives Monetary Authority (MMA), market capitalization and growth, GDP from Agriculture in the Maldives increased to 3.87 MVR billion in 2020 from 3.63 MVR billion in 2019. This shows the size of the market and its potentiality (AgroNAT, 2020).

The newly elected government of Maldives in the year 2018 stipulated in the national strategic plan to develop and establish agriculture across the Maldives, to make it an economically viable industry which is also part of the government's "Blue Economy". To achieve this, the government established a 100% state owned company named Agro Na-

tional Corporation (AgroNAT) under Maldives Fund Management Corporation (MFMC) with an overall mandate to develop and assist local farmers in the development of reliable agriculture and reduce imports 17 types of crops (includes fruits and vegetables) by at least 50% by the end of the year 2023 (AgroNAT, 2020). AgroNAT is administered by the government budget and its programs are funded by Maldives Fund Management Corporation, UNDP Maldives, and other donor agencies. Under the contract farming business model AgroNAT provides financial and technical support to local farmers in the islands to cultivate selected crops and harvests that are bought and distributed to local market points, supermarkets, resort suppliers as well as directly to resorts close by the point of cultivation. AgroNAT recruited more than 1000 farmers from five regions of Maldives and among these recruited farmers 260 farmers are actively working as scheduled farmers by the end of the year 2021. Also, AgroNAT has acquired 4,758,000 sq. ft of agricultural land by the end of the year 2021. It is worth mentioning that the typical measure of land in the Republic of Maldives is sq. ft (square feet) because of a shortage of the agricultural area, where 1 sq. ft ~ 0.0929 square meters and 1 hectare ~ 107639 sq. ft. However, the annual report of AgroNAT shows that it is running below breakeven, with negative cash flow and negative profitability as stated in the financials (AgroNAT, 2020).

The major objective of this study is to identify the efficiency of farms in crop production from three different regions of Maldives, which have started the contracting farming in 2021 to improve their sustainability and farm management. The research novelty would derive from applying optimization modeling to crop efficiency evaluation and to clarify how the production of crops can be distributed among 3 regions of Maldives to optimize farming under conditions of soil limits and climate changes. The novelty of the created optimization model would contribute to identifying the perspectives of contracting farming as the business model for sustainable development of agriculture of Maldives.

## Literature Review

Sustainable agriculture includes adaptive measures taken to address the adverse effect of climate and enhance the resilience of the agricultural system. The Maldives is a country that has a thin water layer an average of 3 meters below the ground surface area near the coastal line at the equator. This puts the country's agriculture system at great risk. Studies show a temperature increase from 1.4–1.8 °C in 2030, 2.1–2.6 °C in 2050, and depletion of the water layer. This would greatly disadvantage the Maldivian smallholder farmers'

food production, food supplies, and food security of these communities (Aryal et al., 2020; Shafeega, 2020). Ahmed and Suphachalasai's 2014 research study on the climatic impact on the agriculture of the Asian countries estimated that the Maldives will experience a 9.9% of economic loss due to fast changing climatic conditions (Aryal et al., 2020).

Studies show that in the future, due to changes in climatic conditions there will be an increase in temperatures, fluctuation in rainfall periods, extreme flooding, and lengthening of the dry periods. These changes will have a devastating effect on the livelihoods of the Maldivian farming communities and the country. 80% of the land is above one-meter sea level and an increase in sea level will destroy the soil, increasing the salinity of the groundwater resource making it unfit for human use even before total inundation of these areas occurs (Shafeega, 2022).

Studies shows that 90% of atoll's population depend on rainwater as their main source of drinking water. In addition, Maldivian soil is made up of a thin sandy layer with a layer of organic matter 15-40cm deep, layer of hardpan 30-50cm deep before reaching unweathered bedrock. (MFAMR, 2006). Moreover, the urbanization of the rural islands is decreasing the land resource available for farming. There are cases where these farmers are largely impacted by adverse weather conditions such as heavy rainfalls washing away the thin nutrient layer of their farm soil (USAID, 2021).

According to Aryal et al. (2020) certain sustainability measures can be taken to address water depletion and soil erosion issues. This includes better soil management for retaining the soil freshwater layer and soil quality and practicing vegetation cover, contour plowing, and contour hedgerows in humid and coastal areas such as the Maldives. Growing leguminous plants for enriching soil nutrients and diversification of crops for reducing plant pathogens transfer are actions that could be taken to improve resilience to climate change. According to Benton et al. 2018 actions such as agroforestry and optimizations of the cropping system could be used as a means for sustainable land management (Aryal et al., 2020).

Abrupt changes in world climatic conditions pose a great threat to the Maldivian food security as the country depends on imports as their main source of staple foods and dairy production. According to the Ministry of Economic Development, 2015 Maldives' agricultural imports accounted for USD 183.3 million to meet the domestic as well as the tourism industry of the country (MoEE, 2006). No means of storing perishable crops and no frequent transport options available to take their production to the market's points are the major challenges smallholder farming communities which produce local fruits and vegetables are faced daily.

