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SEARCH THEME

Economic effects related to water adaptation strategy in the Mediterranean agriculture the areas of Baalbeck–Hermel (Lebanon)

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Abbreviations

IPCC	Intergovernmental Panel on Climate Change
MedECC	Mediterranean Experts on Climate and Environmental Change
CC	Climate Change

Introduction

Global climate change has already had observable effects on the environment. A predicated increase in temperatures of greater than 2 ° C by 2040 (Hoegh-Guldberg et al., 2019; Nasser et al., 2020) and a decrease in rainfall will reduce water availability and cause drought conditions and degradation of soil (Darwish et al., 2005). The Mediterranean basin is one of the regions the most susceptible to climate change, especially its water resources.

Moreover, the environmental crises have lengthy threatened agricultural production around the world (Menike and Arachchi, 2016). The agricultural sector is strongly affected by climate change, given that it is highly dependent on specific meteorological conditions of rainfall and sunshine to have a good yield (Martin et Vaitkeviciute, 2016). Additionally, the agricultural sector in Lebanon is largely made up of small farms, which face several constraints (economic crisis, input price, lack of market, low quality of production….), and consequently, are exposed to dangers and shocks. This sector is characterized by rain-fed but primarily irrigated crops, and generally, the majority of crops require additional water resources, especially during the hot season (Verner et al., 2018). However, due to climatic risks, water availability has decreased and the farmer in rural regions faces the challenge of water scarcity. The farmer will consequently have to find the most effective manner of adaptation to face those challenges.

The Baalbeck Al Hermel is one of the most important regions in Lebanon where farming systems play a strategic role and show relevant critical issues related to natural resources exploitation. Concerning the water, for example, this region is, indeed, characterized by irregular rainfall, with long periods of drought (FAO, 2018). However, certain agricultural practices adopted by farmers, such as vegetables, typically consume a huge amount of water, which leads to the overexploitation of water resources, and therefore, the reduction in the level of aquifers. In addition, the recourse to irrigation from groundwater is proving to be impossible and climate change is further aggravating the situation.

Thus, the situation in the Baalbek Al Hermel region prompts us to ask the following question: How to increase the resilience of farms in that region and reduce their vulnerability, in the short and long term, to the repercussions of climate change? How to ensure a transition of farms in Baalbek Al Hermel towards sustainable agricultural practices, profitable, and concomitantly, less water consuming? And what are the difficulties and challenges that may hinder this process?

To better understand the adaptive capacities of rural populations, it is necessary to understand the livelihoods of farmers (Menike and Arachchi, 2016) and the role of agriculture as a resilient livelihood for these populations. In agriculture, the resilience of production systems is "the ability to reorganize and maintain the function and structure of systems, which are interconnected and span different spatial and temporal scales” (Souissi et al., 2018).

In this context, this study aims to understand how farmers in these areas currently perform in the face of limited water resources with little or no government support, in order to predict what could be the behaviour of those farmers in case of a decrease in water availability in the future. Based on this concept, and based on decision-support tools, the second objective will be to assess (using bioeconomic modelling) the resilience of farmers in the semi-arid Baalbeck El Hermel zone to climate change in a context of limited water resources. To meet this objective, we have developed a methodology based on several main stages: the characterization of the diversity of agricultural systems in the study area according to a quantitative typology, the design of a bioeconomic model, and the simulation of a scenario identified for a single agro-climatic zone of Baalbeck El Hermel, and the analysis of the resilience and adaptive capacity of these agricultural systems by comparing the indicators calculated by the bioeconomic model.

This work will follow a quantitative typology of a multivariate statistical analysis based on the two techniques Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HAC) using the Tanagra statistical software. Further, in this research, the use of diagnostic analysis in relation to irrigation water management helps structure the analysis of problems and the identification of potential solutions related to water management. It is within this framework that this first stage of the research action takes place, the aim of which is to take stock of the current situation of water management at the level of an irrigated field in Baalbek Al Hermel.

The designed study will propose strategies for adapting farms in the Baalbek-Hermel region to climate change in order to increase their resilience; therefore, it will ease farmers’ mission and may supply them with a plan that will help lessen farms' vulnerability to risks.

