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MASTER 2

ECONOMICS

"MEDITERRANEAN FARMING SYSTEM DESIGN
FOR A SUSTAINABLE FOOD-SYSTEM"

Thesis submitted by: **DUKA Armela**

Analysing farming systems behaviour while facing water scarcity with the help of bio economic modelling. Case of Baalbek- Hermel, Lebanon

Supervised by **BELHOUCHETTE Hatem**

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Abstract

Climate is a key topic that is affecting the whole world and its biggest impact is on the dry areas. This study focuses on the impact of rainfall variability in the productivity of the crops in Lebanon as part of the project SupMed. Considering that, 6 representative farm types have been modelled with the help of a dynamic bio economic model. In the context of water scarcity in the area two scenario have been chosen to be tested in the model, aiming at making the farmers more competitive in the market. After the implementation of the scenarios it resulted that farmers who decide to convert their production of olives and almonds to bio will experience an increase in productivity and revenues.

Author keywords

Climate change, water scarcity, bio economic modelling, farming systems.

Title : Analyser le comportement des systèmes agricoles face à le manque d'eau à l'aide de la modélisation bioéconomique. Cas de Baalbek-Hermel, Liban.

Abstract

Le climat est un sujet clé qui affecte le monde entier et son impact le plus important concerne les zones sèches. Cette étude porte sur l'impact de la variabilité des précipitations sur la productivité des cultures au Liban dans le cadre du projet SupMed. Considérant cela, 6 types d'exploitations représentatifs ont été modélisés à l'aide d'un modèle bioéconomique dynamique. Dans le contexte de pénurie d'eau dans la région, deux scénarios ont été choisis pour être testés dans le modèle, visant à rendre les agriculteurs plus compétitifs sur le marché. Après la mise en œuvre des scénarios, il en est résulté que les agriculteurs qui décident de convertir leur production d'olives et d'amandes au bio connaîtront une augmentation de la productivité et des revenus.

Mots-clés de l'auteur

Changement climatique, manque d'eau, modélisation bioéconomique, systèmes agricoles.

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Introduction

Climate change is one of the most serious environmental challenges of the twenty-first century, and it will have a considerable influence on global agricultural output as a result of rising temperatures and shifting precipitation patterns throughout the world. The Middle East and North Africa (MENA) area is one of the most vulnerable to climate change, particularly water shortages. Climate change uncertainty and population increase make water security a pressing problem for many countries.

Lebanon, although being one of the MENA region's countries with the largest water availability in comparison to others, is threatened by water scarcity due to limited water storage capacity and a lack of water management laws.

The main objective of this study is to assess the impact of the rainfall variability on the production systems in Baalbek-Hermel over a 10-year period. To address this objective, the research question is how will the farmers react to the impact of climate change in their production systems and what will be their adaption strategy to these changes?

This study will be divided in four main parts. The first part is the literature review where we focus on explaining the main concepts that helped us carry on this study such as climate change and water scarcity as a main problem of Lebanon in the last years and also an important part of the literature is the bio economic model for its importance in the conduction of this study. Apart from the base concept of bio economic modelling we will have a look at the generic farm models as models that can be adapted quickly and easily in different context and location.

In the second part of the study is explained the methodology we followed to conduct the study. Some of the main points of the methodology are the selection of some representative farm types in four of the villages that are part of this study, the construction of a bio economic model to simulate the selected farm types and in the end we test two scenarios as a possibility for the farmers to adapt to future climate changes.

In the third part which is the results part we will analyse the 6 representative farm types in terms of area and land renting capacity as well as their crop contribution in the gross margin. In a second step we will analyse a scenario of conversion from conventional to organic for olive and almond systems in Hermel and the scenario of intercropping in Nahleh, where we will focus on the changes in productivity afrer the implementation of the scenarios.

The last part, the discussion part we will make a short analysis of the results and a return to the methodology used for the study where we point out the advantages and the limitations of our work as well.

This study will be divided in several chapters, where first of all we will do a literature review on the main topics of interest and which are going to give a general idea and clarify the methodology chosen for this study, as well as a description of the study area.

Part I

Literature review

I - Climate change

1. Climate change

Climate change is a raised concern all over the world and its impact is already being felt everywhere due to the risk of extreme events like floods and droughts. The global surface temperature will continue to increase through at least the middle of the century under all possible emission scenarios. In the twenty-first century, global warming will exceed the 1.5° to 2°C threshold unless CO2 and other greenhouse gas emissions are significantly decreased (Delmotte et al., 2021).

One of the industries that is heavily impacted by climatic disasters like drought or changes in rainfall is agriculture. The rainy season and rainfall, which are more varied and unpredictable than previously, as well as rising average temperatures, which are anticipated to rise by up to 4.8 percent by 2100 interfere with crop development calendars, reducing agricultural production (World Bank, 2017).The availability of resources limits agriculture's potential to flourish further, despite these changes in the environment (Bazza et al., 2018).

However, there is fear that the growing global consequences of climate change may worsen food insecurity. Not only that but, also poorer agricultural productivity might result from a variety of factors related to climate variability including temperature increases, altered precipitation patterns, extreme weather events, and water scarcity. If extreme weather events happen more frequently and grow more severe, food distribution can be affected and food price spikes as well are expected to happen more frequently (Melillo et al., 2014).

Furthermore, future climate change will have an impact on the worsening of soil conditions, loss of biodiversity, reduction of crop yields and increasing production costs for agricultural fuel, fertilizers, and irrigation in various regions around the world due to areas experiencing decreased precipitation and increased temperatures (Taheripour et al., 2020).

2. Farmers adaption to climate change

Agriculture as of the primary sectors to be affected by climate change has to be always ready to confront the challenges and adapt into the new conditions. Farmers play a crucial role in the process with their actions and their capacity to adapt. It is proven that knowledge and perception of farmers on climate change influences their action and their adaptability in the future (Mahfoud and Adjizian-Gerard, 2021).

Over the years, farmers based on their experience have used their knowledge to prepare for climate change and have developed agricultural systems that are easily adaptive to climate variability, weather and diseases. Their systems are based among others on the diversity of crops cultivated, increased water harvesting, extensive planting, inter cropping and use of drought-tolerant local varieties, which has allowed famers to avert the risks.

The resilience of the faming system to climatic events is seen to be related with the diversity of farms and is proven that farms based on intercropping, cover crops and agroforestry are more resistant and can overcome easier the effects of extreme events (Altieri and Koohafkan, 2008).

Looking into the way that people and farmers in the past have succeeded in adapting to new climatic conditions while having resilient systems to face the risks of the environment, it is necessary to find ways to insure the sustainability of the farming systems, now that the climate change is closer than ever and its consequences are starting to affect these systems (Altieri and Koohafkan, 2008).

3. Climate change impact on water scarcity

Water scarcity is already one of the most pressing global challenges, and according to (Delmotte et al., 2021) climate change will have a negative impact on water resources all around the world, affecting the water availability, even though the impact can be somehow different in different regions due to the characteristics of each region. It is caused by climate change through a number of factors, including decreasing rainfall and rising temperatures and it is estimated to become even more essential in the future (IPCC, 2014).

Water scarcity can be defined as the lack of access to adequate quantities of water for human and environmental uses. Basically it refers to the lack of fresh water resources to meet water demand (World Bank, 2017). It is a term widely used to describe areas characterized by water resources under pressure. Even though it is a widely used concept there’s not a fixed definition for water scarcity and also since there are a lot of different methods to measure the scarcity, based on the method we choose we can get different regions that are the scarcest in water resource.

The MENA region is one of the world’s greatest water scarce regions when the scarcity is measured by the water stress index or Falkenmark indicator which measures the scarcity as the amount of renewable freshwater that is available for each person each year (World Bank, 2017), (White, 2014). MENA countries account for approximately 6.3 percent of the global population but only account for 1.4 percent of the world's renewable freshwater resources (Roudi-Fahimi et al., 2000).

The concern related with water scarcity comes due to the rapid population growth, the increase of demand for water, economic development, urbanization, dietary changes and regional conflicts, migration, pollution and the change in climate that affects the variability of water supply while putting pressure on water resources, resulting in continued water scarcity affecting the region's social and economic potential, increasing land vulnerability to salinization and desertification, and raising the risk of political conflict over the region's limited water supply (White, 2014), (Tropp and Jägerskog, 2006), (World Bank, 2017).

Furthermore, its greatest impact is in agriculture which is the sector that consumes nearly 70% of total world water and specifically in the MENA area which is characterized by dry climatic conditions with high evapotranspiration and infiltration rates the effect of water scarcity would be a decrease in the moisture of the soil which would require imperatively irrigation for the development of crops (World Bank, 2012, 2017).

Lebanon is one of the countries already experiencing these effects of climate change coming from the decrease in the amount of water from different sources, together with an increase in population size which are resulting in the issue of water scarcity.

4. Water situation in Lebanon

Lebanon experiences serious water shortage in summer even during wet years (Frenken, 2009). Some of the factors affecting the further shortage and decrease in quality of water are related with climate change, urbanization, population and economic growth. Population growth within Lebanon together with the refugees and displaced population impact the demand for water which is 8-12% higher (Ministry of Environment, 2015), (UNDP, 2020).

Agriculture is the largest water consumer, consuming around 64 percent of the water from surface and groundwater sources and its demand for water is expected to keep increasing in the following years (UNDP, 2020). Agriculture in Lebanon is separated between irrigated and rain fed agriculture, with irrigated land accounting for about half of all agricultural land. Despite this, climate change affects both types of crops, either in terms of water for rain fed and irrigated crops, or in terms of temperature increase for other crops subject to temperature change (IWMI, 2021), (Hassan, 2010).

Lebanon's limited water storage capacity and a lack of water distribution infrastructure and networks (Frenken, 2009), makes the agricultural production to be strongly dependent on yearly precipitation for rain fed and irrigated farming as well.

Despite the fact that it has a comparatively significant water endowment per capita, Lebanon is on the edge of water shortage. There are several factors that affect the imbalance between the supply of water during the winter and demand for it in the summer including the low water storage, distribution network, rising demand of urban and industrial sectors and untreated wastewater (Shaban, 2020). The persistent water deficit has an impact on both the quality and amount of accessible water, making it a necessity the investment in the country’s water system networks (UNDP, 2020).

II - Bio economic modelling

In the context of climate change and water scarcity, bio economic modelling is one of the most adequate methods used in agricultural economics to help farmers to manage their production systems, in the land use decisions as well as to address environmental policies.

1. Integrated assessment

Integrated assessment and modelling (IAM) integrates the evaluation of a system's biophysical, economic, and social characteristics using computerized methods, with the goal of incorporating stakeholders in the evaluation. (Brouwer and Ittersum, 2010).

IAM tools have been developed and used widely in order to address the complex issues of sustainability and sustainable development, as well as to support policymaking (van Ittersum et al., 2008). Policymakers are also becoming more aware of the importance of using IAM to support policy development. The European Commission, for example, has recently introduced Impact Assessment of its policies as an essential step in the development and implementation of new policies (European Commision, 2005), which IAM may assist with.

IA tools can be split into two groups: analytical (models, scenarios and risk analysis) and participatory (dialogue methods, policy exercises and mutual learning methods). Among these methods, Integrated Assessment and Modelling (IAM) includes a variety of quantitative models as well as scenario-based approaches. (Brouwer and Ittersum, 2010)

The usefulness of these tools comes from the fact that they provide a conceptual and operational framework to evaluate the effectiveness and trade-off among different policy measures, while integrating the knowledge from a variety of disciplines and/or stakeholders which is needed while dealing with complex system problems and related interactions and feedbacks.

There is little empirical support for ex-ante assessment, or policy evaluation prior to implementation. In this case, mathematical modelling has proved to be a valuable source of information for the assessments.

2. Bio economic modelling

The conceptualization of bio economic modelling began in the 1970s with the idea of integrating a biological modelling component into economic models when the choice of techniques is strongly subject to the influence of biological functions (Flichman and Jacquet, 2003a).

Bio economic models are based on the coupling of an economic model, modelling the decisions of farmers in terms of resource management (optimization model under constraints) to a biophysical model which makes it possible to establish the relationship between the components of entry and exit of an agricultural production system. (Flichman and Jacquet, 2003b)

These models are decision-support tools to analyze the complexity of agricultural systems under various agro-ecological and socioeconomic conditions in order to assist farmers and policymakers in identifying the best strategies for maximizing sustainable resource management at spatial and temporal scales and to assess as well impacts of agricultural policies and scenarios (Jones et al., 2016) (Ejaz Qureshi et al., 2013).

Economic models are used widely in farm level and combined with the biophysical models they help in the prediction and evaluation of the effects of climate change while the main goal is the ability to understand the behaviour of farmers while facing climate, market and policy changes (Shrestha et al., 2016).

3. Statistical vs dynamic model

Two approaches can be used when modelling agricultural systems: the statistical stimulation model and the dynamic stimulation model.

Statistical models have been developed using existing datasets and observed variables over the years such as for example, crop regional yield and weather variables to predict crop yield (Jones et al., 2016). These kinds of models are not suitable to estimate climate change impacts because they cannot account for unobserved changes in soil properties, pest and diseases, management.

Dynamic models are a widely used approach and in contrast with the statistical models, they take into account the changes in system as a result of external factors like weather conditions or management practices (Wallach et al., 2018). Some of the dynamic models (CROPSYST, APSIM, EPIC) can be quite complex, requiring many input and a lot of variables and parameters, so a reduced form of these models can be used especially when we want to integrate crop models into economic models at different scales (Jones et al., 2016).

4. Generic bio economic farm models

Bio economic farm models, in theory, allow for the replication of assessments for a wide range of spatial conditions and farming practices. BEFMs can be generic if they can be adapted and transferable between locations and farm types. (Jones et al., 2016).

The creation of a generic bio economic farm model is based on an existing model, restructured and enriched with elements from other models. It needs after the development a clear maintenance approach, as many tools never progressed beyond the initial creation phase and were only used once (Janssen et al., 2010).

According to (Janssen et al., 2010), there are various advantages to having a generic BEFM with one common and recognized idea and implementation produced by a community of scientists. Some of these advantages can be as follows: BEFM applications are easily repeatable and reproducible by a larger community, allowing for large-scale, accurate application to a wide range of agricultural systems. Using a generic model research groups may collaborate more easily so this may facilitate more multidisciplinary research. Also, it permits scientists to concentrate on new developments and modifications on the actual model rather than starting from scratch for each application, saving time and resources. The base model can be improved, with each research group contributing their particular specialty and attributes to the model. A generic BEFM makes peer review easier and more transparent because reviewers are more likely to be familiar with the model's common notions (Janssen et al., 2010).

Looking at all the advantages of having a generic bio economic farm model, the development of such a model by combining elements and extending an existing one with features of other models can be of a great interest for future applications in order to save development time and efforts.

Despite of the assumptions that some models can be easily transferable between different locations and farm types, there is not enough evidence from the literature proving this transferability. What makes these models hard to adapt to other locations and farm types can be the specific nature of the model build especially based on the characteristics of the area and farm types. Also, researchers may prefer to build their own models instead of using already existing ones. Even though a small and simple model with a clear structure can be easily transferred compared with a big model that requires a lot of data and inputs, still it requires time and effort to make it generic. The absence of generic BEFMs may restrict BEFM's utility as a tool for assessing policies and technical developments on a broader scale outside of the study area, as developing and using BEFMs is still a time and resource-intensive process that requires researchers to have specialized knowledge (Janssen and van Ittersum, 2007).

III - Study area

1. SupMed project

This study is done in the frame of SupMed project Collective and contextualized strategies to promote resilient and sustainable agricultural production in rural Mediterranean areas) which started in June 2020 and is expected to finish in 2024. The SupMed project aims to support farmers in Lebanon and Egypt in implementing climate change adaptation and mitigation strategies. The project aims to structurally and sustainably reduce the overexploitation of water resources and improve the income of agricultural households in Lebanon and Egypt in a context of climate change.