The height of the negative impact on the country's food security is immense. At the same time if sustainability measures are not taken at the very grassroots level its impact on soil, land, water, and the nutrient content of the farmland is huge. These are direct factors that impact the production yield. Factors such as the demographics of the farming communities and gender disparity also play a huge role in sustaining the farming communities (MoFA, 2019).

Smallholder farm communities mainly consist of women farmers who depend on their farm-based earnings as a main source of income and supporting their families. According to the MoFA, 2018 database, 54% of the registered farmers are rural women who work in the farmlands without proper farming equipment and knowledge (FAO, 2019). This not only results in the loss of the natural resource but in their health as well. These farmers have very poor knowledge of managing soil nutrients, and little knowledge of the correct application of fertilizer and chemicals (Gasith, 2018). Their actions and methods further deteriorate the condition of their farmlands. Moreover, one thing observed among the Maldivian farmers is that more than 80% of the farmers are above 40 years of age and practice farming with the knowledge passed on by their elders. Women farmers who are involved in farming are also being marginalized to menial jobs such as weeding, planting, and harvesting where men play the decision-making role (FOA, 2019; MoFA, 2019; MoEE, 2006).

For the sector to achieve sustainability women and men should be equally represented in farming. Farmers need to have proper knowledge and skills that will push the smallholder farming communities in achieving sustainability.

Contract farming is a new model of agriculture, that has been introduced into the Maldivian agriculture system in the year 2021 in the hope of pushing the agricultural system to new heights such as increasing local production, reduction of agricultural imports, moving farming from conventional farming to technology integrated climate smart farming and enhancing country's food security and nutrition (Bellemare, 2013). There is no research study or done on the impact of this model on the development of the agricultural system in the Maldives. This literature analysis is focused on Asian countries, as the Maldives belong to the Asian group of countries, and the socio-economic structure of the country is quite like the chosen Asian countries. This includes Sri Lanka, India, and Indonesia.

First, let's look at the concept of "contract farming". Contract farming is an agreement between AgroNAT and the farmer to provide farmers with the required support and in return, the farmer produces and sells to AgroNAT their products for a pre-agreed price. That is the contractor is required to provide the farmer with quality inputs and technical sup-

port required for the cultivation, sowing, and harvesting of crops. Farmer is expected to supply land and labor to produce, the quantum of produce based on required yield and contracted acreage (Shubhabrata, & Ramsundar, 2013).

Asian countries such as India, Sri Lanka, and Indonesia's agriculture comprises smallholder farming communities, and the policymakers of these countries, and the private sector is putting effort to speed up the development of agricultural value chains by introducing contract farming models in the agriculture (MIRA, 2019, MPF, 2019 & Bellemare, 2013). Neglected and greatly disadvantaged farming communities are being moved from low income earning farmers to high income earning households. New employment opportunities are being created and small holder farm productions are improved in terms of quality and access to local and international markets. As a whole introduction of contract, farming has propelled these small holder farming communities out of the poverty trap, to a more economically and socially sustainable community status than before (Bellemare, 2019).

Madhya Pradesh of India produced wheat and these farmers were not able to produce quality wheat and had no market access for their products. Though they had enough land and labor they lacked the technical expert knowledge, skills, and efficient tools and mechanisms to produce quality products to meet the market demands (Shubhabrata & Ramsundar, 2014). The Hindustan Lever Ltd (HLL), Rallis, and ICICI introduced the contract farming concept to this state of farmers. HLL acquired the raw materials produced by the Madhya Pradesh wheat farmers assuring guaranteed markets as well as supporting them with technical support and inputs supply. All the parties benefited from each other where the wheat farmers gained market access and the ability to produce quality products with higher production yields and the Rally and HLL strengthened their value chain (Shubhabrata & Ramsundar, 2014).

Similarly, city of Zahura, in Hoshiapur district of Punjab, grew tomatoes as their main crop and targeted to produce for the international market. However, they could not produce, to the standards of the international markets in-terms of quality and quantity. Pepsi Foods Ltd supported these farmers through the contract farming model providing them with seeds, agricultural practices, and regular inspection of the crop and advisory services on crop and changed their products to value added products to meet the international market standards (Shubhabrata & Ramsundar, 2014).

Fruit and Vegetable Industry in Sri Lanka showed that the contract farmers in rural small holder farming are the main mean of income for rural households which provided employment opportunities to a large part of the rural communities. In Sri Lanka they produce, many fruits and vegetables

but 30-40% of their products go to waste due to the poor harvest and handling techniques as well as lack of technology, and accessibility to markets (Esham & Kobayashi, 2006). The study carried out on "gherkin production" in the Kurunegala district of the Northwestern province in Sri Lanka, showed that introducing a contract farming model into the smallholder farming communities advantaged the farmers in many ways. That is, it prevented farmers' crops from going to waste, by providing timely technical assistance and support to the farmers by establishing and recruiting extension officers from the local communities. In addition, it ensured a continuous supply of quality inputs to farmers preventing crop failures of highly sensitive crops. This increased the income gained by farming households and ensured a market for their products (Esham & Kobayashi, 2006).