This study took a region of the Mediterranean area, which is one of the regions that are considered the most threatened in terms of climate change. Finally, this study is considered a model for adoption in many Mediterranean regions, by going to crops that do not need a lot of water and that resist desertification, in addition to adopting new and modern methods to reduce costs, which helps to increase agricultural income.

Chapter I

State of Art

Part I: Climate Change

Global Climate Change

People ignore nowadays the issue of climate change that many of us can perceive its effects. Climate change manifests itself in various forms such as heat wave in summer, snow-free winter, and floods in one part of Europe while another suffers from terrible droughts (Baaklini S, 2020). Beyond the climate, the consequences are much more complex. Due to the ocean warming and the melting of ice caps, the sea level is rising which endangers many archipelagos and lowlands, such as the Netherlands and Bangladesh (Nasser et al., 2020). Additionally, if the most pessimistic predictions become true, archipelagic nations, like the Maldives, could be wiped off the map. Thus, the geopolitical consequences would be enormous, and the 21st century may be the first to see the emergence of "climate refugees". These climatic upheavals disrupt the flora and fauna, the geographic distribution of which tends to shift northwards. Moreover, these changes have an impact on agriculture, health, and the economy (G. Derive, 2008).

They shape the models of societies generated by the market economy. Subsequently, science is called upon by the most optimistic to find the solutions. But will it go fast enough, especially when we look at the economic boom in emerging countries like China, India, and Brazil, which together represent around 40% of the world's population? What will happen when China becomes a developed country like the United States, which in 2007 emitted 5 times more CO2 per capita than China? In addition to technological advancements, some emphasize the need to completely review our modes of societal organization. They call for the limitation or reduction of overconsumption and waste, as well as the limitation of unnecessary transport of goods (for example products making a return trip between two production sites to go through two processing stages).

Besides, Climate change is not managed by an ideology and the controversy is underway concerning the responsibility of man, as well as the questioning of the impartiality of the IPCC (Intergovernmental Panel on Climate Change) by some scientists, who dispute the accuracy of the numbers as well as some methodologies. The alarming catastrophe should not portray the goal of climate change. However, a focus on this issue is necessary, while recalling that despite the conclusions relating to the exact causes of climate change, we adopt renewable energy such for example the installation of a photovoltaic panel or a wind turbine can be an asset. We will not have to deprive ourselves of our modern comfort while following a wise principle making it possible to avoid a lot of trouble: the precautionary principle (G. Derive, 2008). Climate change is not new; it is indeed as old as our planet Earth. During the 5 Ice Ages, the climate was generally rather warm, as shown by the major trends in global temperature over geological time. The last is that of the Quaternary, in which we are currently living. However, current climate change should not be viewed as an ordinary modification. The warming of our climate can be, by its magnitude and its speed, really described as extraordinary in the history of our planet.

Further, the disruption of the global climate system is the main issue of the century, in which no continent has been spared from its major repercussions at different scales (Souissi et al., 2018). It is characterized by increases in temperature and regressions in precipitation which have impacts on all activities. According to the World Meteorological Organization, in a report published on March 10, 2020, the year 2019 is considered the 2nd warmest year, with a global temperature that is higher than pre-industrial levels (1850-1990) of 1.1 ° C. That shows that we are not on track to meet the goal of the Paris Agreement, which is to maintain an increase in the average temperature of the planet below 2 ° C compared to the pre-industrial levels by the end of the 21st century (Guiot J, 2017).