Two study have been chosen for this project, Luxor in Egypt and the Beqaa valley or more specifically Baalbek-Hermel governorate in Lebanon. The reason behind this choice of study area is the representativeness of these areas in terms of agricultural biodiversity, soil occupation, socio-economic structure and climate including the risks of climate. They are both important agricultural areas in their respective countries where the Beqaa valley on its own represents one third of all the cultivated lands in Lebanon not to mention the large variety of productions.

The study area for this work will be precisely the Beqaa valley in Lebanon and more specifically we will focus on four villages of the Baalbek-Hermel governorate; Hermel, Medwi, Bouday and Nahleh which we will describe later on in the study area part.

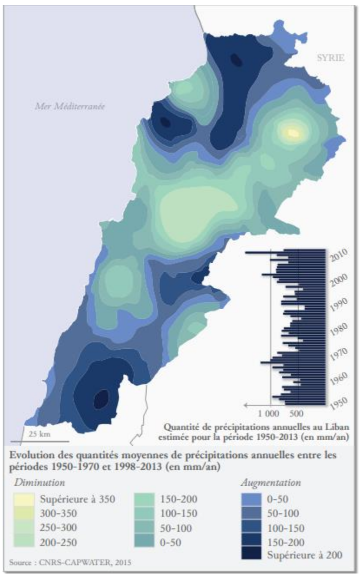
2. Study area

Lebanon is a small highland territory on the Mediterranean Sea's east coast, with a total land area of 10,450 km2. Its topography is rectangular in form, with a length nearly three times that of its breadth, with lowlands and highlands running parallel from north to south:

1) The Mediterranean Sea's coastal strip
2) Mount Lebanon
3) The Beqaa Valley
4) The Eastern Lebanon mountain range

Lebanon has an area of 10 452 km2 and ample water resources. It has a Mediterranean climate with heavy rain from October to March and a very dry summer season which has resulted in the formation of over 40 major watercourses, only 17 of which are perennial (Verdeil et al., 2016). The average annual rainfall is estimated between 600 and 900 mm along the coastal area, to 1 400 mm on the high mountains, and decreasing to 400 mm inland, with a minimum of 240 mm in the north of the Bekaa valley (Solh and Saxena, 2010). For the past 50 years, the total precipitation that fell on Lebanese territory has been relatively constant. They have decreased dramatically in the driest areas of the country, notably in parts of the northern Beqaa, while increasing in the north and south-east. There has also been a temperature change of two-degrees over the years which impacts the average temperature in the country and increases the gap between the minimum and maximum temperatures that contribute to the desertification processes (Verdeil et al., 2016).

Figure 1: Precipitation in Lebanon between 1950-2013



Source: CNRS- CAPWATER, 2015

The storage of surface water is currently relatively limited, and the demands are mostly met by massive groundwater consumption. They currently meet 50% of agricultural needs and 80% of drinking water demands. Partially unregulated, this exploitation has already resulted in a drop in aquifer levels and considerable saltwater incursions in the most densely inhabited coastal areas (Verdeil et al., 2016).

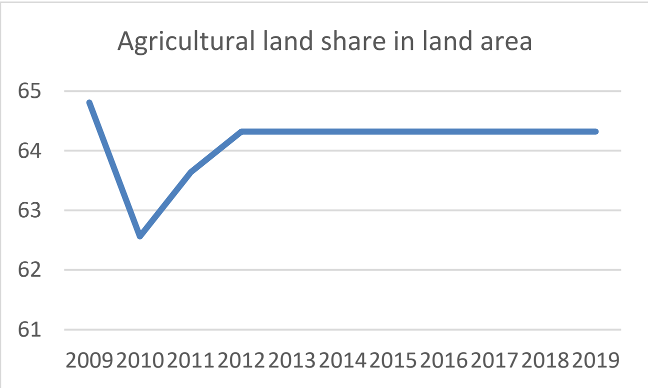
A. *Agricultural situation in Lebanon*

Because of its topography Lebanon has limited arable land, but diverse agricultural and livestock production systems exist, which are well adapted to the variability of the agro-ecological zones.

Agriculture is an important sector in Lebanon when taking into consideration the diversity of crops produced thanks to the diversity of bioclimatic zones of the area. Even though agriculture contribute in Lebanon's GDP was only 3 percent for 2020, this variates among the different regions where the areas with a bigger production have a higher contribute of agriculture in the country's GDP (Dal et al., 2021).

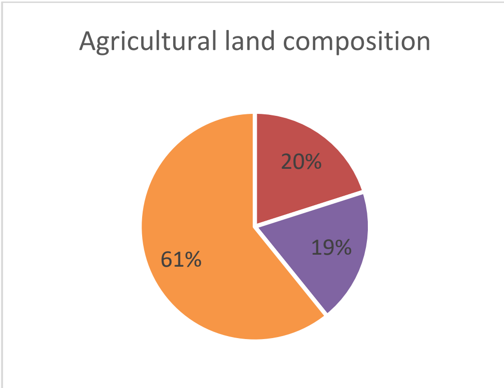
The area dedicated to agriculture has generally increased over the years and in the last 10 years it has remained constant. From 2010-2019, approximately 658000 ha of land is agricultural land which represents 64.32% of total land area. 258000 ha of land is cultivated which means 39% of the agricultural land.

Figure 2:Agricultural land share in land area



Source: FAO database 2019

Figure 3:Agricultural land composition



Source FAO database 2019

The agricultural land is composed of 400000 ha permanent meadows and pastures which accounts for 61 percent of the total agricultural land, 132000 ha of arable land representing 20 percent of the agricultural land and 126000 ha land under permanent crops with a 19 percent of the agricultural land.

B. *Agriculture challenges in Lebanon*

The agricultural sector in Lebanon faces several challenges which make it hard for the sector to develop furthermore and have a bigger impact in the country's GDP.

The existing problems of the sector are mainly related with the farm size, socio economic factors like education, gender, revenues, water scarcity and water stress and market access.

The majority of farms are small subsistence farms where around 70% of farms are less than 1 ha, 26% are between 2 to 6 ha, 4% are more than 6 ha and less than one% of farms have more than 20 ha that means that there are only a few large farms oriented to produce for the market.

Farmers education level is a problem when it comes to new technologies. Based on the background and the education level the farmers can adapt differently to new technologies and farming practices. In Lebanon farmers generally have a low education which makes them less likely to easily adapt to the new practices and as a result this may affect the productivity as well as the quality of their production.

Farmers income is another element that impacts the development in agriculture. In Lebanon farmers have difficulties in increasing their incomes because there is a number of external factors that keeps them from achieving higher incomes. Among these factors are the limited local production of inputs, the price of agricultural inputs due to the fact that the majority of the inputs are imported and there is also a lack of access to credit by the farmers.

Water stress and scarcity that Lebanon is experiencing the last years is one of the biggest challenges that the agricultural sector is facing nowadays. Climate change, even though is the primary reason it is not the only one responsible for the situation of water scarcity. The lack of dams and the management issues of the water sector also contribute in the shortage of water supply. The scarcity brings various consequences such as the use of wastewater and polluted water for irrigation which can result in soil degradation and a lower quality and quantity of agricultural production.

The agricultural product itself faces some challenges like the quality of the products, lack of certifications and competitiveness, lack of trade agreements as well as an insufficient infrastructure for export. All of the above make it harder for the Lebanese products to access the international markets.

Despite all the challenges that it faces, the agricultural sector has great potential for development taking into consideration the wide variety of agricultural land and the diversity of agricultural product which helps in the dependency to a small variety of crops (Ministry of Agriculture, 2020).

3. **Baalbek Hermel**

Baalbek Hermel governorate is situated in the northern part of Bekaa valley which is the main agricultural region and accounts for 43 % of the cultivated land (Fao database for 2019), producing the majority of wheat and most of the cultivated crops in Lebanon. Beqaa valley is also responsible for the production of around 65% of cereals produced in the country.

In some of the poorest parts of the country like Baalbek and Hermel agriculture plays the most important role in the employment and revenues of the families there, contributing with up to 80 percent in the local GDP (FAO, 2018), (Solh and Saxena, 2010).

The semi-arid to continental climate on the valley makes it experience both unpredictable rainfall as well as drought at the same time. So the climatic conditions combined with the soil types affect the varieties of the crops cultivated in the region. According to World bank study, the Beqaa valley has mainly shallow soils and are cultivated with rain fed crops which don't require a lot or not at all irrigation and the rest of the soils are cultivated with fruits and crops in need of irrigation (World Bank, 2012). Due to the high percentage of cultivated area, Beqaa represents 55 % of the irrigated cultivated area of the country. It is the biggest producer of cereals, fruit trees, olives and vegetables in the country.

Table 1:Distribution of crops in % of total area

	Cereals	Fruit trees	Olives	Industrial crops	Vegetables	Total
Beqaa	74	57.6	37.5	6	48.9	42.1
North Lebanon	13	27.6	21.4	49	14.6	27.2
Mount Lebanon	1	4.2	18.9	10	2.2	9.5
Nabatiye	7	5	3.9	17	25.1	8.6
South Lebanon	5	5.6	18.3	18	9.3	12.6
Total	100	100	100	100	100	100

Source: Ministry of Agriculture (Haddad et al., 2014)

IV - Objective

Taking into consideration the different problems of farmers in the region and the challenges that they face every day while trying to improve the production and ameliorate their economic situation, we came up with the main problematic of the study which is:

What Is the farmers' choice of production considering climate change (precipitation) and how it affects their revenues?

Farmers of the region are producing under the context of a water scarcity were the rainfall are low and the cropping systems that are resistant to drought are few, so it is important to find a way to make these farmers be able to improve their production and be competitive in the market.

These are some of the objectives that will help in building a path towards the answer to the research question above:

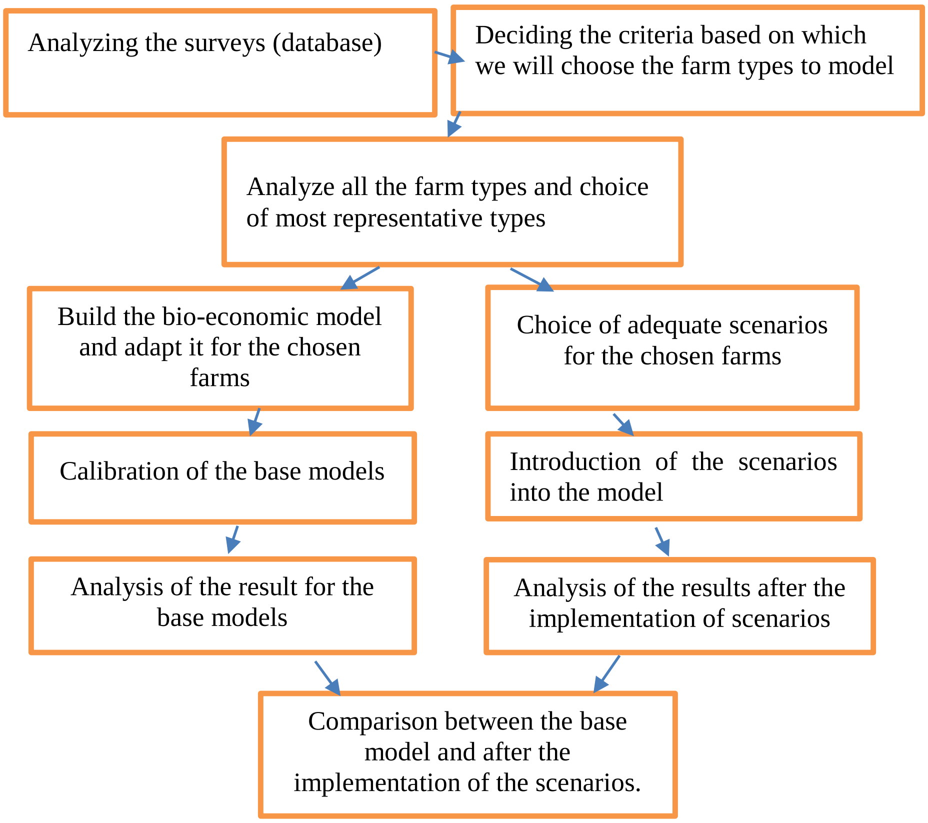
- Choice of representative farm types through the analysis of the surveys and with the help of several criteria chosen as most important in the decision making
- The construction and adaption of a bio-economic model into the climatic and cropping system conditions of the study area.
- The evaluation of the possibilities for improvement through the scenarios to be tested in the bio economic model.

Below are described some of the steps followed to achieve the objective of the study. The first step is the analysis of the surveys and responses of farmers with the aim to identify the most important criteria for the selection of the representative farm types to be modelled.

After selecting the criteria based on which we are going to do the farm types selection, the next step is the analysis of all the farm types based on the selected criteria such as revenues, labor and water use and choice of one to two farm types per village which represent best the rest of the farm types of the area.

The following step is the construction of a bio economic model based on all the available data from the survey and some other complementary data necessary from the literature review. After the construction of a base model the next issue is its replication for the rest of selected farm types as well as the calibration and validation of the models to make sure that they represent well the reality and the data are similar with what we observe in reality. In the end comes the analysis of the base models and the analysis after the introduction of the scenarios agreed with the actors and field experts.

Figure 4:Outline of the methodology



Part 2

Methodology

I - Farm typology

The study is made while taking into consideration the surveys that were already done in the frame of the SupMed project. The surveys used for the study are built in two steps where the first data is collected in the survey done in 2010 where all the necessary information is gathered from the farmers and then these data are analyzed and a farm typology is made from where some farm types derived. After this first step the necessary data is recollected from the farmers where the existing data is validated and at this point it has been noticed that the actual typology has changed, some farm types have disappeared and some others have changed an important part of their production so in the end we are dealing with 14 farm types across 4 villages in Baalbek-Hermel region.

The surveys contain demographic data about the farmer such as age, gender, job, family size and also revenues from outside the farm. Another group off information that we get from the surveys are the land size of the farmer, the ownership if it is owned or rented and in case it is rented its cost, information on crops, type of soil, yield, irrigation dose and cost, planting cost, irrigation source and technique, fertilization and pesticide use, mechanization level, labor and consumption patterns.

Hermel

Hermel is considered as one of the driest areas of the study area where most of the production is rain fed and only part of it is irrigated. In the best case up to 55% of the cultivated land is irrigated and the source of irrigation are the wells while the rest of the area is rain fed. There are present 4 farm types which are characterized by the ability to rent land for their production. The dominant crop in the area are the fruit trees, salad, tomatoes, eggplants, mlukhiye and thyme. The part of production that goes to the market for sale is almost as important as the part of production that goes to self-consumption, while for the almond systems almost 80% of the production goes for sale.

Table 2:Main characteristics of farm types in Hermel

Farm type	Size	Rented land (ha)	Irrigated area	Irrigation source	Soil type	Production reason
Almonds	1.06 7%	-	0.10 9%	85% Rain fed, 15% Well	Clay, calcaric, cyltique	81.5% sold 18.5 self-consumption
Fruit trees	6.47 44%	1.78	3.58 55%	44% Rain fed 66% Wells	Clay, Cyltique	64.5% sold 35.5% self-consumption
Vegetables	3.68 25%	1.56	1.3 35%	48% Rain fed 52% wells	Clay, calcaric	50.5% sold 49.4 self-consumption
Olives	3.46 24%	0.90	1.69 48%	19% Rain fed 81% wells	Clay, cyltique, calcaric	56.5% sold 43.5% self-consumption.

Medwi

Medwi is characterized by small farms on an average of 0.5 ha and there is no possibility for the farmers to rent land. the irrigation source is the lake and the dominant crops cultivated in the area are apricots, cherries, apples, tomatoes, cucumbers, haricot. The part of production that goes to self-consumption is very little and inferior to the part of production sold.