The contract farming model of agriculture was also introduced to the sweet pepper growing smallholder farms of Indonesia. These farmers experienced poor agricultural infrastructure, a lack of knowledge and skills in producing quality products, and an inability to meet the demands of the rapidly changing market conditions. The introduction of the contract farming model empowered smallholder farming communities by increasing their household income (Shubhabrata & Ramsundar, 2014). A similar study carried out by Cahyadi and Waibel (2013) showed that providing farmers with input supply, technical support, finance, and market access increased the Indonesian palm oil farmers' household income improving their economic and social well-being (Cahyadi & Waibel, 2013).

All these specific cases of contract farming models show that certain principles lead to the success of this method of farming. This includes:

- Providing quality inputs on time.
- Providing technical expertise and support promptly.
- Improving the agricultural infrastructure (powerhouse, water storage, input storage and cold storage)
- Regular monitoring and improving the quality of the products to the standards.
- Ensuring the farmer benefits by increasing their earnings and creating an economically and socially viable community.
- Improving farmers' knowledge and skills of farming methodology:
- Strengthening the relationship between producers and the markets.

It also shows that introduction of the contract farming model has improved these smallholders' farmer's capacity in producing quality products. This increased farmers' income as well as guaranteed a market for these farmers' products. It strengthened their farming capacity by moving them from

traditional farming to more technology-based farming increasing farmers' capital and infrastructure (Behra & Swain 2021).

Contract farming gives farmers a higher price than the market price by removing the middleman and reducing the cost of production by increasing efficiency and increasing the income share of the smallholder farmers (Vogel & Meyer, 2018). One other advantage of the introduction of contract farming models in empowering smallholder farming communities is that it provides improved quality inputs and better technical assistance than the government agricultural extension services propelling these farmers to produce quality increased yield. Furthermore, it shields the farmers from market price fluctuation risks maintaining these farmers' productivity throughout (Vogel & Meyer, 2018). This is true because contract farming companies ensure that farmers are relieved from the credit, input, and output market constraints thus increasing farmers' productivity and efficiency. This gives contract farmers an advantage over non-contract farmers (Vogel & Meyer, 2018).

### Material and Methods

According to FAO, 2011 success story report, Maldives has a total land area of 30, 000 hectares of which only 4000 ha are arable. Half of this land is found on 36 islands which are given for the commercial agricultural purpose. According to FAO, 2011 and 2019 reports, the amount of arable land available to families for subsistence agriculture or family farms is very less compared to the land areas given to commercial activities. It also reflects that among the 7500 estimated number of registered farmers more than 80% of them are family farmers (UNDP,2020 & MIRA, 2019).

AgroNAT has divided the islands of the Maldives into 5 agricultural regions from which 2 agricultural regions remain inactive farming regions due to the in-availability of land resources. Therefore, this study will consider 3 agricultural regions of the country (Fig. 1).

Region 1: Region 1 includes Ha. Kelaa, Ha. Baarah, Hdh. Nolhivaranfaru, Hdh. Nolhivaran and Hdh. Vaikaradhoo. There is a total of 165 contract farmers in region 1 with a to-