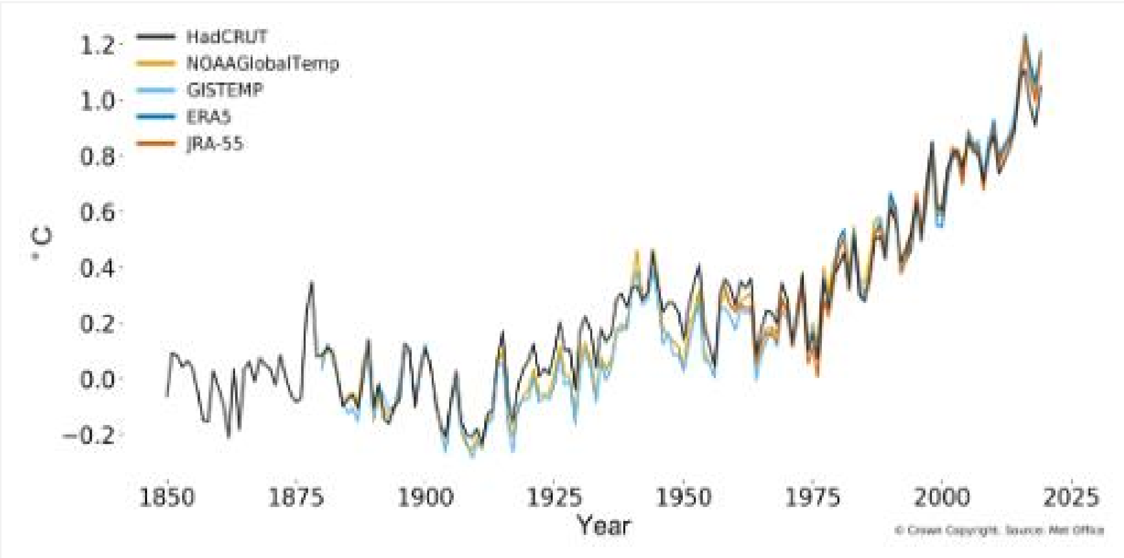

Figure 1 Increase in mean annual temperature over the years (Source: OMM, 2020)

As illustrated in Figure 1 above, this increase is not only at the level of the year 2019. However, the trend of the global temperature is accelerating over the years such that even the year 2020 began with extreme record heat. Apart from the increase in global temperature, the melting of glaciers and ice sheets continues, which causes the ocean level to rise faster, as shown in Figure 2 and Figure 3. Moreover, the ocean heat that has reached a record, combined with the problems of acidification as well as deoxygenation, harms biodiversity and marine ecosystems. These fluctuations in the climate are the main factors of food insecurity, droughts, water shortages, floods, forest fires which lead to air pollution. In addition, climate fluctuations result in increased hunger especially in the most disadvantaged areas, levels of greenhouse gases like carbon dioxide that keep breaking records, hence putting current generations at risk as well as future generations (OMM, 2020).