Table 3 :Main characteristics of farm types in Medwi

Farm type	Size	Rented land (ha)	Irrigated area	Irrigation source	Soil type	Production reason
Fruit trees	0.64 59%	-	0.64 100%	46% Rain fed 54% Lake	Clay, Celtique	94.8% sold 5.2% self-consumption
Vegetables	0.43 41%	-	0.43 100%	17% Rain fed 83% Lake	Clay, Celtiqe	98.3% sold 1.7% self-consumption

Bouday

In Bouday there is a diversity of farms considering their size which varies from 1.47 (smallest farm type) to 7.73 ha which is the biggest farm type focused on vegetables production. The farmers except their own land, also rent land to expand their production which in Bouday goes primarily for sale and only a small percentage up to 13 % is consumed within the farm. Tabaco, wheat, olives, cherries, barley, onions, cucumber and tomatoes are among the most cultivated crops. Farmers of the area take water for irrigation from lakes and wells.

Table 4:Main characteristics of farm types in Bouday

Farm type	Size	Rented land (ha)	Irrigated area	Irrigation source	Soil type	Production reason
Fruit trees	2.65 15%	0.70	0.05 2%	90% Rain fed, 10% lake	Red, silt	93% sold 7% self-cons
Vegetables	7.73 44%	0.09	7.45 96.5%	9% Rain fed 82% lake 9% wells	Red, silt, white	98 % sold, 2% self-cons
Cereals	3 17%	0.14	1.91 63.7%	62% Rain fed 33% lake 5% wells	Red, silt, white	86.4 % sold 13.6% self-cons
Tabaco	2.73 16%	0.44	1.94 71.1%	50% Rain fed 37.5% lake 12.5% wells	Red, silt, white	87 % sold 13% self-cons

Tabaco/Cereals	1.47 8%	0.55	0.55 37.3%	50% Rain fed 50% lake	Red, silt, white	89 % sold 11% self-cons

Nahleh

In Nahleh, the three farm types are around 0.5 ha and only the system of fruit trees rents land. Fruit trees and cereal farms are mostly rain fed, meanwhile vegetable farms are totally irrigated by wells and lakes. Farms in Nahleh have also access to the river for irrigation. The crops that are cultivated the most are: apricots, cherries, apples, figs, nuts, almonds, olives, haricot, potatoes, tomatoes, cucumbers, barley, onions, chick peas and more than 65 % of this production goes for sale.

Table 5:: Main characteristics of farm types in Nahleh

Farm type	Size	Rented land (ha)	Irrigated area	Irrigation source	Soil type	Production reason
Fruit trees	0.47 39%	0.01	0.19 40 %	60% Rain fed, 22% Lake, 9% River + wells, 9% Wells	Calcaric	65.4 % sold 34.6% self-consumption
Vegetables	0.19 16%	-	0.19 100%	66% wells 44% lake	Calcaric	80% sold, 20% self-consumption
Cereals	0.55 15%	-	-	82% Rain fed, 18% lake	Calcaric	79% sold 21% self-consumption.

1. Farm type selection

In order to continue with the modelling of the farm types in the study area we need to choose some of the farm types that we will simulate in the model. Based on the criteria that are important to the study area coming from the literature and the problems of the zone we will select the farm types representative and the ones that better cover all the diversity of agricultural system of the area.

To do this selection:

- Choose some of the most important criteria that will help to select the farm types to simulate. I choose the access to resources such as labor and irrigation and the level of farmer's revenue to see how the use of these factors will be reflected in farmers' revenues considering that these are limiting factors for the farms and their use will affect the final production and revenues.
- Taking into consideration the factors mentioned above we make a division of the farm types considering the level of intensification into extensive and intensive ones and also the level of revenues so in the end our farms will be divided into four categories: extensive farms with low revenues, intensive farms with low revenues, extensive farms with high revenues, intensive farms with low revenues. In order to do this, we build a graph with two axes where in the horizontal axe it is the revenues and in the vertical one the use of labor and irrigation. The axes will cross each other on the point where we have the average revenues and average use of labor and irrigation. So all the farms types that have revenues

lower than 9940$ will be positioned on the left side hand of the graph, on the left of the vertical axe and the one with revenues higher than 9940$ will be considered high revenues farm types and will be on the right hand size of the vertical axe. The same logic is used for the labor and irrigation where the farm types with water use less than 12396 m^3 and labor less than 47 persons per ha which is the average for the 14 farm types, they are considered extensive farm types and the ones with a higher use of resources are considered intensive farm types.

- After making this categorization it is important to see the dominant farms among these categories in order to decide which one of the farm types we will select from each category based on the importance in terms of dominance in area.
- To select the farm types to simulate we take into consideration the combination of the intensification level with the revenues and dominance. This means that for each combination of intensity and revenues we will take at least one farm type which will be representing that category.

Figure 5:Scheme of farm type selection based on revenues and water use

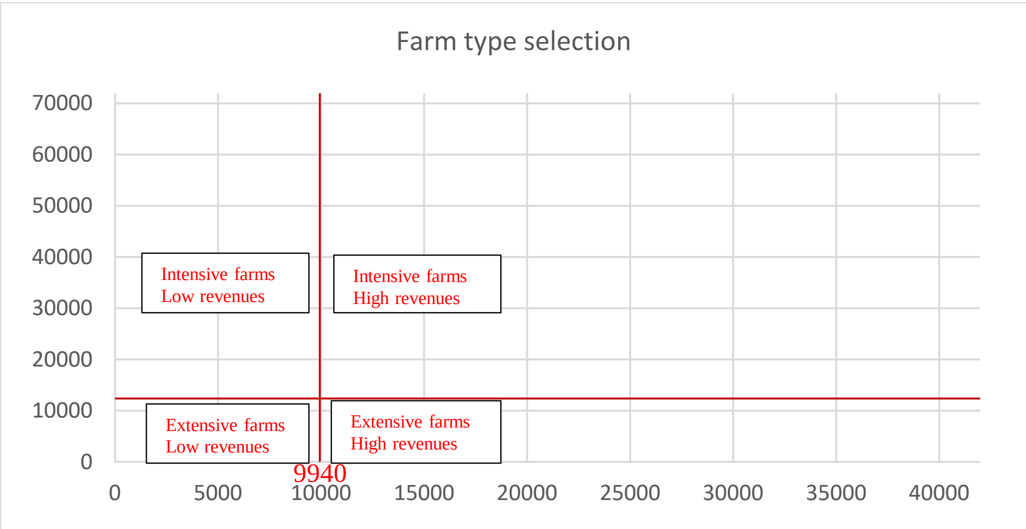


Figure 6:Scheme of farm type selection based on revenues and labor use

The farm types that were chosen as most representative are described shortly on the table below.

Table 6:main characteristics of selected farm type

Village	Hermel		Medwi	Bouday		Nahleh
Farm type	Almonds	Olives	Vegetables	Trees	Vegetables	Trees
Revenues	5437	41251	12890	2085	6272	1499
Gross Margin	5287	40978	12248	1987	6147	1315
Labor (person/ha)	40	73	195	23	15	38
Irrigation (m3/farm)	643	11282	12617	3000	76800	71691

According to the database, the olive farm type in Hermel has the highest revenues when compared with the other farm types. However, it doesn't use as much water and labor as the other farm types. On the other hand, there are farm types that use more water and labor but have lower revenues in return. With the help of bio-economic modeling we are going to test the performance of these different types of farms that are sometime extensive in labor use but intensive in water use or the contrary and generating a certain level of revenues.

II - Bio economic modelling

1. Models

Bio economic modelling is the model that was used in this study to analyze the farmers' behavior when presented with environmental challenges such as temperature changes, rainfall. GAMS is the tool that was used to write the bio economic model and it is a software package for designing and solving various types of models. GAMS is the abbreviation for General Algebraic Modeling System and it was developed by economists at the World Bank for economic models, but it is very useful also in any other field of study (Minot, 2009).

The following model is a mathematical programming model with the goal to optimize farmers' revenues while taking into consideration several limiting factors like the available land, water and labor. The planning horizon of the model is ten years and it is a dynamic model.

The model includes a biophysical part which explains the impact of rainfall on yield. The rainfall data is taken from the local station of Mansoura near Hermel and it contains rainfall data for 10 years.

The model calculates the maximal and the real evapotranspiration for crop cycle which is calculated based on several components like irrigation dose, rainfall, land occupation per crop, efficiency of irrigation technic, crop coefficient, Et0, Ky (Yield sensibility to water stress), soil useful reserve.

The evapotranspiration is then used to calculate the yield for ten years and for different cropping systems, irrigation systems, soil types.

Objective function

The objective function is a maximization function of the farmers' revenues over the years taking into consideration the risk.

$$U = \Sigma MBtotal(t) - \Sigma(PHI * ecartype(t))$$

Where :

- MBtotal(t)- Gross margin for à given year t,
- PHI- risk aversion coefficient,
- Ecartype- standard deviation of farmers revenues

-The risk aversion coefficient is used in this model to calibrate the results

The standard deviation is calculated

$$Ecartype(t)=\sqrt{(MBtotal(t)\text{-}RALrdt(Emar,t))^2}$$

Where:

RALrdt(Emar,t)- random revenues according to market state for a given year

RALrdt is calculated as:

$$\mathrm{RALrdt} = (\mathrm{X(c, I, sol, ti, s, t)} * \left(\mathrm{pxc(c, t)}\right) * \mathrm{varpxc(Emar, c)} * \mathrm{Rdt\_r(c, i, sol, ti, t)} - \mathrm{cout\_tot(t)}$$

Where:

- Pxc(c,t) - selling price per crop and year
- Varpxc(Emar,c)- price variation according to market state
- Rdt_r(c,I,col,ti,t)-real yield

In the model we don't specify the part of production that goes for self-consumption and it is for this reason that we put a low selling price for the crops that are produced for self-consumption, in order to represent their costs but not to calculate a profit.

Land renting capacity

The ability of the farmers to rent land is a characteristic of this model and the total area of land that he can rent depends on the yearly incomes (gross margin).

$$minivit + (Surf\_louee('louee', t) * \sum_i loc\_terre(i) \leq MB\_total(t)$$

Where :

- Minivit
- Surf_louee1('louee', t)
- Loc_terre (i)
- MB_total(t)

Land constraint

The actual area that the farmer has together with the area that he rents and can rent should be equal to or greater than the sum of the areas that can be used for the cultivation of each crop.

$$\sum_{c,i,sol,s,ti} x(c,i,sol,ti,s,t) \leq Surf\_propre + Surf\_louee1(t)$$

Where:

- x(c,i,sol,ti,s,t)-area for each crop(c), crop management dry or irrigated (i), soil type(sol), Irrigation source (ti), land status own or rented (s) for a given year t
- Surf_propre- land owned by the farmer
- Surf_louee1(t)- land that the farmer can rent during a year

The area for the crops cultivated in the land owned by the farmers should be less than or equal to the area that he possesses.

$$\sum_{C\_p,i,sol,ti} x(C\_p,i,sol,ti,'propre',t) \leq Surf\_propre$$

Where:

- C_p- crop cultivated in farmers own land

The area for the crops cultivated in rented land should be less than or equal to the area of land that the farmer can possibly rent during a year.

$$\sum_{C\_l,i,sol,ti} x(C_l,i,sol,ti,'louee',t) \leq Surf\_louee1\ (t)$$

Where:

- C_l- crops that can be cultivated in rented land

Fruit trees

Fruit trees are perennial crop and for this reason the area dedicated to these crops cannot vary from year to year so we fix this area to be the same for all the years and to be equal to the area of fruit trees that we have from the surveys.

$$\sum_{i,sol,ti} x(Ca,i,sol,ti,s,t) = Surf\_Arbo(ca,s,t)$$

Where :

- x(Ca,i,sol,ti,s,t)- area dedicated to fruit trees
- surf_arbo(ca,s,t)- fruit trees area in reality

Labor constraint

The labor requirements for production for a given year should not exceed the availability of labor which is composed by family labor and hired labor.

$$\sum_{c,i,sol,s,ti} x(c,i,sol,ti,s,t) * bmoc\_J(c,task) \leq dmofamilial\_J + MO\_louee$$

Where:

- Bmoc_J(c,task)- the labour needs for each crop and each task

- Dmofamilial_J – availability of family labour in days
- MO_louee- rented labour

Water constraint

The quantity of water used by the farmers for irrigation for the specific area for each crop should not exceed the water availability.

$$\sum_{c,i,sol,ti} x(c,i,sol,ti,s,t) * doseirri(c,i,sol,ti,t) \leq deau(t,s)$$

Where:

- doseirri(c,I,sol,ti,t)- irrigation dose for each crop
- deau(t,s)- water availability for a year and land type own or rented.

2. Calibration

Calibration consists in adapting a model to a set of observed data to allow its application to similar conditions. To calibrate this model, we look at different results of the model such as the crop area and yield and we compare the simulated values in the model with the observed ones in reality. In order to get the most similar results to the reality we can calibrate the model by changing the risk aversion coefficient and also the price variability values. When changing the price variability, it affects the areas allocated to each crop in the model and in this way we can regulate the model to approximate the results with the reality. Another way to check if the model is calibrated and represents well the reality is to see the yield. If these values are similar to the real data, then the model represents well the reality and we can use these results to test scenarios and do predictions for the years to come.

In order to see if the results of the model concerning the rotation are correct and well calibrated, the following equation can be used:

$$Area = \frac{surf\_crop(c) + x.l(c,i,sol,ti,s,t)}{surf\_crop(c)} * 100$$

Where :

- surf_crop(c)- observed crop area
- X.l(c,I,sol,ti,s,t)- simulated crop area

The closer this value is to 100 the more the results are well calibrated and the closer the model is to representing reality.

For the yield the following equation is used in order to check the results:

$$Calibration\_Yield = \frac{rdtm\ (c,i,sol,ti,t) + Rdt\_r(c,i,sol,ti,t)}{rdtm\ (c,i,sol,ti,t)} * 100$$

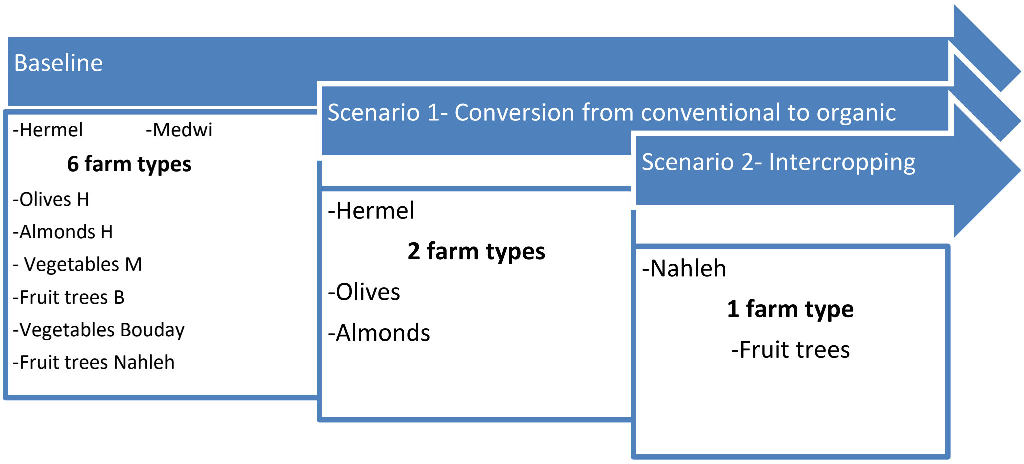
Where:

- Rdtm(c,I,sol,ti,t)- observed values of the yield
- Rdt_r(c,I,sol,ti,t)- simulated yield.

The closer the calibration value is to 0 that means the closer the value of the simulated yield is to the observed one and we have a well calibrated model.