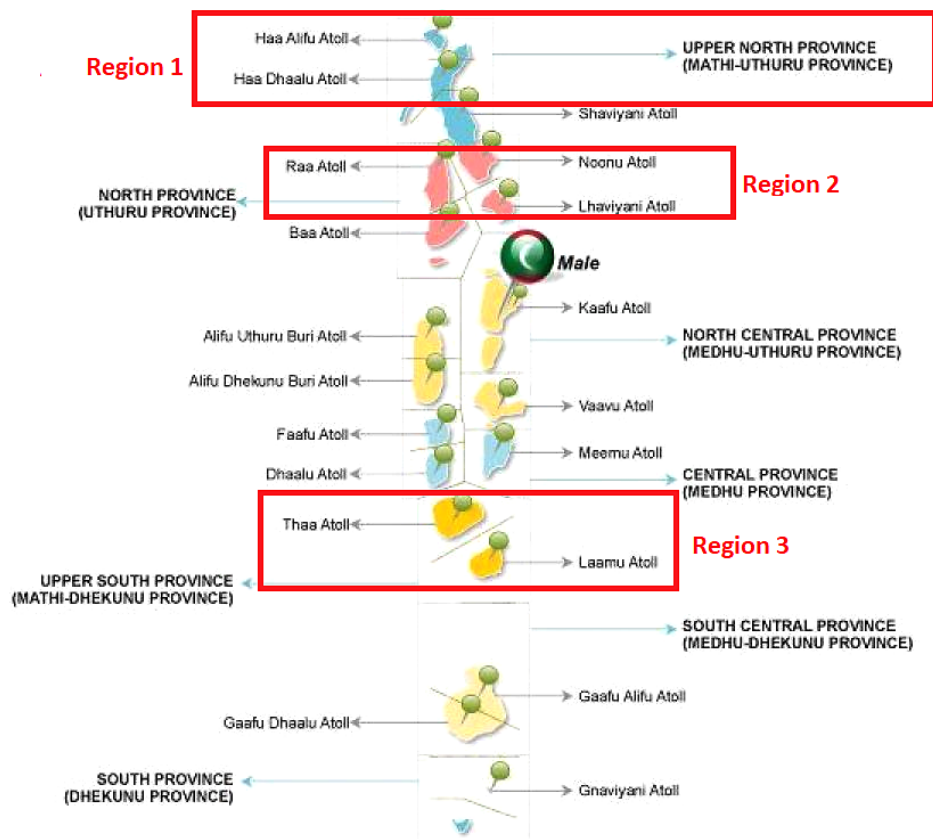


Fig. 1. Investigated regions involved in contract farming in Maldives

tal land area of 475839 sq. ft. Region 1 islands are in the upper north province and these islands experience, hot, humid conditions throughout the year and typically receive about 193.14 mm of rain throughout the year (MFMA, 2006).

Region 2: Region 2 includes R. Kinolhas, N. Manadhoo, and Lh.Olhuvelifushi. There is a total of 116 contract farmers in this region with a total land area of 845565 sq. ft. Region 2 falls within the North province region, where the climate is hot and humid, and typically receives about 210.95 mm of rain throughout the year (MFMA, 2006).

Region 3: Region 3 includes L.Isdhoo and L. Kalaidhoo. L.gan, L.Fonadhoo and Thaa. Kandoodhoo. There are 200 contract farmers in this region with a total land area of 451556 sq. ft. Like region 1 and region 2 these regional islands also experience hot and humid climates throughout the year. Farmers of this region experience 219.67 mm of rain throughout the year (MFMA, 2006).

Each region was considered from the point of soil productivity, production capacity, market access.

### Soil productivity

There are no nationwide or largescale sample surveys carried out to study the soil fertility and soil demographics of the Maldivian agricultural system. However, a master's study project carried on the archeological analysis carried by Gasith Mohamed, 2018 shows that the soil system of the islands is shallow, with a lack of clay particles, and a freshwater lens less than a meter below the surface soil layer. The study also shows that there is a low level of NPK in the soil system all over the Maldives (Gasith, 2018).

### Production capacity

According to the Agricultural Survey statistical report in region 3, the most grown crops include banana, watermelon, brinjal, and pumpkin and in region 1 it includes banana and cucumber. Based on the data collected, observed, and recorded in AgroNAT the most grown crops in region 2 includes cucumber, butternut, and pumpkin. Similarly, it was also observed that region 2 and region 3 farmers grow sponge gourd abundantly in these regions. In household farms of region 3 farmers grow brinjal and papayas as well. Information gathered in the agricultural survey carried out by MoFA (Ministry of Fisheries and Agriculture of Maldives) in the year 2019, and market reports show the most grown crops in the Maldives include watermelon, banana, pumpkin, and butternut (based on the 9 crops of this study). According to the Gasith, 2018 report Maldivian farmers consider chili and watermelon to be the most nutrient demanding crops and thus 29% of the farmers grow chilli and 34% of the farm-

ers grow watermelon. Comparing three regions based on the productivity, region 3 production is higher compared to regions 1 and 2, where region 2 produces the lowest amount of production. There is no data collected or recorded so far on the amount of total amount of crops produced islands-wise or region-wise. However, based on the number of products sold at the main market, it shows that region 3 produced 50% more crops such as watermelon, banana, cucumber, and pumpkin compared to region 2 and region 1 (NBS, 2018).

### Access to the markets

Comparing the economic status of the farmers of the 3 regions it can be said that the farmers of region 3 and region 1 are more economically stable compared to the region 2 farmers. Region 3 farmers have the advantage of higher rainfall, and nutrient-rich soil as well as farmers who have more economical means for technology-based farming compared to all the other regions. Region 2 farmers are economically poor and have fewer means of self-sustaining due to less rainfall, dry soil, and lack of other income-earning opportunities on the island.

Market accessibility of the three regions also greatly differs and this puts region 3 and region 1 more advantageous over region 2. Region 1 farmers have better market access because they have frequent transport options available to and from the main market. In addition, this region's farmers have access to "Kulhudhufushi Saturday Market" which is the main point to sell local farmers' products (ADB Technical Assistance Report, 2016, p.309) Region 3 farmers have nearby resorts, but only commercial farmers meet the standards of the resort market demands (based on volume and quality). However, region 3 farmers' main target is the capital city market where these farmers dominate with their production. Region 2 farmers are the most disadvantaged farmers in terms of the market as they lack transport and easy access to market points such as the capital city and resort markets. As a result, region, 2 farmers mostly grow their crops for the local consumption purpose at the island level. Region 1 and region 3 main target consumers are locals, restaurants, and hotel customers.