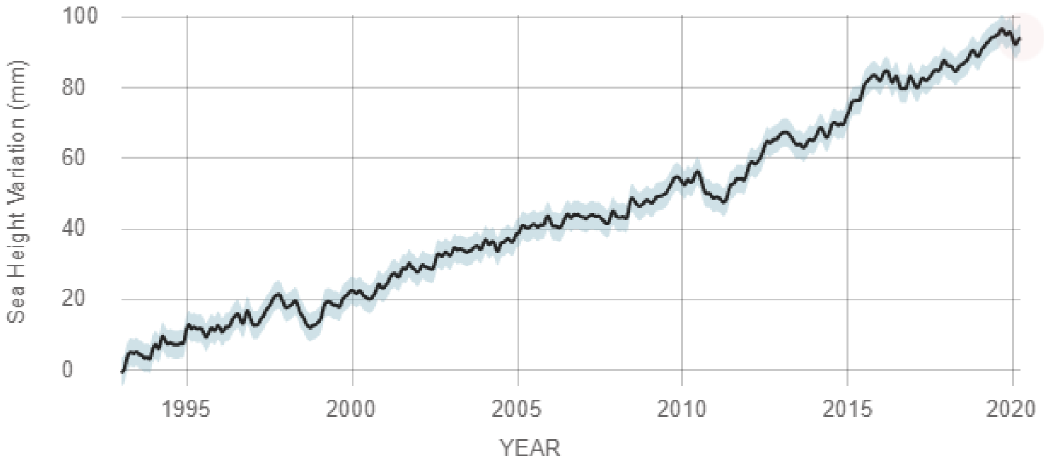

Figure 2 Ocean level rise over the years

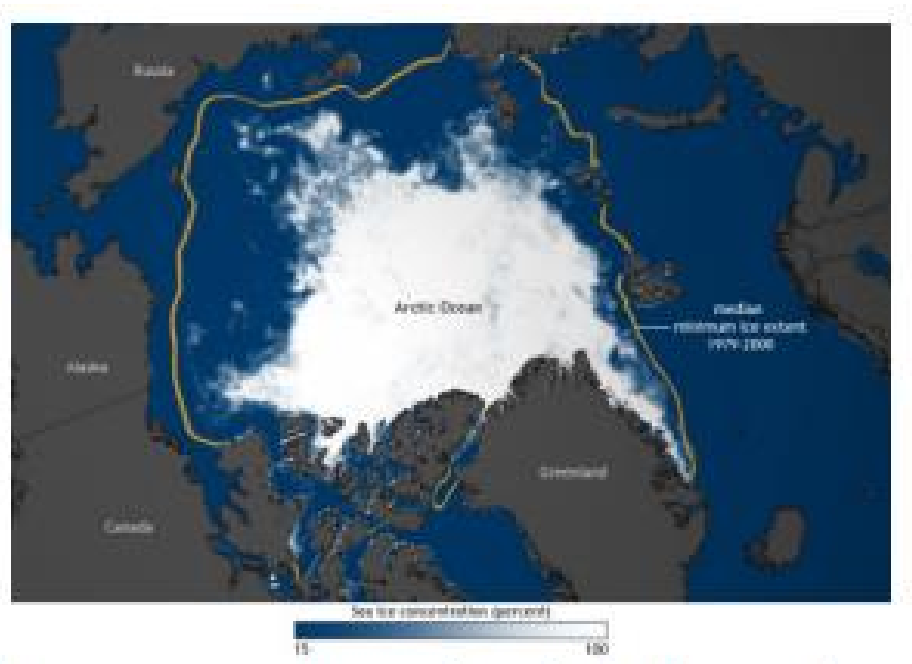

Figure 3 Decrease in the area of the Arctic ice pack

IPCC predicts, by the end of the 21st century, a significant increase of extreme precipitation in the land masses of the high and middle latitudes and in the humid tropics. In contrast, the arid and semi-arid zones of the mid-latitudes and the subtropics will experience droughts and a decrease in rainfall (DGRIS, 2017).

These fluctuations in temperature and precipitation have strong impacts on different activities. We can summarize the impacts of climate change, at the global level, on the following main sectors: agriculture, marine and coastal ecosystems, and human health.

Firstly, the agricultural sector is very dependent on the climate as it requires specific meteorological conditions such as rainfall and sunshine. Due to climate change, there are many losses in this sector, especially in terms of production and productivity as the yield, and quality has decreased. That decrease is due to the irregular seasons, the water resources which decrease in the face of increasing demand, and the Extreme Temperatures which cause disturbances at the level of the cycles of agriculture. These impacts differ from one region to another, for example in areas at high latitudes as well as in cold and humid areas, the available water should increase by 10 to 40% as they experience an increase in yields. However, available water in hot and dry regions should decrease by 10 to 30% as they experience a drop in yields (FAO, 2016). On the other hand, even the prices of food products will fall for many reasons, including the increase in the frequency, intensity and duration of droughts and the accentuation of the phenomenon of desertification during years (DGRIS, 2017).

Secondly, in addition to the direct effects, both physical and climatic, of global warming, the latter will have influences on ecosystems, particularly in the modification of biodiversity. The abnormal temperature rise will cause a change in the distribution of organisms or even the extinction of certain animal and plant species. Besides, the high concentrations of carbon dioxide (CO_2) will lead to acidification of the ocean.

Finally, climate change has become a dangerous threat to public human health and is causing a change in the way in which man plans to protect the most vulnerable populations. The impact of climate change on human health is depicted in Figure 4 below. According to the latest IPCC report, human activities have a strong effect on the climate and result in its upheaval. At the same time, this climate change has consequences for humans as they have caused and still cause deaths and diseases that are due to natural disasters such as heat waves, droughts, and floods (WHO, 2019).

On one hand, major negative consequences of climate change on humanity are foreseen in the 21st century as the following: (IPPC, 2007)

- A decline in potential agricultural yields in most of the tropical and subtropics zones;
- A decrease in water resources in most of the dry tropical and subtropics zones;
- A decrease in the melt water, following the disappearance of the ice sheets and glaciers.
- An increase in extreme weather conditions such as torrential rains, storms, and droughts, as well as an increase in the impact of these phenomena on agriculture;
- An increase in forest fires during warmer summers;
- The extension of areas infested by diseases such as cholera or malaria;
- Increased risk of flooding, both from rising sea levels and changing climate;
- Higher energy consumption for air conditioning purposes;
- A drop in potential agricultural yields at mid and high latitudes (assuming strong warming).