III - Scenarios

Figure 7: Scenarios



1. Scenario 1: Conversion of olive and almond systems to organic

The scenarios that will be simulated in the model are chosen because of the importance given to them by the actors in the field and also related with the actual situation in the area not only regarding the climate and rainfall but also taking into consideration the production patterns and technology. Two big groups of scenarios that will be tested are: the conversion from conventional to organic production for olives and almonds systems and the introduction of intercropping as an agriculture practice.

The first scenario will be tested in Hermel which is one of the villages that are part of the study and is the driest area of all so the opportunities are limited and the conversion to organic is seen as one of the opportunities to be competitive and increase the revenues. The second scenario will be tested in Nahleh which is considered as a more wet area and has a higher precipitation.

The first scenario to be tested is the conversion of olives and almonds systems from conventional to organic. This scenario will be tested in two farm types in Hermel and the conversion will be applied only to olives and almond systems which are already in the way of organic production. According to the field experts, the producers of olives and almonds have already made the first steps towards the organic production with the low use of pesticides and the use of organic fertilizers. The scenario will help to see if the conversion to organic production will bring farmers higher revenues and also if they choose to adopt this type of production when will they decide to do this conversion and when it will be profitable for them as well as what part of their land will they dedicate to the organic production?

One hypothesis is that the conversion to organic will bring farmers higher revenues in the long term. In order to test this scenario, it is needed to add a new set in the baseline model which will allow the model to choose between conventional and organic technic of production for the olives and almond system. The next thing to do is to set a condition so that the model can decide on the area that it will be converted from conventional to organic.

In this scenario we consider that in the first year of stimulation the total land will be dedicated only to the conventional production and in the next years it can decide to convert to organic production, but each year the area dedicated to organic production can be only equal to or greater than the area of the previous year, meaning that the farmer once he decides to convert to organic cannot go back to conventional production.

The time also is an important factor in the simulation of this scenario because we consider that there is a difference in the yield that a crop can give in the first years of conversion to organic compared with the following years. So, in order to see this change in the model an option is to have different value for the yield for the 5 first year which will be lower that the yield of conventional product and then a different value for the other years where the organic production will be giving higher yields.

In order to test the scenario of conversion from conventional to organic production, it is needed to add a new set in the baseline model which will allow the model to choose between conventional and organic technic of production for the olives and almond systems. The next thing to do is to set a condition so that the model can decide on the area that it will be converted from conventional to organic.

The constraint that obliges the model to choose only conventional olives in the first year:

$$\sum_{i,sol,ti,s} X('olivier', i, sol, ti, s, 'conv', t) = Surf\_Arbo('olivier', 'propre', t) + Surf\_Arbo('olivier', louee', t)$$

In the end it is needed a constraint that indicates that once the total area of the crop is converted to organic it will remain the same even in the following years.

$$\sum_{i,sol,ti,s} X('olivier', i, sol, ti, s, 'conv', t) \leq \sum_{i,sol,ti,t,s} X('olivier', i, sol, ti, s, 'conv', t-1)$$

This equation explains the fact that the land dedicated to organic production the first year will be

$$\sum_{i,sol,ti,s} X(c, i, sol, ti, s, 'org', t) = 0$$

This equation enables the model to choose the area to convert to organic for each year to be greater than the area of organic production for a previous year.

$$\sum_{i,sol,ti,s} X(c, i, sol, ti, s, 'org', t) \geq \sum_{i,sol,ti,t,s} X(c, i, sol, ti, s, 'org', t-1)$$

The last equation explains that the sum of areas for conventional and organic olives should be equal to the actual area of olives.

$$\sum_{i,sol,ti,s} X('olivier', i, sol, ti, s, 'conv', t) + \sum_{i,sol,ti,s} X('olivier', i, sol, ti, s, 'org, t) = Surf\_Arbo('olivier', 'propre', t)$$

2. **Scenario 2: Intercropping**

Intercropping is the scenario that will be tested in Nahleh for fruit trees system where the aim of the scenario is to introduce new crops in the current production system with the goal to optimize the use of its land and increase the yields at the same time.

Concretely, in fruit trees farms in Nahleh we introduce in the model a crop that is the combination of two existing crops in the system. In our case we introduce two new crops: olive_haricot and cerise_haricot. For the new crops their costs will be represented by the sum of the costs of each crop separately while for the prices and yield it is needed to do an estimation. In order to determine the price of the new crops we assume that the price will be composed of two thirds of the price of the tree crops (olives and cherries), and one thirds of the price of haricot.

The equation to be adapted for this scenario is the land constraint for the fruit trees where the left hand size of the equation or the sum of areas for olive and olive_haricot, should be equal to olive area.

$$\sum_{i,sol,ti} X('olive', i, sol, ti, s, 'propre', t) + \sum_{i,sol,ti} X('olive\_haricot', i, sol, ti, 'propre', t) = Surf\_Arbo('olivier', 'propre', t)$$

Part 3

Results

I - Calibration results

To calibrate the model, the area allocated to each crop (simulated area as an average of 10 years) is compared with the observed area of the crops (annex 2). The risk aversion coefficient as well as price variability is used to correct the areas and to get similar results. The model is calibrated when the simulated areas of fruit trees are the same with the observed ones and for the annual crops the simulated area should be equal to the observed one if we take them as a single crop and not separately.

Table 7 shows the results for olive farm type in Hermel where the observed area for salad, thyme, tomato, haricot and mlukhiye is 1.16 ha while the simulate area for the same crops is 1.17 ha, which means that the model is well calibrated in terms of crop area.

Table 7:Calibration of the areas in the model

Olives Hermel	Observed area		Simulated area	
	Own land	Rented land	Own land	Rented land
Nuts	0.22	-	0.22	-
Olives	1.2	0.9	1.2	0.9
Salad	0.09	-	-	1.07
Thyme	0.9	-	0.89	-
Tomato	0.04	-	0.28	
Haricot	0.09	-	-	
Mlukhiye	0.04	-	-	
Total area	**2.56**	**0.9**	**2.56**	**1.97**

The graph nr.8 shows the simulated and observed areas for each farm type depending on the land status that can be owned by the farmers or rented. We notice that for the crops cultivated on the land owned by the farmers the area is well simulated and the results are similar with the observed areas. Whereas for the crops that can be cultivated in rented land, the simulated areas are generally higher than the observed areas since the farmers have the possibility to rent up to 5 ha of land in most of the farm types modeled.

Figure 8: Calibrated area for each farm type and for type of land

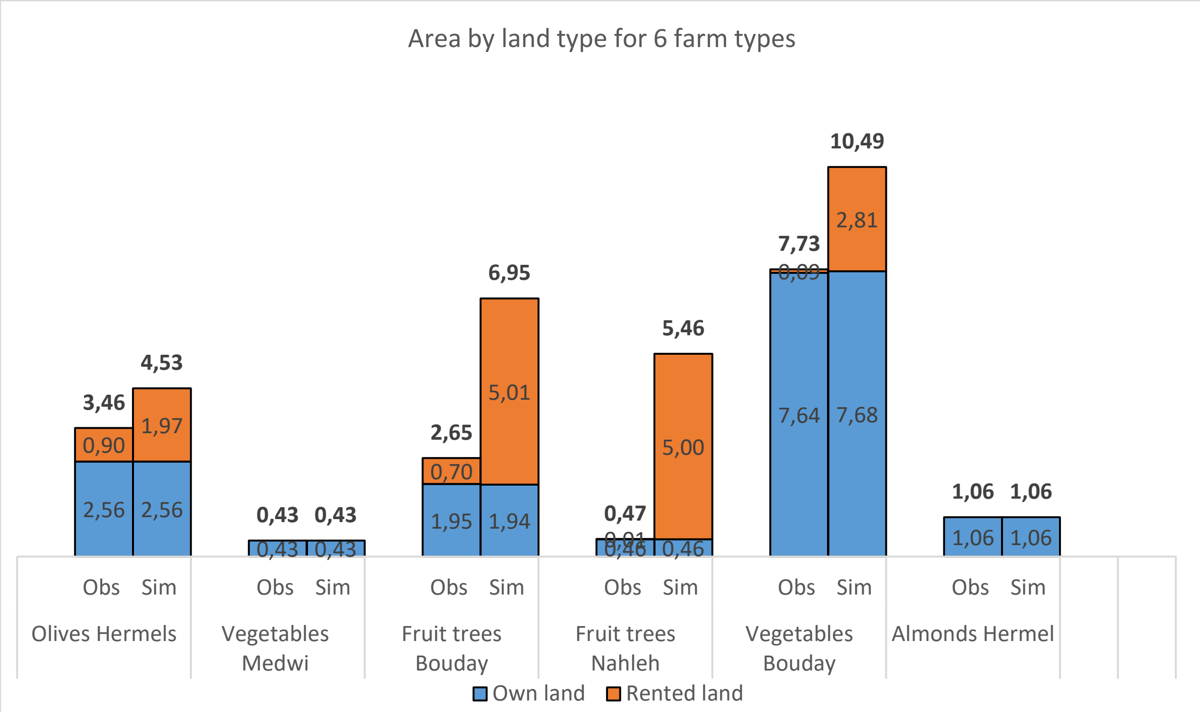
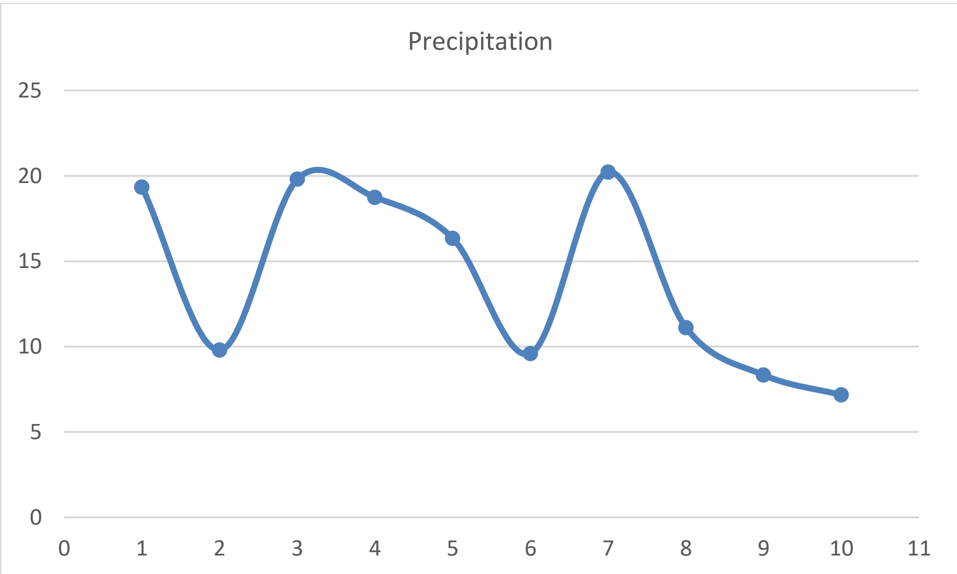


Figure 9 shows the average yearly precipitation in the study area for 10 years and it results that for the 1st year, 3rd year and 7th year the average rainfall is the highest which explains later on the variation of productivity per crop during these years.

Figure 9: Average precipitation for years 2009-2018



II - Results according to each farm type

1. Olive farms in Hermel

The farmers use all the available land for the production of their crops and the land is indeed a limiting factor in this farm type because the farmers could have greater revenues if they had more land to cultivate, and 1 ha of additional land would bring them a profit of around 10000 dollars. Looking at the situation, the farmers of this farm type rent up to 1.97 ha of land. Not only land, but water is a limiting factor too, but only for the crops cultivated in rented land where 1 m3 of additional water could make the farmers gain up to 16$ more.

Average revenue of olive farm type is around 38354.2 $ a year and its costs variate between 1600 to 1750$ per year.

The following graph (figure 10) shows the trend of gross margin for 10 years and considering the variation in precipitation during the same years which will have an impact in the productivity per crop. In the same graph is presented the farmers capacity to land rent and it can be seen that it goes in the same line with gross margin since their investment capacity depends directly on their revenues.

Figure 10: Gross margin and investment capacity

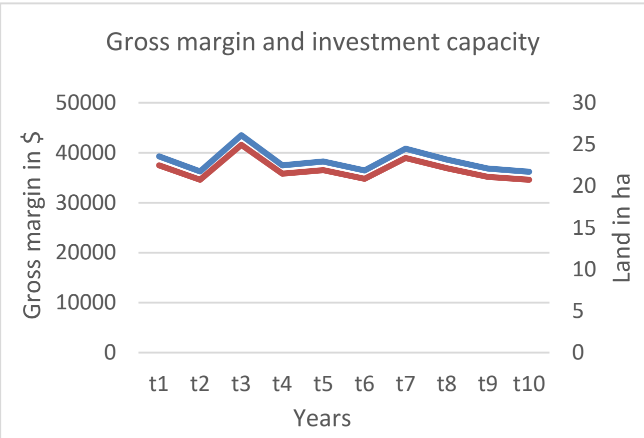


Figure 11: Distribution of gross margin per crop

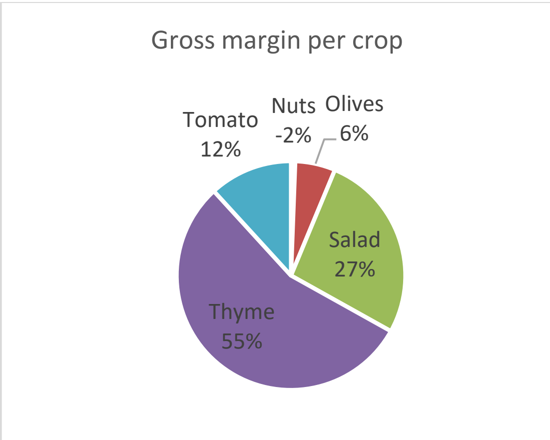


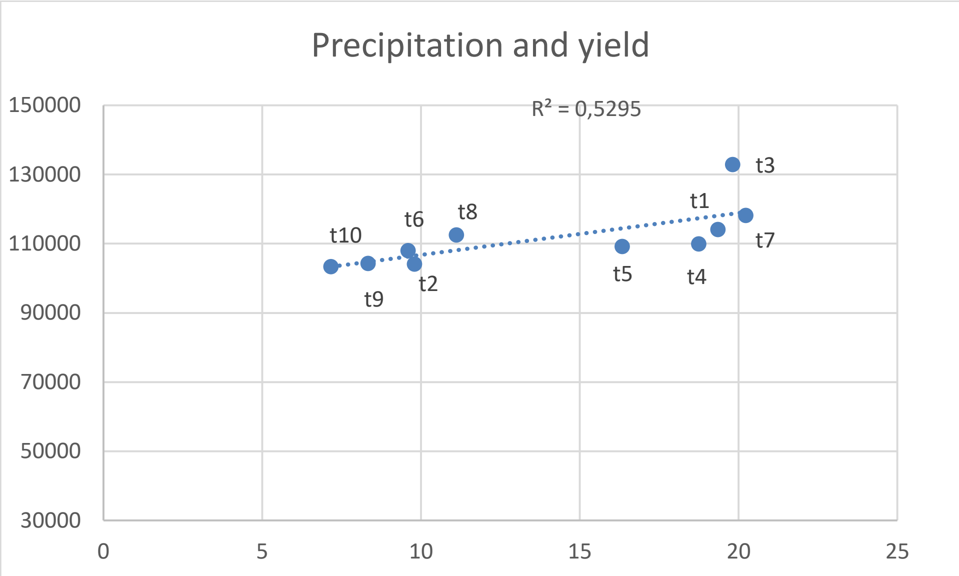
Figure 11 shows the contribution of each crop in the average gross margin and it shows that thyme is the most profitable crop for farm type 1, contributing up to 55% in the total gross margin. The less profitable crop for this farm type is nut, considering that it is a crop that is produced for self-consumption and it doesn't give a return in profit to the farmers.