### Types and sources of data

This study principally used, the 2021 AgroNAT contract farmers' production latest information. This study used the total amount of crops produced by the farmers from 3 regions for the year 2021, and the total land area used for the crop production. The amount of input cost was calculated based on the total amount of fertilizers, chemicals, the total amount of operational expenditure spent on logistics, cold storage facility costs as well as the amount of money spent on inte-

grating technology into the farming system of these contract farmers. The data was collected directly from the farmers and the AgroNAT record keeping. A total of 13 islands were visited and data from 700 farmers were collected. In addition to this, more than 1200 farmers were directly intervened to understand the nature of their farming and understanding the situation of agriculture in the Maldives.

## Results and Discussions

The offered optimization model included the most demanded crops in the Republic of the Maldives such as:

- 1 – pumpkin (*Cucurbita pepo* L.)
- 2 – banana (*Musa paradisiaca* L.)
- 3 – watermelon (*Citrullus lanatus* L.)
- 4 – butternut (*Cucurbita moschata* L.)
- 5 – cucumber (*Cucumis sativus* L.)
- 6 – papaya (*Carica papaya* L.)
- 7 – melon (*Cucumis melo* L.)
- 8 – brinjal (*Solanum melongena* L.)
- 9 – sponge gourd (*Luffa aegyptiaca* L.)

The basic pros and cons of these crops are as follows. The 9 crops include fruits and vegetables that are most used by the locals as well as by the tourist resorts. Farmers all over the Maldives grow these 9 crops due to the given fact that these can be grown easily in a tropical climatic country like the Maldives, where the average temperature remains the same throughout the year (Banana, watermelon, papaya, and melon are the main fruits that are consumed by the Maldivians and these fruits need to be available in the market throughout the year. More than 90% of the population depends on bananas, papaya, and watermelon as their main fruit (MoFA,2012). There is a great demand for watermelon throughout the year especially from tourist resorts as this is the most popular drink that is being served in resorts. In addition, in the Maldives, there is the holy month of Ramazan, where there is a huge demand for watermelon. Most of the time watermelon needs to be imported from the neighboring countries since the local farmers are not able to produce to meet the market demand. In addition to this, there is a constant demand for these fruits throughout the year.

Pumpkin, butternut, and brinjal are the main local vegetables upon which all the Maldivian depends as their main source of the nutrient. These vegetables can be grown locally and are less expensive compared to the carrot, beans, cabbage, and potatoes that need to be imported from neighboring countries. There is a great demand for these vegetables by locals as well as by hotels, and resorts. Cucumber is one important vegetable that is used by locals in every meal as

a salad. Compared to cucumber, sponge gourd has a lesser demand in the market as this is mainly used by the expatriate workers who reside in the Maldives. There is not much demand for this crop in the local market but an average of 1 ton is required by companies that employ a larger number of expatriate workers from Sri Lanka and Bangladesh. Consumer demand for the above 9 crops is high. However, farmer preferences in growing these crops differ. The majority of the farmers' preference in choosing these crops depends on the market price, input cost required, and how long the crop last. Many farmers consider how long they can store the crops before they go bad since they do not have the means to keep these crops fresh and there are no regular transport options available for them to take these crops to the main market. Considering all these reasons, farmers who are farming on an island nearby the capital city and resorts, grow mainly cucumber, papaya, watermelon, and melon. This is because they can easily transport these perishable crops to markets. There is a huge resort market demand for melons whereas, there is a lower local demand for melons. Farmers who farm on faraway islands further away from the capital city choose butternuts, pumpkins, and sponge gourd to grow as they can stay fresh for more than a week time, which gives farmers time to take to the market.

Though there is transport difficulty, around 60% of the farmers choose crops from which they can earn more profit such as melon, banana, watermelon, and papaya as throughout the year there is a good price for these fruits in the market (AgroNAT, 2020).

Most farmers do not prefer to grow brinjals because it is difficult to grow due to the high input cost required in pest management of this crop. However, similar to melon, brinjal has a good market price which has a higher demand in the local and resorts market. Thus, farmers along with some other crops always choose to grow brinjal on their farmland. Similarly, cucumber is one crop that almost all the farmers all over the Maldives choose to grow since this crop can be easily grown in Maldivian soil and there is a continuous demand for this crop in the market.

Sponge Gourd is one crop that most farmers choose to grow in their fields as it requires less attention, time, and investment to grow. This plant grows on its own and gives a higher yield. Farmers choose to grow this crop because the input cost required to grow these vegetables is zero. Most of the time sponge gourd farmers do not experience loss in growing this crop in cases such as the availability of transport and market access. There is no resort market for this crop at all.

The listed crops are intended for growing in three Regions. The model aim was to redistribute the regional agri-

cultural lands under the listed crops, in other words, to find optimal areas

$$X_{ij} (X_{ij} \geq 0), i=1..3, j=1..9, \quad (1)$$

associated with region  $i$  and crop  $j$ . The Maldivian climatic conditions allow harvesting two times per year for all of the listed crops except one harvest of banana and papaya. For the sake of consistency, the created model provides an annual distribution of the agricultural lands and takes into account a number of harvests with regard to the coefficients of input costs and yields.