On the other hand, positive consequences are also associated with the expected global warming in the 21st century:

- Lower winter deaths at mid and high latitudes;
- A possible increase in water resources in some dry tropical and subtropics regions;
- An increase in potential agricultural yields in some regions at mid-latitudes (assuming little warming);
- The opening of new shipping lanes in the Canadian Arctic following the melting ice in the Northwest Passage.

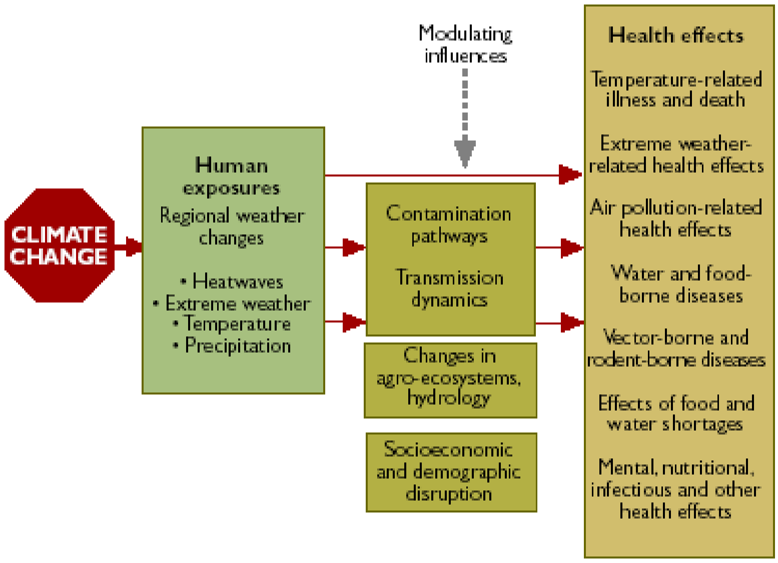

Figure 4 The impact of climate change on human health (Source: WHO, 2019)

Climate change and agriculture

Climate change is considered among the most pressing environmental problems. It is mainly due to the emissions of greenhouse gases which are of anthropogenic origin. These accumulate in the atmosphere and capture the infrared radiation that is emitted by the surface of the Earth, thus causing climatic changes, more precisely, global warming.

Agriculture represents an important part in the emission of greenhouse gases, such that, at the global level, its emissions represent about 14%. Taking into account changes in land use, for example, deforestation, this percentage increases to 33%, which represents a very significant percentage. In addition, scientists estimate that emissions from the agricultural sector increased by 17% between 1990 and 2005. The main greenhouse gases emitted by agricultural activities are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Furthermore, no one can deny the dependence of agriculture on meteorological conditions which are very precise, including sunshine and rainfall. At the same time, the upheaval of the climate has a huge influence on the agricultural sector by modifying the physiological, hydraulic and pedagogical features for the plant, whether in a positive or negative way.

The increase in the causes of climate change on agricultural production can be summarized in the following: (Bouzidi, 2012)

The impact of increasing CO2 on agricultural production

Generally, the increase in CO_2 in the atmosphere has positive impacts on agricultural production, by promoting plant growth. Normally, plants take up the atmospheric CO_2 by an organic molecule whose number of carbon atoms differs from one species to another: there are plants in C3 (containing 3 carbon atoms) and those in C4 (containing 4 carbon atoms). These plants react differently to the variation in the amount of atmospheric CO_2. If by the end of this century, this amount doubles, this will have an impact on gross photosynthesis which will increase by 30% for plants in C3 like wheat and rice; therefore, they will assimilate 20% of carbon. Moreover, gross photosynthesis will increase by 15% for C4 plants such as maize which will thus assimilate 10% more carbon. As CO_2 increases, in addition to a number of light conditions, temperature as well as nutrients, humidity and production will increase. Moreover, CO_2 plays the role of antiperspirant, such that at high concentrations it allows the decrease of transpiration. Therefore, water consumption by the plant will be more efficient, thus the soil will be protected against erosion and low temperatures of the topsoil layer. That further stimulates plant growth especially in dry regions, and produces an "anti-desertification" effect. We can add to this those high concentrations of CO_2 can reduce the damage caused during plant growth by pollutants like N_2O and SO_2, due to the small openings of the stomata. Additionally, CO_2 plays the role of a fertilizer; it can even modify the biological functioning of the soil. That is, the increase of the latter can compensate for the deficiency in nutrients by increasing the inputs of fertilizers, which further stimulates the increased root growth. On the other hand, the increase in carbon dioxide in the atmosphere can have a negative impact on agricultural production, such as stimulating the development of weeds, resulting in lower yields (Bouzidi, 2012).