30% (1.4 ha) of the total land is cultivated with rain fed crops while the other 70% (3.3 ha) of the land is allocated to irrigated crops.

Figure 12 shows the relation between the rainfall and yield for ten years of simulation and it shows that for the years when the average rainfall is higher the production will be higher which explains also the variation of gross margin between the years. For the 3rd and 7th year of simulation we get

a bigger production coming from an increase in the average annual rainfall and it's in these years that we have an increase in the gross margin. However, this is not true for all type of crops because looking at the results we notice that thyme has a stable average production during the years.

Figure 12:Yield and precipitation



2. **Almonds in Hermel**

In Hermel, almond farms have a fixed area for perennial crops so all the available land is cultivated and the farmers do not rent land because they have only two type of crops both of them fruit trees with a fixed area. The limiting factor in this farm type is the land since they use all the available area whereas for the water it is an opportunity factor since only a little part of the available water is used for irrigation.

Apple is produced for self-consumption that is why it affects the gross margin with a decrease of 0.5% while almonds give a maximal profit of 4500 dollars per year and the total cost for this farm type is 232$.

Despite the fact that apples give a considerable production and slightly lower than the one of almonds it affects negatively the gross margin being that they are produced for self-consumption so they don't give a profit to the farmers but only costs.

Depending on the value of gross margin per year the farmers have a capacity to rent up to 1.8 ha of land if they decide to cultivate other crops despite the perennial crops that they already grow.

Figure 13:Productivity per crop

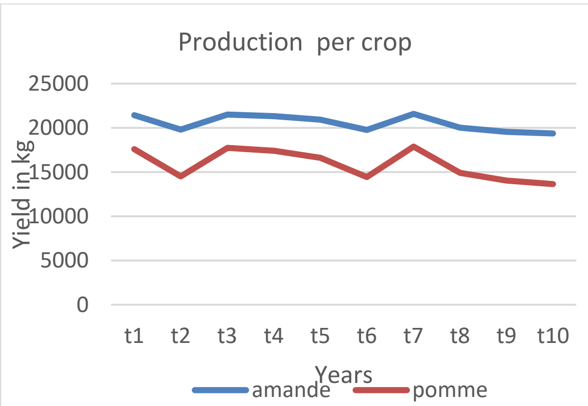
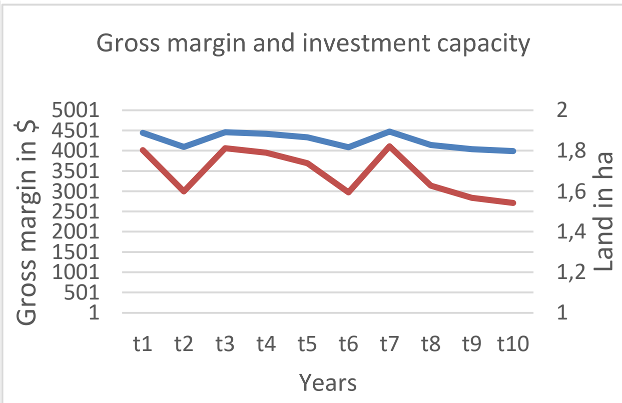


Figure 14:Gross margin & investment capacity



3. **Vegetables in Medwi**

The available land for this farm type is allocated mostly to cucumbers and tomatoes with a distribution of around 0.2 ha to each of the crops. Cucumber is the most profitable crop giving the farmers a gross margin of 10000$, while the tomato crop contributes with up to 1920$ in the total revenues and the total cost go up to 2660$. The farmers currently don't rent land but they have a renting capacity up to 1.2 ha per year based on their revenues.

The following graphs show the variation of gross margin for the 10 years of simulation which variates between 11000$ - 13500$.

Figure 15: Productivity per crop

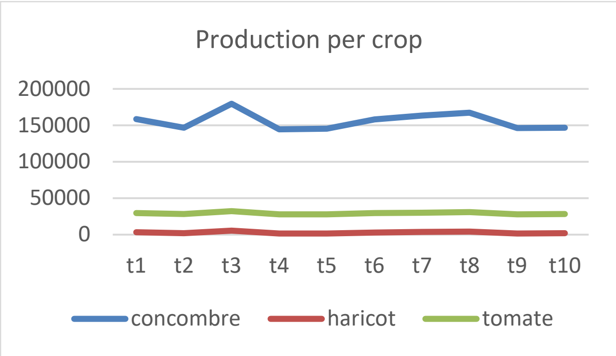
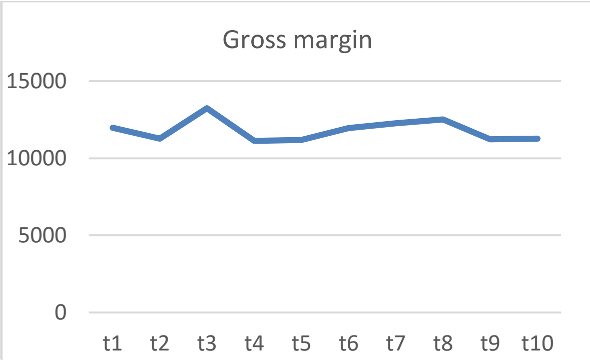


Figure 16:Gross margin



4. Fruit trees in Bouday

In Bouday, fruit trees farm type is using all the available land and with the available resources if the farmers had more land available they could have an additional profit of around 2500$ per year. This is why they use their land renting capacity to rent land up to 5 ha and most of the rented land is used for the production of wheat which is the most profitable crop for this farm type contributing with 42% in the gross margin. Despite the 5 ha of land that they actually rent they also have the possibility to rent another 2.4 ha considering the level of revenues that they have.

The most common crops cultivated in this farm type are wheat, Tabaco, figs and apricots which bring also the highest return in monetary value, whereas barley is cultivated only during one year in the simulation period.

Figure 17: Crop area

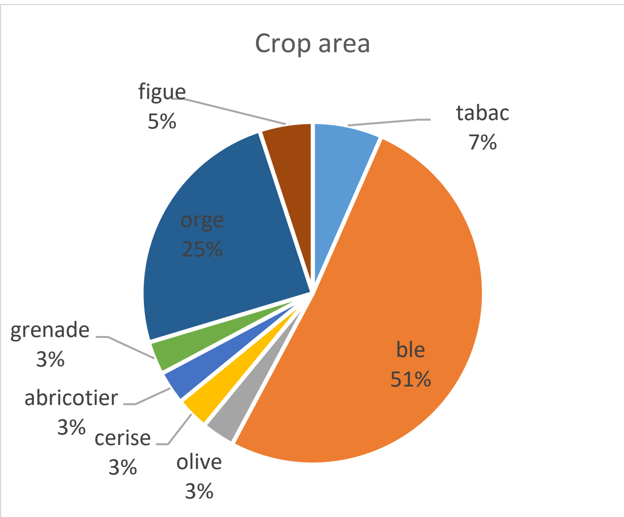
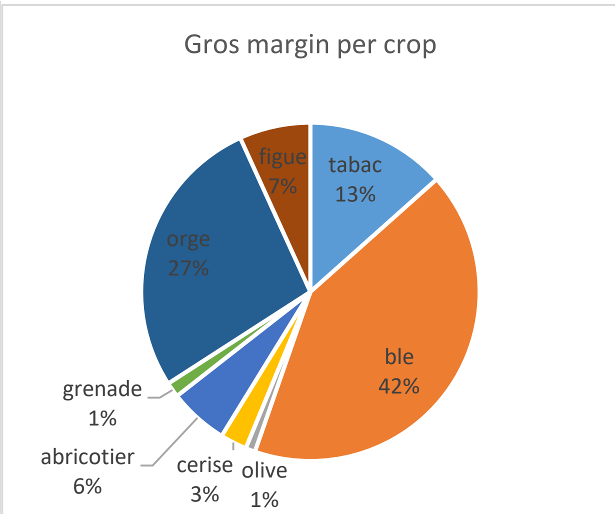


Figure 18:Gross margin per crop



5. **Vegetables in Bouday**

Vegetable systems in Bouday have a distribution of crop production between potatoes, Tabaco, wheat and onions. The total cultivated area is 9.8 ha which is divided between 7.64 ha own land and 2.1 ha rented land. Despite this, farmers have the capacity to invest in the renting of another 14.5 ha land. The total gross margin per year is around 153400$, with potatoes and Tabaco having the biggest impact in this value. Water in this farm type limits the production and it is completely used for both types of production in own or rented land. Not only water but land as well is a constraint since it is used totally for the production and a unit more of both resources could result in a profit for the farmers.

Figure 19:Crop area

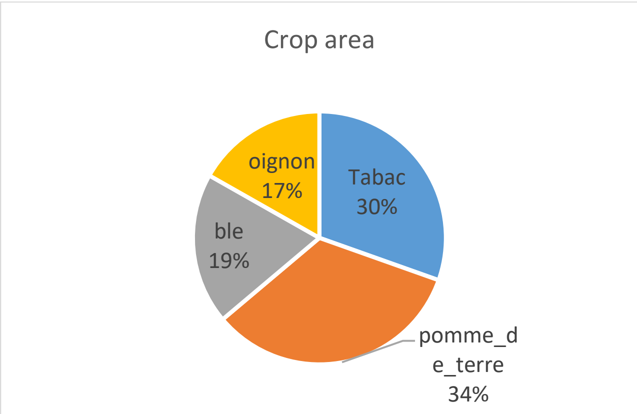
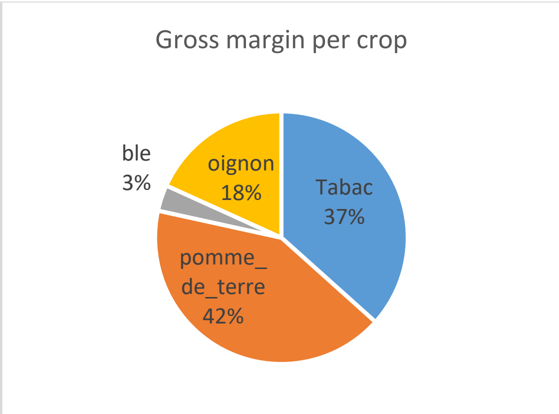


Figure 20:Gross margin per crop



6. **Fruit trees in Nahleh**

Average gross margin for 10 simulated years is around 110000$. The total area of 0.46 ha is distributed among several crops and another 5 ha of land is rented to produce potatoes, tomatoes and nuts. Despite the high costs of this farm type, farmers have the possibility to rent another 11 ha of land since its' availability is a limiting factor for the farmers and they would have higher profit for one ha of land cultivated beyond the farmers own land. In fact, the marginal value for one ha of land can go up to 15000$.

The distribution of crops is similar in farmers own land whereas the rented land is occupied by tomatoes and potatoes.

Figure 21:Crop area in own land

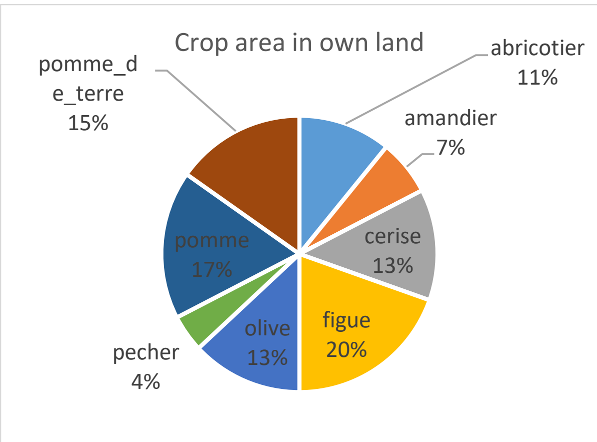
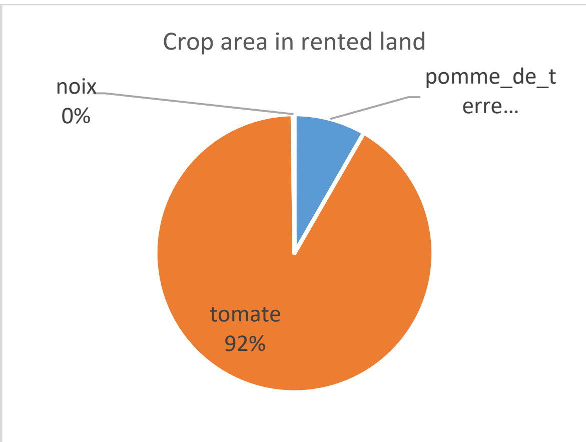


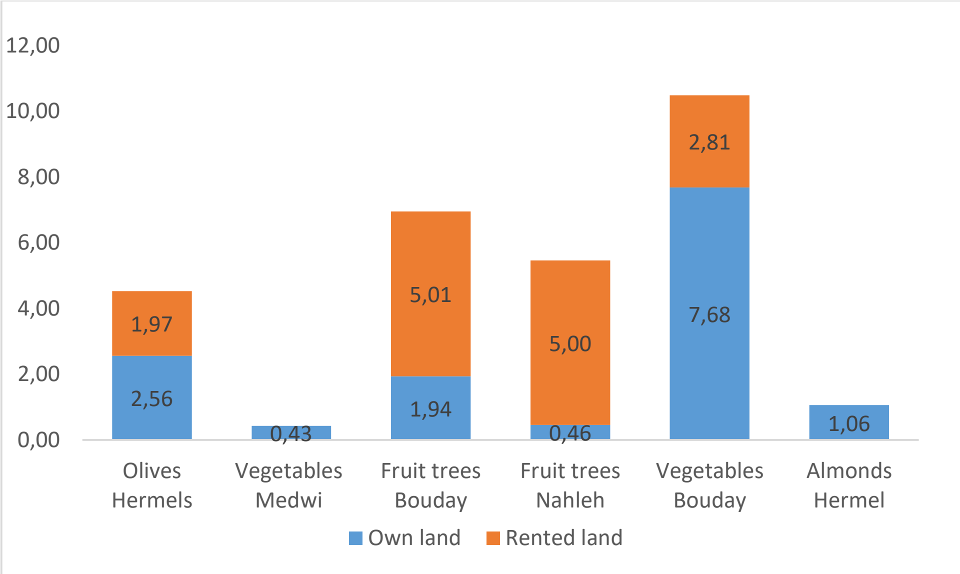
Figure 22:Crop area in rented land



III - Comparison of results between farm types

The following graph shows the cultivated areas for each of the farm types and we can see that for two of the farm types based on fruit trees production, the land is a constraint and they rent all the available land that is for rent.

Figure 23:Crop area for each farm type and land status



Crop area for each farm type

Graph 25 shows the dominant crops in terms of area for each of the farm types. There is a big diversity from farm to farm and the crops that are cultivated in bigger areas are mostly almonds, wheat, tomatoes, potatoes, olives, Tabaco and barley.