If the total agricultural land in region  $i$  is  $A_i$ , then we need to face a set of inequalities

$$\sum_{j=1..9} X_{ij} \leq A_i, i=1..3. \quad (2)$$

It is worth mentioning that the left expressions calculate the real area involved in agricultural production by regions.

Let  $B_i$  denote a financial limit to production expenditures covered by AgroNAT in region  $i$  and  $C_{ij}$  be an annual unit input cost for crop  $j$  in region  $i$ . Then the corresponding restrictions take form

$$\sum_{j=1..9} C_{ij} \cdot X_{ij} \leq B_i, i=1..3. \quad (3)$$

Here the left sums evaluate actual expenditures on regional agriculture.

When it comes to the development goals, AgroNAT determines a pair of maximal ( $D_j$ ) and minimal ( $E_j$ ) output quantities for each crop  $j$  which has an annual yield of  $F_{ij}$  in region  $i$ . It results in the following set of inequalities

$$\sum_{i=1..3} F_{ij} \cdot X_{ij} \leq D_j, j=1..9, \quad (4)$$

$$\sum_{i=1..3} F_{ij} \cdot X_{ij} \geq E_j, j=1..9. \quad (5)$$

It should be noted that the left expressions calculate the planned optimal harvests by the analyzed crops.

At last, let  $G_j$  denote a buying price for crop  $j$  paid by AgroNAT to farmers and  $H_j$  be a wholesale price for crop  $j$  established by AgroNAT. Then the total farmers' income amounts to

$$\sum_{j=1..9} \sum_{i=1..3} G_j \cdot F_{ij} \cdot X_{ij} \rightarrow \max, \quad (6)$$

and the created optimization model of (1)-(6) is in favor of the farmers' interests. Similarly, the total AgroNAT's profit equals

$$\sum_{j=1..9} \sum_{i=1..3} ((H_j - G_j) \cdot F_{ij} - C_{ij}) \cdot X_{ij} \rightarrow \max, \quad (7)$$

and the corresponding optimization model of (1)-(5), (7) is beneficial for AgroNAT.

The values of the introduced parameters were derived from AgroNAT official reports and aggregated in Tables 1, 2, and 3. It is worth mentioning that in order to get the most reliable recommendations we operated in the local currency of MVR. Data from Table 1 depict some discrepancy in financing agriculture between regions as the smallest by area region 1 spends the largest total input cost. This is due to geographical location and less fertile soil of the islands in this region farmers are required to plough their island and add more fertilizers into the soil before they cultivate their crops. Also, farmers experience more pest related issues in growing crops and lower yield of crops such as cucumber and watermelon. As a result, farmers of this region are required to use more inputs such as fertilizers and pesticides to grow their crops. In addition, owing to poor germination experienced by the farmers most of them use hydroponic systems and grow bags to grow their crops which resulted in higher input cost.

**Table 1. The model values of  $A_i$  and  $B_i$**

Parameter	Region 1	Region 2	Region 3
$A_i$ , sq. ft	412643	777925	446556
$B_i$ , MVR	1379422	1344018	696619

Source: compiled by the authors

It might be explained by the fact that, farmers of this region grow mostly cucumber and brinjal which requires more fertilizers and chemicals for the growth of the plants. In addition, brinjal is a costly crop to grow due to the pest issue faced by the farmers and the pricey pesticides required to tackle this problem.

It should be noted that a far too large value of the unit input cost of growing cucumber in region 1 emerged because of practicing a special technology of using "grow bags" which required coco peat which is more expensive than the cow dung that is used by other farmers who grow cucumbers in soil. This is because cucumber variety called "Riches or salad cucumber" that are grown in a medium other than soil gives more profit to the farmer compared to the conventional cucumber variety "Madam" that is grown in soil. A zero value of the unit input cost  $C_{ij}$  concerning sponge gourd in region 2 marked that the local farmers didn't cultivate this crop. According to the values of the annual yield  $F_{ij}$  region 1 is especially beneficial for growing cucumber, melon, and sponge gourd as these crops can be grown in small land areas to give high volume of production. Namely, melon, which is



**Table 2. The model values of Cij and Fij**

Parameter		Crop 1	Crop 2	Crop 3	Crop 4	Crop 5	Crop 6	Crop 7	Crop 8	Crop 9
Cij, MVR/ sq. ft	Region1	0,96	2,07	1,12	0,90	11,84	1,17	3,36	2,93	2,29
	Region 2	0,96	2,07	1,13	0,89	1,40	1,14	3,11	2,91	0,00
	Region 3	0,97	2,07	1,13	0,89	1,39	1,15	2,94	2,96	1,98
Fij, kg/ sq. ft	Region 1	0,03	0,09	0,07	0,03	0,09	0,07	1,30	0,05	7,80
	Region 2	0,03	0,01	0,08	0,02	0,02	0,01	0,00	0,00	0,00
	Region 3	0,24	0,08	0,25	0,02	0,06	0,04	0,05	0,09	1,53