The effects of increasing temperature on agricultural production

Since it is difficult to separate the physiological effects from the ecological effects, it is difficult to say whether the increase in temperature influences the plants positively or negatively. Generally, scientists and researchers believe that the rise in temperature has a positive impact in cold and mountainous regions, as it allows an acceleration of the decomposition of organic matter in the soil, earlier maturation of crops and longer seasons of plant growth. In addition, the rise in temperature can allow completing several cropping cycles during the same season, thus generating an increase in agricultural production. On the contrary, in regions that are warmer, the increase in temperature would lead to a decrease in plant productivity, especially during the months which are warm. During these months, the rise in temperature could accelerate the rate at which plants release carbon dioxide during respiration, thus resulting in unfavourable conditions for net growth.

In addition, the rise in temperature can lead to an increase in the number of pests that harm crops. Besides, rising temperature can have a positive impact on agricultural production, by reinforcing the role of CO2 as a fertilizer as well as an antiperspirant on type C3 and C4 plants, provided that these plants do not exceed an optimum temperature. Otherwise, the plants will have a negative reaction, and therefore this could lead to a drop in yield as well as an increase in peak irrigation needs (Bouzidi, 2012).

1. The effects of reduced precipitation on agricultural production

The decrease in rainfall, caused by climate change, directly influences agricultural production, causing a decrease in yields as well as in crop quality. For example, France experienced a drought in 2003, which led to a drop in production of 20 to 30%. The United States also experienced a drought in 2012, and which caused an increase in 50% of the price of corn and wheat on the Chicago Stock Exchange (Bouzidi, 2012).

2. The effects of water availability on crop production

Climate change has a huge influence on water availability, and consequently on plant production. Indeed, climate change modifies the conditions necessary for the establishment of a crop, such as rainfall, evaporation, run-off, and moisture storage in the soil. Concomitantly, the emergence of water stress, during the different stages of flowering, pollination, and grain filling, would harm the vast majority of crops (specifically corn, soybeans, and wheat) (Bouzidi, 2012).

Lower precipitation combined with worsened evaporation from the soil and rapid transpiration in plants will surely create moisture stress. In turn, this latter can increase the risk of salt accumulation in the soil, which makes the development of more drought-tolerant varieties necessary. In contrast, increased precipitation in sub-humid to semi-arid regions would allow an increase in plant growth, and therefore, this would protect the soil, and increase rain-fed agricultural production. This decrease in precipitation may cause, in some areas, a greater demand for irrigation water, in addition to great competition between farmers and the urban environment, in addition to factories around water resources. In addition, the drop in the piezometric surface, in parallel with an increase in energy required for pumping water, would lead to the adoption of more expensive irrigation systems. As well, more investment will take place for the construction of dams and reservoirs for the development of new irrigation networks in new places. On the other hand, an abnormal increase in precipitation would lead to a decline in the quality and quantity of land and water resources, and this is due in particular to increased run-off, erosion and flooding. At the same time, this intensification of precipitation would create storage sites in rivers, lakes and artificial reservoirs, which can benefit farmers, whether in the water supply or intensification of irrigation (Bouzidi, 2012).