Figure 24:Crop area for each farm type (in ha)

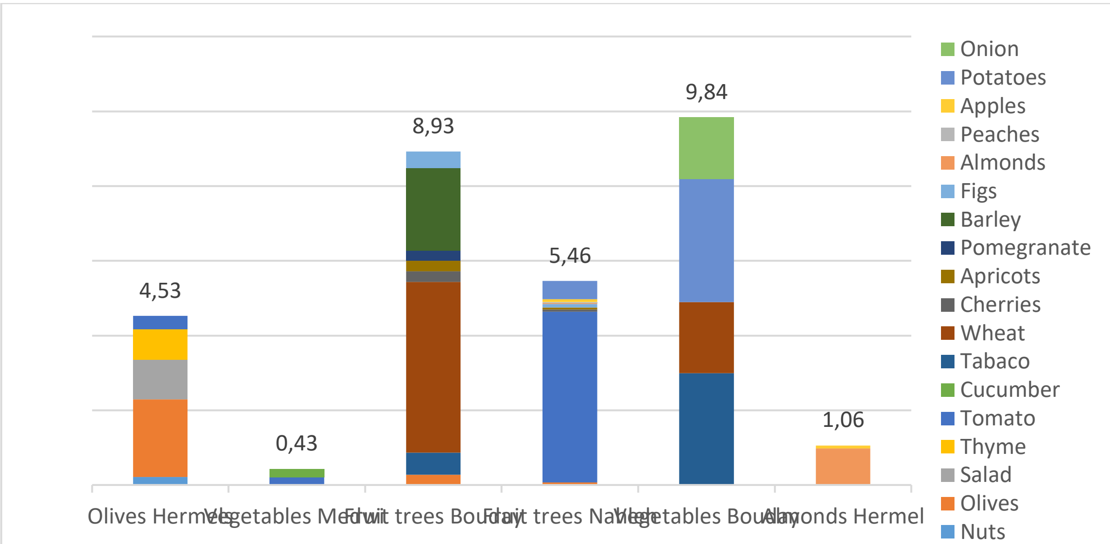
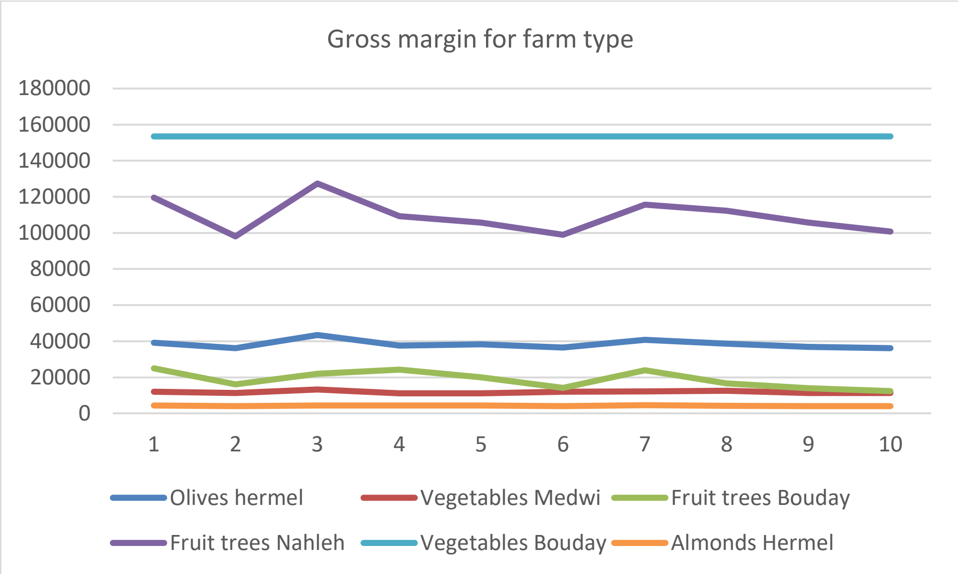


Figure 25 shows the trend of the average gross margin for each farm time during 10 years. We can notice that the gross margin for vegetables farms in Bouday is stable and it doesn't variate a lot between the years.

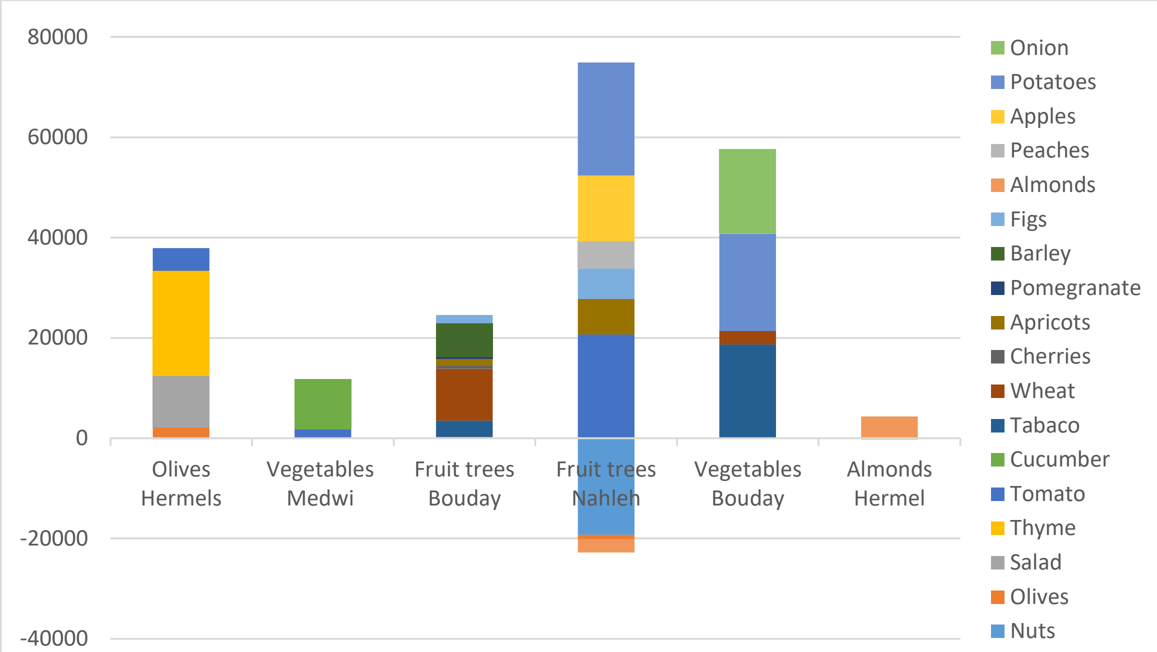
We can say the same thing for almond farms in Hermel and Vegetables farms in Medwi, while for the rest of the farm types there is bigger variation of the gross margin among the years. The highest values for the gross margin are in year 3 and 7 and it can be explained by the high amount of precipitation during the same years.

Figure 25:The trend of average gross margin for farm type



The following graph shows the most profitable crops for each of the farm types. The gross margin is calculated per crop and per farm so it takes into consideration the size of the land allocated to each crop. For olive farm the most profitable crops are thyme and salad, for vegetable farms in Medwi the most profitable one is cucumber while for fruit trees in Bouday wheat and barley are the two most important crops. As for fruit tree farms in Nahleh tomatoes, potatoes and apples are among the most profitable crops. In the meantime, vegetable farms in Bouday have Tabaco, onions and potatoes as the most profitable crops while almond is the most important crop in almond farms in Hermel.

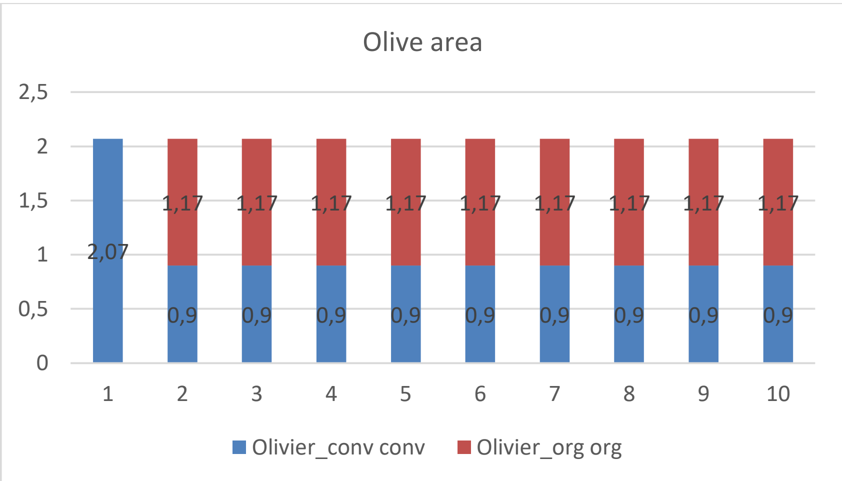
Figure 26:Contribution of each crop in the gross margin per farm type



IV - Conversion of olive &almond systems to organic

In the scenario of conversion of olive crop to organic the farmers continue to have the same area for the olive and in the first year they produce it only in conventional and starting from the second year they decide to convert a part of their production to organic while keeping less than half of the area in conventional.

Figure 27:Olive area after the implementation of scenario

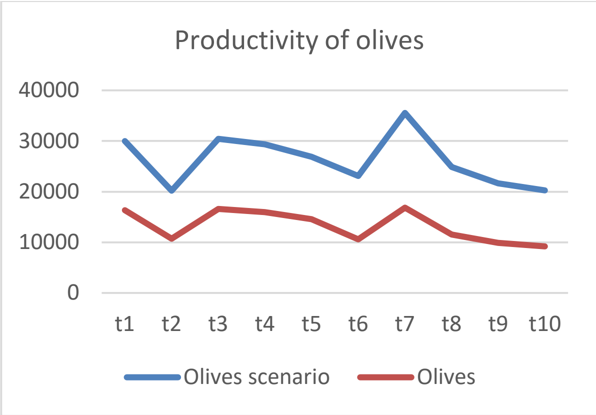


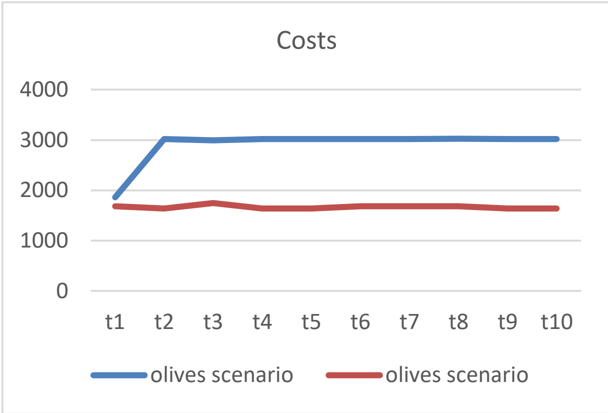
The productivity of olive crop increases by 45%-55% in the new situation where a part of it is converted into organic production.

In the graph 29 we see that after the implementation of the scenario of the conversion to organic for olive crops, the cost of production will almost double after the first year when the farmers convert a part of the olives production in organic

Figure 28:Productivity of olives in the baseline and after the implementation of the scenario

Figure 29:Cost after the conversion





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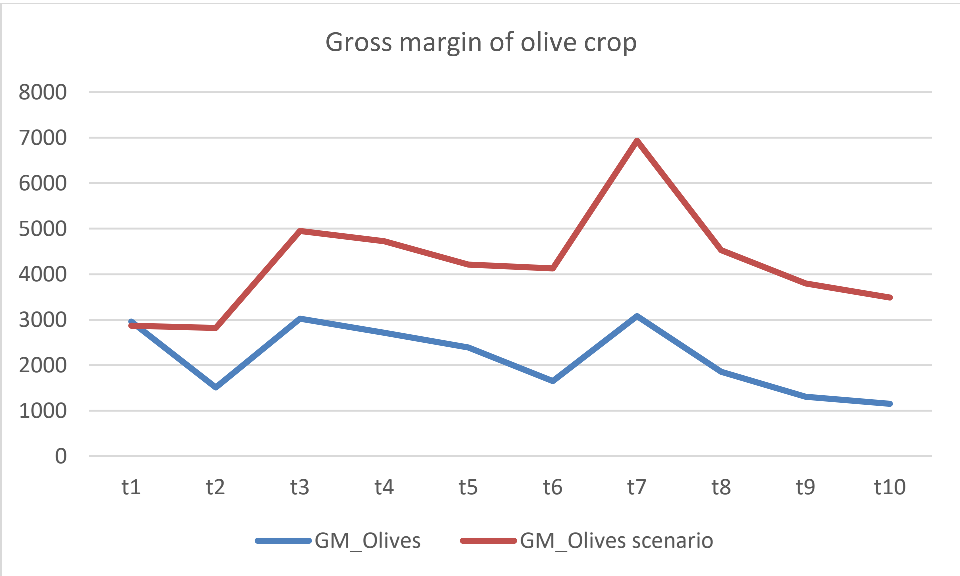
The gross margin for olives trees will be almost the same for the first year while the farmers are still producing in conventional, but after the first year it will increase by 87% in comparison with the gross margin of the conventional production and the increase in production for organic olives can go up to 200%.

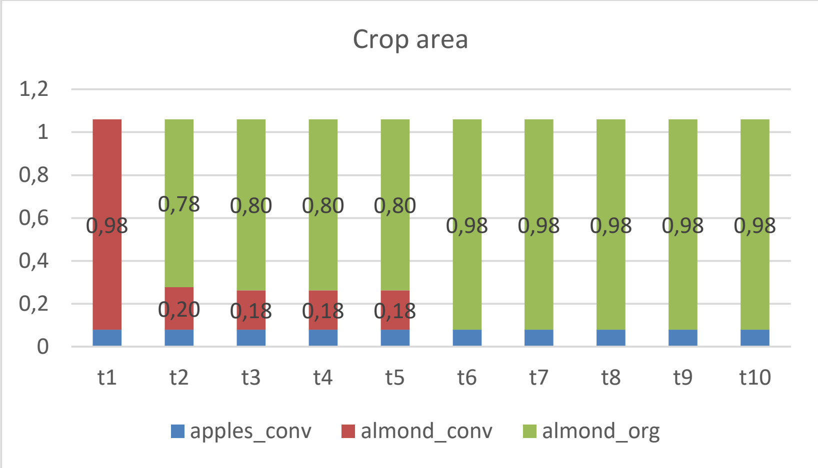
Figure 30:Gross margin for olive crop



V - Conversion of almond system to organic

When we implement the scenario of conversion to bio for almonds system in the first year the farmers will continue to produce in conventional way. The second year up to the 5th year, they decide to convert partially their almond production in organic until the 6th year when they convert all area allocated to almonds to organic production.

Figure 31:Crop area for almond system when converting to organic production



After the implementation of the scenario of conversion to organic for almond system it results that the conversion to organic will increase the productivity of almonds by up to 100% and the gross margin as well for this crop will increase.

Figure 32:Gross margin of almond after the conversion

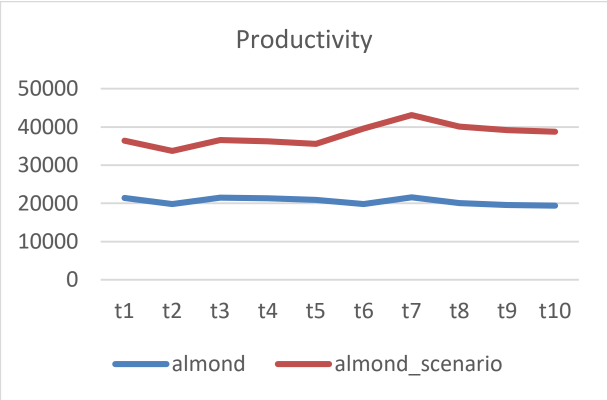
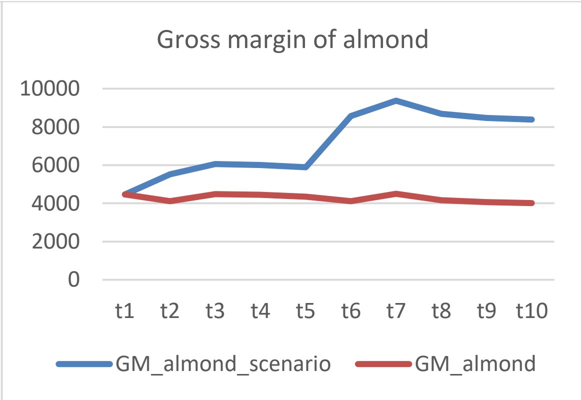


Figure 33:Gross margin after the conversion



VI - Intercropping

When introducing the 2 new crops in the farming system the area allocated to each crop will change.

The difference from the baseline to scenario is that we have the substitution of cherries and olives with the new crops that and during the years they will exchange areas as in figure.