Source: compiled by the authors

**Table 3. The model values of Dj, Ej, Gj, and Hj**

Parameter	Crop 1	Crop 2	Crop 3	Crop 4	Crop 5	Crop 6	Crop 7	Crop 8	Crop 9
Dj, kg	125000	568769	453091	120000	234000	23000	152000	43000	31106
Ej, kg	13334	36452	59248	6840	17196	2311	11104	2490	31106
Gj, MVR/kg	8	18	10	15	10	8	30	18	9
Hj, MVR/kg	13	27	16	22	16	16	43	27	14

Source: compiled by the authors

required to be grown in hydroponics, can provide 70% higher yield in small areas than cultivated in open fields. Cucumber also can be grown in “grow bags” in small areas. Sponge gourd can be harvested 11 times from one cultivation cycle and in each week, it will produce 65 kg of sponge gourd from 93 plants (that is in a 3000 sq. ft). Total of 706.8 kg of sponge gourd can be produced from 3000 sq. ft. This is because, the germination rate of sponge gourd is high, and the chance of pest and plant disease is far less in sponge gourd compared to other crops. Farmers usually sow 4 to 5 sponge gourd seeds in a pit and 90% of the cases 5 seeds successfully germinate. If the farmers water the sponge gourd plants weekly twice, then these plants grow and produce qualitative undamaged products.

The same can be said about harvesting pumpkin and watermelon in region 3. Pumpkin is one crop which requires watering twice daily and that grows only in nutrient rich soil with proximity of fresh water. Region 3 has soil which shows high percentage of pumpkin seed germination as well as the farmers of this region has better access to fresh water for watering these plants from the stage of cultivation to the harvesting point. Moreover, farmers experience less salinity of water in this region which gives farmers of this region a better chance of growing quality pumpkin with a higher production yield. In addition, farmers can easily grow watermelon without pest and plant disease. Compare to the other regions farmers from this region do not face the challenge of cracking of watermelons due to high temperature and wilting of watermelon plants. The zero value of Fij about growing melon, brinjal, and sponge gourd meant unfavorable natural conditions for growing these crops in region 2. This is

because, compared to other regions, region 2 farmers' farmlands are close to each other, and thus, there is a difficulty in controlling pest and plant diseases that mostly damages crops such as brinjal. Brinjal fruit borer fly flies from one field to another infecting the neighboring plants. The fields which were used to grow brinjal show poor germination of other crops such as sponge gourds. Melon is one crop that cannot be grown in poor quality soil and most of the region 2 farmers depend on the soil as the growth medium. Melon needs to be grown in a controlled medium such as a hydroponic system to provide enough nutrients and minerals to ensure that these fruits reach their maturity. Farmers experienced poor quality melons with a dehydrated nature when they grew melon in islands which believed to have nutrient rich soil.

The model calculations were performed with the tool Solver built in the spreadsheet MS Excel. The model results were combined in Tables 4 and 5. Optimal plan #1 was intended for the maximal farmers' income related to the model (1)-(6). Optimal plan #2 was meant for the maximal AgriNAT's profit associated with the model (1)-(5), (7). Initial plan #3 was used as a reference point in order to compare a real land distribution with its calculated options.

In terms of production Table 4 recommended that region 1 should focus on growing banana, cucumber, papaya, melon, and sponge gourd. Whereas cultivating butternut and cucumber are the most beneficial for region 2. However, optimal crops for region 3 appeared to be pumpkin, banana, watermelon, cucumber, and brinjal. The calculated land distribution would provide twice as much as the initial production of banana, watermelon, butternut, and melon. This

**Table 4. Production model outcomes**

	Indicator	Crop 1	Crop 2	Crop 3	Crop 4	Crop 5	Crop 6	Crop 7	Crop 8	Crop 9
1	Area, sq. ft									
	Region1	0	309009	0	0	55690	35054	8902	0	3987
	Region2	0	0	0	292171	485754	0	0	0	0
	Region3	55993	106369	239994	0	16753	0	0	27447	0
	Harvest, kg	13334	36452	59248	6840	17196	2311	11582	2490	31106
2	Area, sq. ft									
	Region1	0	310406	0	0	54661	35054	8534	0	3987
	Region2	0	0	0	292171	485754	0	0	0	0
	Region3	55993	104825	239994	0	18297	0	0	27447	0
	Harvest, kg	13334	36452	59248	6840	17196	2311	11104	2490	31106
3	Area, sq. ft									
	Region1	44100	87708	121925	38775	73585	13500	2750	28275	2025
	Region2	82500	332250	85500	39725	69950	61500	5500	89500	11500
	Region3	38356	73500	55000	52500	139200	25000	40500	12500	10000
	Harvest, kg	13334	18226	29624	3420	17196	2311	5552	2490	31106

Source: calculated by the authors

**Table 5. Financial model outcomes**

#	Total input cost, MVR			Farmers' income, MVR	AgroNAT's profit (loss), MVR
	Region 1	Region 2	Region 3		
1	1379422	940768	650277	2320583	
2	1368898	940768	649231		-1725364
3	1379422	1344018	696619	1464062	-2615802

Source: calculated by the authors

result is especially commendable for several reasons. This is because, region 3 has more fertile soil and better access to water resources compared to other regions. For many years, region 3 has been famous for growing huge volume of these crops given the fact that the local farmers experience less climatic challenges, strong wind and flooding in this region which benefits them growing banana, watermelon, butternut, and melon throughout the year.