3. The effects of other factors linked to climate change on agricultural production

Other than temperature, CO_2 and precipitation, some factors can have impacts on plant production such as extreme weather phenomena. For example, sea level rise has serious consequences on agriculture, especially for the coastal lowlands. Given that an elevation could limit the surface water drainage as well as groundwater, it could cause infiltration of seawater into estuaries and aquifers. There are also other negative impacts of climate change on crop production, such as it can cause disruptions in the growth schedule of fruit trees. As well, it can delay, in case of lack of cold, breaking dormancy, in addition to flowering which is increasingly precocious. (Bouzidi, 2012)

4. The positive effects of climate change on agriculture

Nevertheless, global warming could also have some positive effects on farmers. Increases in carbon dioxide fertilize many crops, increasing growth rates and increasing water use efficiency. (FAO, 1997)

Winter rainfall is expected to increase due to elevated evaporation except in Mediterranean countries which would see more droughts in a context where violence and /or the frequency and severity of climatic hazards could increase. (Denhez, 2007)

Further, the conjunction of warming and the increase in the level of CO_2 in the air and the rains could, in the temperate zone (apart from arid zones which could become even more so) and circumpolar, initially, increase the productivity of ecosystems. In this case agriculture in the northern United States, Canada, Russia and the Nordic countries could benefit from it, (F. Denhez, 2007) but signs of forest decline already appear in these areas. In an opinion (EESC,2009) dated on February 3, 2009, the European Economic and Social Committee underlines those comparative studies conclude that, with regard to the consumption of raw materials and energy and with regard to carbon stored or greenhouse gas emissions, organic farming has a better balance on average than that of so-called conventional agriculture. (Klimaschutz and Öko-Landbau, 2008). Despite taking into account the lower yields of organic farming, the German government includes it among the means to fight against climate change. An adapted reoriented agriculture could also, as being recalled by the European Economic and Social Committee, help to lessen or slow down the effects of global warming (Greenpeace, 2007).

The committee refers to the climatologist Paul Josef Crutzen who specifies that the nitrous oxide emissions induced by the cultivation and production of biodiesel are sufficient, under certain conditions, to cause the rapeseed methyl ester to have worse climatic effects than those of diesel made with fossil fuel. (Crutzen, 2007)

The question about traditional manures is also raised by the committee wondering whether the full use of plants, as planned in the context of second generation biofuels, does not risk undermining the objectives set in a matter of development of the “humus layer”, that is, to further deplete organic matter in soils. On the other hand, the committee highlights the problem of the eco-assessment of biofuels. The committee cites a comparative study by Empa, (EMPA,2008) concluding that to cover 10,000 km an average car (Volkswagen Golf) required, with the observed yields in Switzerland, a floor area of 5,265 m2 of rapeseed (biodiesel) compared to 37 m2 of solar panels (134 times less). The adaptation of crops to global warming is also a subject of studies intended to select, for example, varieties that develop earlier in the year, or which are more resistant to higher temperatures. But the fact of combining within the same species mechanisms of adaptation to multiple constraints stands out as another difficulty that requires a solution. In sum, still uncertain models of the future climate must then be the basis for the choice of species planted for several decades and their place of planting. (Debaeke et al., 2014).

Climate change and water

Climate change has a strong impact on water resources, whether in terms of quantity or quality. The rise in temperature affects the different water systems: precipitation, ice melting, sea level rise, soil-water concentration, the intensity of run-off, water flow, etc.

Moreover, the impacts of climate change differ from region to region. According to the IPCC, in general, precipitation, as well as the flow of river water, should increase in high latitudes (example: Northern Europe) and in some regions of the tropics which could cause flooding. On the contrary, the subtropics and the Mediterranean region should experience a decrease in precipitation, and therefore, this could induce episodes of drought, which may be more intense and more frequent. According to what IPCC experts estimated, if temperatures rise above 4C during this century, the number of human beings who will suffer from water scarcity could triple to 3.2 billion. And of course, the poorest populations would be the first to be affected by this problem.

We can summarize the impacts of climate change on water in the following:

- Melting glaciers: Due to global warming, our earth is gradually experiencing melting of the glaciers of the Himalayas or the Andes, which is accentuated and accelerated further. That acceleration can cause the disappearance of the single source of water for some populations, especially during the warm season. In addition, a sixth of the world's population depends heavily on the melting of glaciers (eg Bolivia, Ecuador ...). In the short term, the melting of the glaciers would lead to an increase in the flow of water. Globally, the melting of glaciers combined with their replacement by precipitation, due to the increase in temperatures, could have as repercussions a great change in the seasonality of rivers.