Figure 34:Crop area for fruit trees in Nahleh

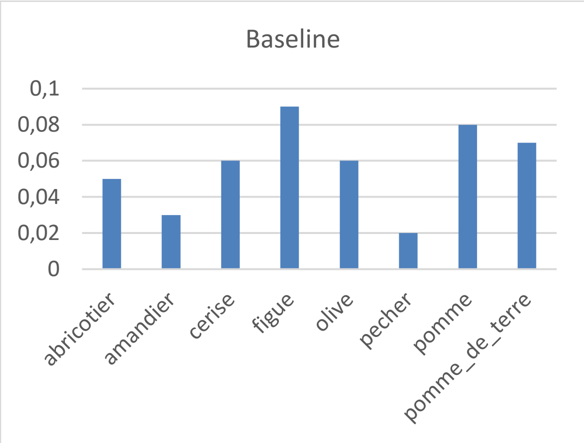
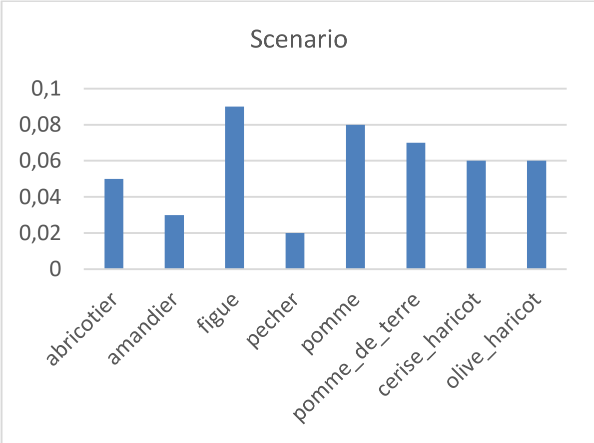
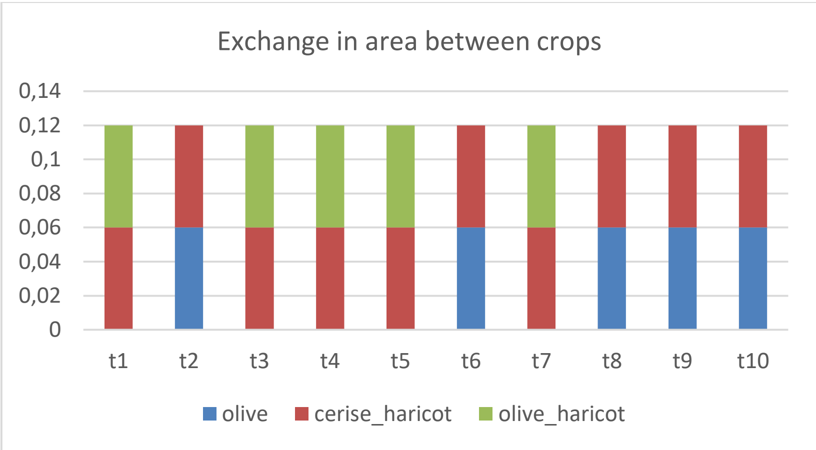


Figure 35: Crop area after the implementation of the scenario



The total area of the crops included in the intercropping doesn’t change during the years but what changes is the area per crop. For half of the area, the new crop cherries_haricot is cultivated during all the years while for the other half it is allocated to olives or the new crop olives_haricot.

Figure 36:Exchange in area between crops



Part 4

Conclusion and discussion

The main objective of this study was to look at the impact of climate change and more specifically the variability of rainfall and what would be its impact on the production during 10 years focusing on 6 types of representative farms in the study area and taking into account that they consist on irrigated and rain fed crops. Although the farms are in different villages, the level of rainfall is considered the same for all four villages and the average rainfall is used to calculate the production of each crop in these farm types.

To answer the main objective of the theses we use bio economic modelling as one of the best methods that incorporates biophysical and economic aspects in order to assess the impact of precipitation on the productivity of farms and simulate it for several years with the goal to predict future trends and to be able to analyse the effect of these external shocks. A big advantage in the use of these models is that with the right data they allow you to analyse a wide variety of indicators and also it is easy to replicate it for other farm types and conditions.

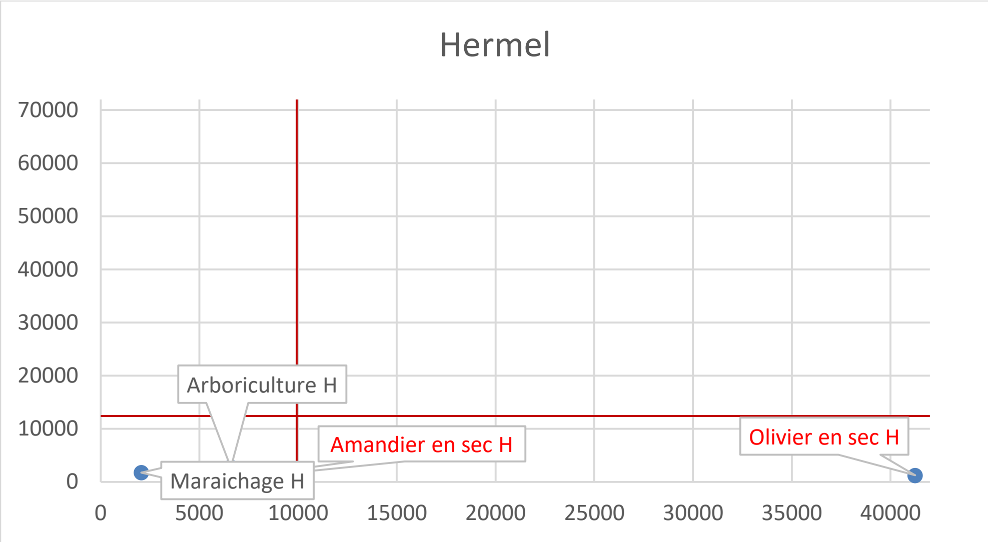
The analysis showed that the level of precipitation impacts the production, which is then reflected in the gross margin of each farm in such a way that in years where the level of precipitation is higher, the production of plants will be higher. But this applies only to plants that have a strong relationship with the level of precipitation and their fluctuation will decrease or increase production.

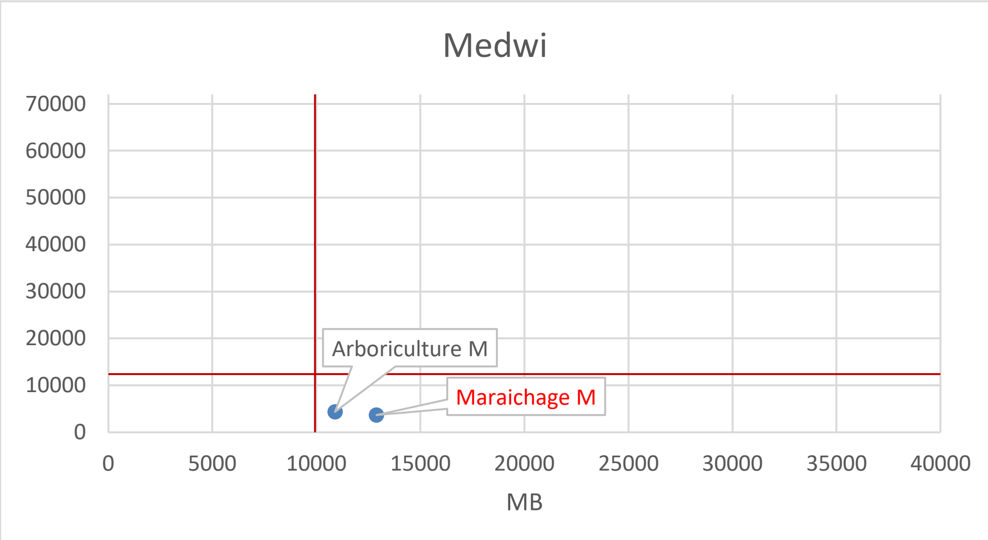
One of the main limitations that we faced during our work with the database was the quality of data. This problem was noticed during the process of introducing the data in the models where it resulted that several data was missing concerning generally the costs of production while some other such as yield and prices seemed to be fictive in some cases due to the fact that the farmers tend to hide sometimes the real information about these data and don't give the true answers. This is something that affect directly the work with the models since it will be hard to represent correctly the real situation and it will affect later on the possibility to predict future changes and to evaluate policy measures.

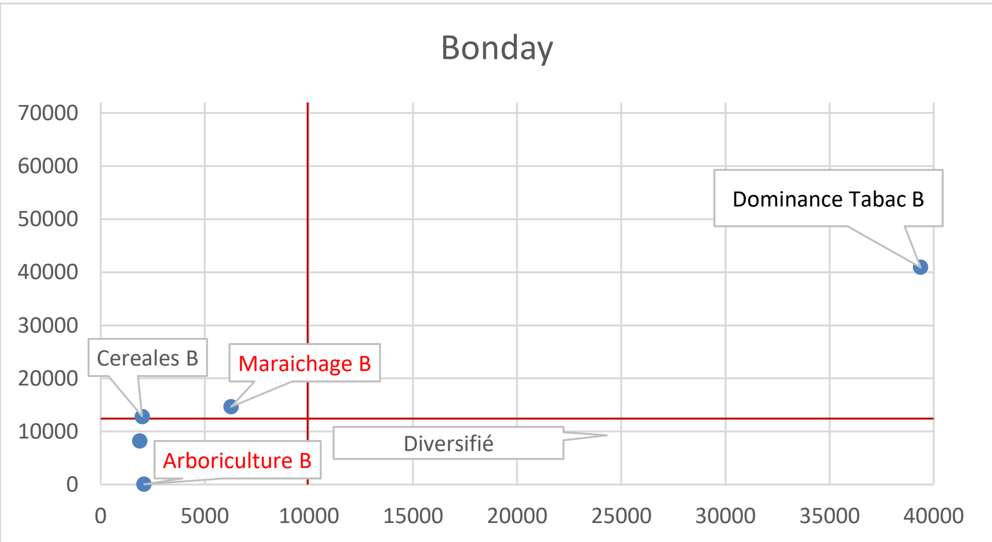
Another limitation of this work is related with the modelling of the farm types. the fact that we didn't divide in the model the self- consumption part from the part of production that goes for sale in the market is a weakness of this model and this creates problems with the results. Since we are calculating the crops that are partially for self-consumption as crops that are for sale, we will have an over estimation of the revenues. In order to be able to justify the production of crops for self-consumption in the model, we put a low selling price for these crops and in this way we artificially fix the problem of having higher revenues by crops that aren't in reality for sale but this isn't the best way to do that and it doesn't generate the best results. This is something that can be changed in future applications of the model in order to get more accurate results and to have a better representation of the reality.