In terms of financial outcomes Table 5 reported about a significant decrease in production expenditures. In particular, region 3 might reduce its input cost by 7%, whereas input cost in region 2 might shrink by 43%. Besides, in compliance with the objective criterion (6) the total farmers' income would rise by 59% with regard to its initial value. It is appealing to providing Maldivian food security and improving welfare of the local farmers.

So far AgroNAT is not profitable. There are many reasons behind this given the fact that it is being only 2 years since AgroNAT has been established and the contract farming model is a new concept to Maldivian agricultural system. There are many challenges such as AgroNAT's inability to provide farmers with required input on time, difficulty in managing farmers who are not willing to switch from conventional method of farming to

scheduled farming guidelines and principles and high percentage of aged farmers who do farming on a seasonal basis and are devoid of contemporary knowledge and skills to increase the production yield and tackle pests and plant diseases.

Technical guidance and support are crucial assistance that all the farmers need all over the Maldives. AgroNAT has only 1 expatriate technical staff who does not speak the native language and another staff who works in AgroNAT on a two-day weekly basis. As a result, AgroNAT completely failed in supporting and guiding farmers.

The business plan on which AgroNAT was formulated lacks a market price analysis. As a result, the buying price of the farmers' crops did not reflect the fluctuating input price which disadvantaged farmers. The farmers' net income per month was less than the number of production expenses.

Moreover, AgroNAT did not do a thorough agricultural analysis on effective regional specialization. So far farmers grew crops without considering soil fertility, access to water, and temperature of the regions which resulted in the loss of crop production and low-quality yields.

In the case of the found optimal land distribution and the calculated objective criterion (AgroNAT, 2020), AgroNAT would decrease its loss by 52% compared to the initial figure.

## Conclusions

Overall, the study findings confirmed the research hypotheses about improper resource management in the considered regions and also clarified plausible options to sort it out within contracting farming arranged by AgroNAT in Maldivian agriculture. The scientific novelty of the created optimization model relates to managing land and financial resources, balancing crop harvests and providing maximal profits for all parties involved in contract farming. The calculated outcomes resulted in the following recommendations which agree with the complex approach to enhancing effective agricultural management (Vasylieva, 2019). Firstly, in compliance with improvements in land management it is advisable to shrink regional varieties of grown crops. In particular, region 1 should redistribute 75%, 13%, 9%, 2% and 1% of its agricultural area under banana, cucumber, papaya, melon, and snake gourd. Similarly, region 2 would benefit from growing butternut and cucumber at 38% and 62% of its agricultural area. Pumpkin, banana, watermelon, cucumber, and brinjal should occupy 12%, 24%, 54%, 4%, and 6% of the agricultural area in region 3. Besides, only region 1 must produce papaya, melon, and snake gourd. 100% of the harvested area under butternut should be in region 2. Pumpkin, watermelon, and brinjal ought to be grown only in region 3. At the same time, 75% and 25 % of banana must be distributed between regions 1 and 3. And also 10%, 87%, and 3% of cucumber should be located in regions 1, 2, and 3. These recommendations depict the most promising development of Maldivian agriculture suitable for the regional climatic conditions.

Secondly, the offered optimal production would double total harvests of banana, watermelon, butternut, and melon compared to their present quantities grown in regions 1, 2, and 3. This output gives a clear way to provide agricultural sustainability and foster food security in the Republic of Maldives.

Thirdly, in compliance with improvements in financial management the recommended shares of covered production expenditures in regions 1, 2, and 3 need to be 46%, 32%, and 22% instead of the current 40%, 39%, and 21%. If implemented, the calculated optimal production plan would increase the farmers' total income by 856521 MVR and save 890438 MVR of the AgroNAT's expenses. These numbers would contribute to an essential increase in effectiveness of the performed contract farming in Maldivian agriculture.

In our view, the relevant further research should be focused on understanding how to increase the production of the identified crops in these regions. In particular, it might be performed through applying the Data Envelopment Analy-

sis (DEA) as well as the Stochastic Frontier Analysis (SEA) after sorting out input and output weights involved in agricultural production. In depth research can be carried out to analyze the post-harvest damage loss of the regional specific crops to understand the production efficiency. This could give insight on how to increase the volume of production as well as the way to enhance its quality.

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