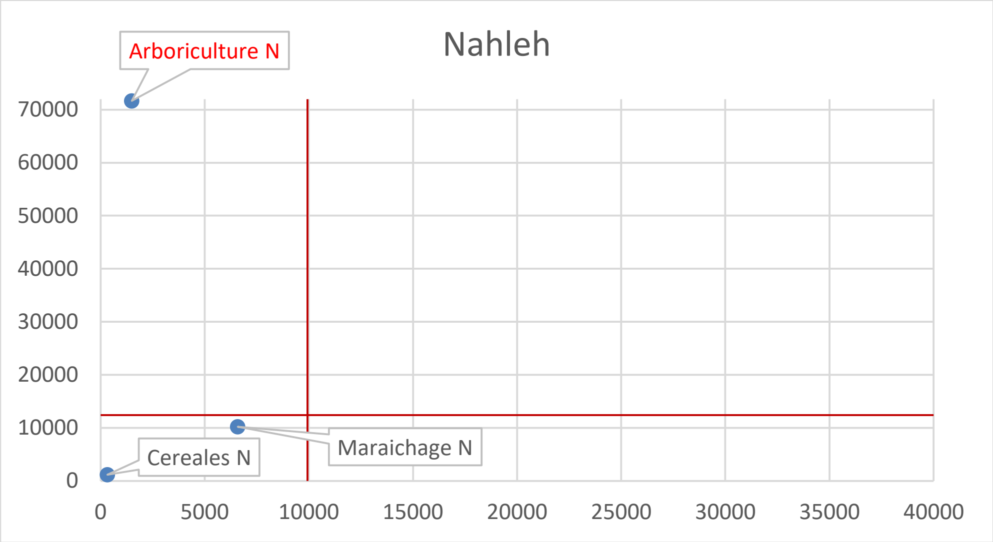
Annex 1

Farm type selection based on revenues and irrigation

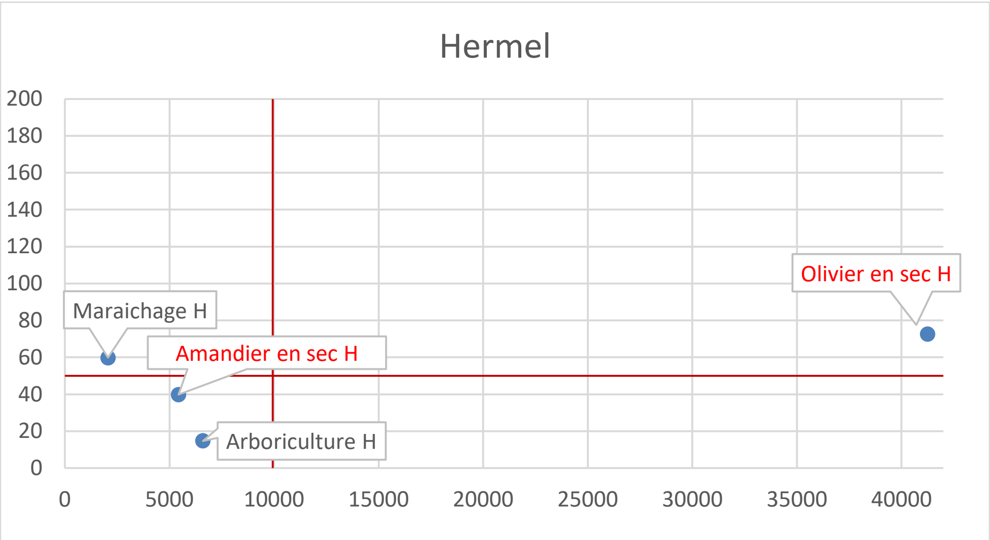


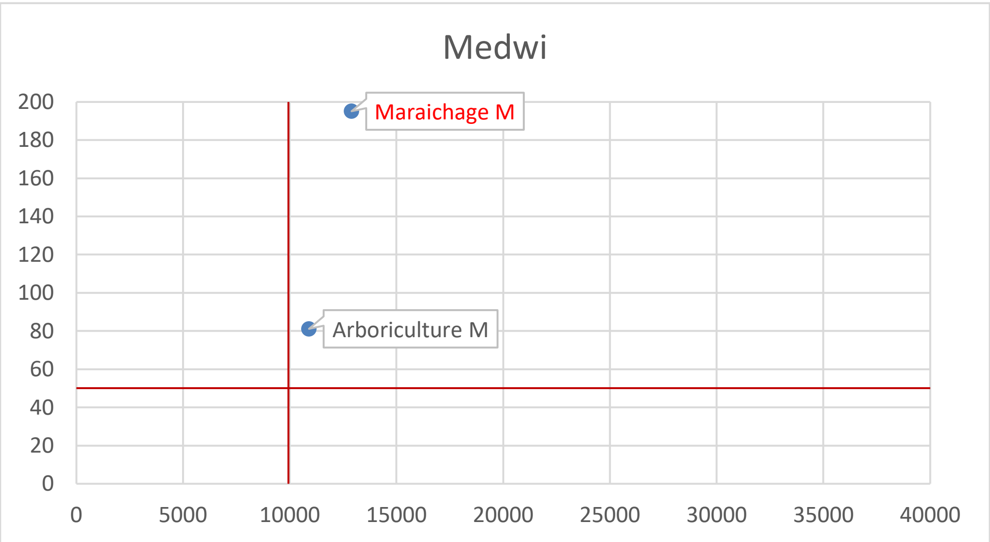


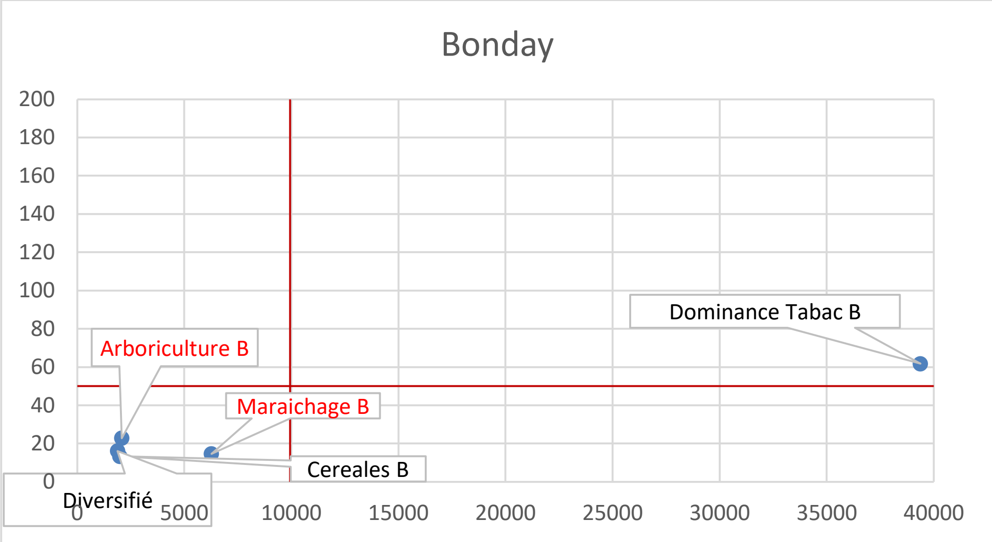


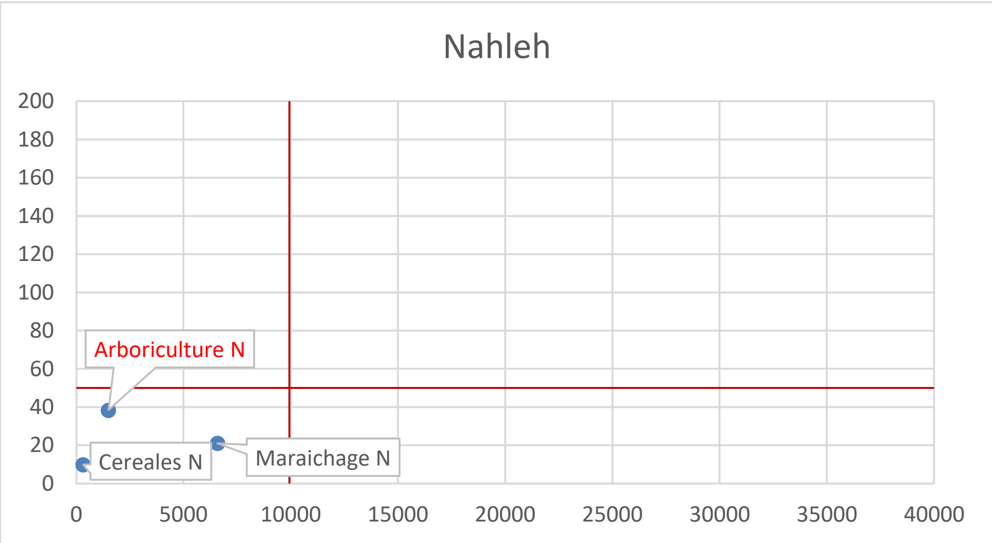


Farm type selection based on revenues and labor use









Annex 2

Calibration for 5 farm types

Almonds Hermel	Observed area		Simulated area	
	Own land	Rented land	Own land	Rented land
Almonds	0.98	-	0.98	-
Apples	0.08	-	0.08	-
Total	**1.06**		**1.06**	

Risk aversion coefficient fixed at 1.7

Vegetables Medwi	Observed area		Simulated area	
	Own land	Rented land	Own land	Rented land
Cucumber	0.12	-	0.22	-
Haricot	0.2	-	-	-
Tomato	0.11	-	0.21	-
Total	**0.43**		**0.43**	

Fruit trees Bouday	Observed area		Simulated area	
	Own land	Rented land	Own land	Rented land
Apricot	0.28	-	0.28	-
Wheat	0.46	0.23	0.2	4.5
Cherries	0.28	-	0.28	-
Figs	0.45	-	0.45	-
Pomegranate	0.28	-	0.28	-
Olives	0.28		0.28	-
Barley	0.47	0.47		0.22
Chickpeas	0.06	-		-
Tabaco	0.11	-	0.2	0.5
Total	**1.95**	**0.7**	**1.94**	**5.01**

Vegetables Bouday	Observed area		Simulated area	
	Own land	Rented land	Own land	Rented land
Wheat	0.62	-	0.95	1.14
Onion	1.99	-	1.54	0.22
Barley	0.62	-	-	-
Potatoes	3.44	0.09	3.25	0.39
Tabaco	1.06	-	1.94	1.05
Total	**7.64**	**0.09**	**7.68**	**2.81**

Fruit trees Nahleh	Observed area		Simulated area	
	Own land	Rented land	Own land	Rented land

Apricot	0.05	-	0.05	-
Almond	0.03	-	0.03	-
Cherries	0.06	-	0.06	-
Figs	0.09	-	0.09	-
Haricot	0.01	-	-	-
Olives	0.06	-	0.06	-
Nuts	0.05	0.01	-	0.01
Peaches	0.02	-	0.02	-
Apples	0.08	-	0.08	0.5
Potatoes	0.01	-	0.07	0.42
Tomatoes	0.01	-	-	4.57
Total	**0.46**	**0.01**	**0.46**	**5**

Bibliography

Altieri M.A., Koohafkan P. (2008). *Enduring farms: climate change, smallholders and traditional farming communities*. Penang (Malaysia) : Third World Network. 63 p. (Environment & Development Series, n. 6).

Bazza M., Kay M., Knutson C. (2018). *Drought characteristics and management in North Africa and the Near East*. Rome (Italy) : FAO. 265 p. (FAO water reports, n. 45). https://www.fao.org/publications/card/en/c/CA0034EN/

Brouwer F.M., Ittersum M.K. (eds.). (2010). *Environmental and agricultural modeling: integrated approaches for policy impact assessment*. 1 ed. Dordrecht (Netherlands) : Springer Netherlands. 322 p. https://doi.org/10.1007/978-90-481-3619-3

Dal E., Diaz-Gonzalez A.M., Cristion Morales-Opazo, Mauro Vigani. (2021). *Agricultural sector review in Lebanon*. Rome (Italy) : FAO. 116 p. (Technical report). https://books.google.fr/books?id=e0s2EAAAQBAJ

Delmotte V.M.-, Pirani A., Connors S.L., Péan C., Chen Y., Goldfarb L., Gomis M.I., Matthews J.B.R., Berger S., Huang M., Yelekçi O., Yu R., Zhou B., Lonnoy E., Maycock T.K., Waterfield T., Leitzell K., Caud N. (2021). *Climate change 2021 the physical science basis: summary for policymakers*. Cambridge (United Kingdom) and New York (USA) : Cambridge University Press. 32 p. https://doi:10.1017/9781009157896.001.

Ejaz Qureshi M., Whitten S.M., Mainuddin M., Marvanek S., Elmahdi A. (2013). A biophysical and economic model of agriculture and water in the Murray-Darling Basin, Australia. *Environmental Modelling & Software*, 2013, vol. 41, p. 98–106. https://doi.10.1016/j.envsoft.2012.11.007

European Commision. (2005). *Better regulation and the thematic strategies for the environment*. Brussels : Commision of the european communities. 7 p. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2005:0446:FIN:EN:PDF

FAO. (2018). *Food security response and stabilization of rural livelihoods addressing the impacts of the Syria crisis*. Baabda (Lebanon) : FAO. 16 p. https://www.fao.org/publications/card/en/c/c847741a-e619-47ac-8339-d00f6d99af75

Flichman G., Jacquet F. (2003a). Le couplage des modèles agronomiques et économiques : intérêt pour l'analyse des politiques. *Cahiers d'Economie et sociologie rurales*, 2003, vol. 67, n. 1, p. 51–69. https://www.persee.fr/doc/reae_0755-9208_2003_num_67_1_1715

Flichman G., Jacquet F. (2003b). Le couplage des modèles agronomiques et économiques : intérêt pour l'analyse des politiques. *Cahiers d'Economie et de Sociologie Rurales*, 2003, vol. 67, p. 51–69. https://hal.archives-ouvertes.fr/hal-01201042

Frenken K. (ed.). (2009). *Irrigation in the Middle East region in figures - Aquastat Survey 2008*. 34 ed. Rome (Italy) : FAO. 424 p. (FAO water reports, n. 34). https://www.researchgate.net/publication/276058258_Irrigation_in_the_Middle_East_region_in_figures_-_AQUASTAT_Survey_2008

Haddad E., Farajalla N., Camargo M., Lopes R., Vieira F. (2014). Climate change in Lebanon: higher-order regional impacts from agriculture. *Region*, 2014, vol. 1, n. 1, p. 9–24. https://doi.10.18335/region.v1i1.19

Hassan Z.E. (2010). Ressources en eau. In : Ministry of environment (ed.). *État de l'environnement et ses tendances au Liban*. Beirut (Lebanon) : Ministere de l'environnement. p. 54–101. https://www.pseau.org/outils/ouvrages/ministere_de_l_environnement_etat_de_l_environnement_et_ses_tendances_au_liban_2010.pdf

IPCC. (2014). Climate change 2014 : impacts adaptation, and vulnerability. Summary for policymakers. 2014, p. 34. https://www.ipcc.ch/site/assets/uploads/2018/02/ar5_wgII_spm_en.pdf

IWMI. (2021). *Reducing the impacts of drought in Lebanon*. : International water management institute. 4 p. https://menadrought.iwmi.org/wp-content/uploads/sites/44/2021/11/MENAdrought-project-Lebanon-country-profile.pdf

Janssen S., Ittersum M.K. van. (2007). Assessing farm innovations and responses to policies: a review of bio-economic farm models. *Agricultural Systems*, 2007, vol. 94, n. 3, p. 622–636. https://doi.10.1016/j.agsy.2007.03.001

Janssen S., Louhichi K., Kanellopoulos A., Zander P., Flichman G., Hengsdijk H., Meuter E., Andersen E., Belhouchette H., Blanco M., Borkowski N., Heckelei T., Hecker M., Li H., Oude Lansink A., Stokstad G., Thorne P., Keulen H. van, Ittersum M.K. van. (2010). A generic bio-economic farm model for environmental and economic assessment of agricultural systems. *Environmental Management*, 12/2010, vol. 46, n. 6, p. 862–877. https://doi.org/10.1007/s00267-010-9588-x

Jones J.W., Antle J.M., Basso B., Boote K.J., Conant R.T., Foster I., Godfray H.C.J., Herrero M., Howitt R.E., Janssen S., Keating B.A., Munoz-Carpena R., Porter C.H., Rosenzweig C., Wheeler T.R. (2016). Brief history of agricultural systems modeling. *Agricultural Systems*, 2016, vol. 155, p. 240–254. https://doi.org/10.1016/j.agsy.2016.05.014

Mahfoud C., Adjizian-Gerard J. (2021). Local adaptive capacity to climate change in mountainous agricultural areas in the eastern Mediterranean (Lebanon). *Climate Risk Management*, 2021, vol. 33, p. 100345. https://doi.10.1016/j.crm.2021.100345

Melillo J.M., Richmond T. (T. C., Yohe G. (2014). *Climate change impacts in the United States : the third national climate assessment*. (United States) : U.S. Global Change Research Program. 841 p. https://www.nrc.gov/docs/ML1412/ML14129A233.pdf

Ministry of Agriculture. (2020). *Lebanon national agriculture strategy 2020-2025*. Beirut (Lebanon) : Lebanese republic ministry of agriculture. 71 p. (National agriculture strategy). https://www.fao.org/faolex/results/details/en/c/LEX-FAOC202167/

Ministry of Environment. (2015). *Lebanon environmental assessment of the syrian conflict & priority interventions updated fact sheet2015*. Lebanon : UNDP. https://data.unhcr.org/fr/documents/details/64715

Minot N. (2009). *Using GAMS for agricultural policy analysis*. Washington, D.C. : International food policy research institute. 56 p. https://www.researchgate.net/publication/266466336_Using_GAMS_for_Agricultural_Policy_Analysis

Roudi-Fahimi F., Creel L., Souza R.-M.D. (2000). *Finding the balance: population and water scarcity in the middle east and north Africa*. Washington, D.C. : Population Reference Bureau. 8 p. https://www.prb.org/resources/finding-the-balance-population-and-water-scarcity-in-the-middle-east-and-north-africa/

Shaban A. (2020). *Water resources of Lebanon*. Cham : Springer International Publishing. 229 p. (World water resources). https://doi.org/10.1007/978-3-030-48717-1

Shrestha S., Barnes A., Ahmadi B.V. (eds.). (2016). *Farm-level modelling: techniques, applications and policy*. Boston (Massachusetts) : CABI. 240 p.

Solh M., Saxena M.C. (2010). *Food security and climate change in dry areas*. Amman (Jordan) : International center for agricultural research in the dry areas (ICARDA). p. 369. 2010, Amman (Jordan).

Taheripour F., Tyner W.E., Sajedinia E., Aguiar A., Chepeliev, Corong E., Lima C.Z. de, Haqiqi I. (2020). *The economic impacts of climate change and water scarcity in the middle east*. Washington, DC : World Bank Group. 100 p. (Technical report). https://documents.worldbank.org/en/publication/documents-reports/documentdetail/614261600439036489/Water-in-the-Balance-The-Economic-Impacts-of-Climate-Change-and-Water-Scarcity-in-the-Middle-East-Technical-Report

Tropp H., Jägerskog A. (2006). *Water scarcity challenges in the middle east and north Africa (MENA)*. Stockholm (Sweeden) : Stockholm International Water Institute. 25 p. (Water for human development). https://www.researchgate.net/publication/281550179_Tropp_H_and_Jagerskog_A_2006_Meeting_the_Water_Scarcity_Challenges_in_the_Middle_East_and_North_Africa_Thematic_Paper_for_UNDP_Human_Development_Report

UNDP. (2020). *Lebanon state of the environment and future outlook: turning the crises into opportunities*. Lebanon : United Nations Development Programme (UNDP). 524 p. (SOER). https://www.undp.org/lebanon/publications/lebanon-state-environment-and-future-outlook-turning-crises-opportunities

Verdeil É., Faour G., Hamzé M. (eds.). (2016). *Atlas du Liban: les nouveaux défis*. Beyrouth (Liban) : Presses de l'Ifpo. 111 p. https://DOI: 10.4000/books.ifpo.10709

Wallach D., Makowski D., Jones J.W., Brun F. (2018). *Working with dynamic crop models: methods, tools and examples for agriculture and environment*. 3 ed. : Academic Press. 616 p.

White C. (ed.). (2014). Understanding water scarcity: definitions and measurements. In : *Global water: issues and insights*. Canberra (Australia) : ANU Press, The Australian National University. p. 161–165. https://DOI:10.22459/GW.05.2014.28

World Bank. (2012). *Adaptation to a changing climate in the arab countries: a case for adaptation governance and leadership in building climate resilience*. Washington, DC : World Bank Publications. 381 p. (MENA development). https://doi.10.1596/978-0-8213-9458-8

World Bank. (2017). *Beyond scarcity: water security in the middle east and north Africa*. Washington, DC : World Bank. 233 p. (MENA development). https://doi.10.1596/978-1-4648-1144-9