- The rise in sea level: Always due to the upheaval of the climate presented by the rise in temperatures mainly, the seas are experiencing a rise in their water. Since half of the humanity lives on coasts within 60 km, as well as a good number of cities are located by the sea, they are supplied the underground water lenses. At the time of extraction of freshwater, salt water from the sea can rise, and therefore, it can contaminate the aquifer. This phenomenon is appearing more and more in several places, the most serious case is the Baden of Gaza. It has only one resource, which is its aquifer, and whose water is no longer drinkable due to the intrusion of salt water into it.

- Modification of inflows and outflows: In some regions, global warming is presented by a decrease in precipitation. Once the latter is combined with increasing evapotranspiration, they result in a decrease in the water infiltrated into the groundwater, and particularly, the free water tables. That process would lead to a change in the recharge conditions of hydrogeological systems. Regarding outflows, there is a very close relationship linking watercourses to underground aquifers, since watercourses represent a source of supply to groundwater in winter, and vice versa in summer. If the periods of low water levels in rivers are important, therefore, groundwater has a crucial role in feeding them. Simultaneously, the outgoing water flow would be significant and last longer. In Figure 5 below, we illustrate the modifications of inflows and outflows in groundwater.

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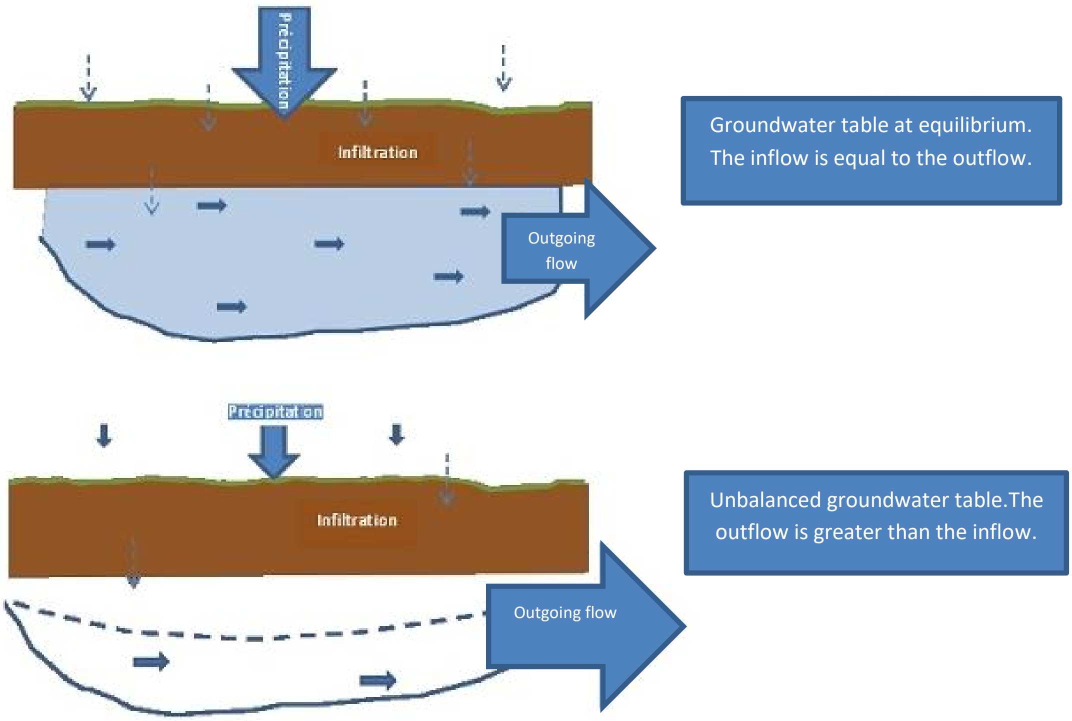


Figure 5 Modification of inflows and outflows in groundwater (SIGESAQI, 2018)

- Drought: This phenomenon is caused by the decrease in precipitation, combined with a decrease in the flow of river water as well as the moisture content of soil. It has affected several regions which have already started to feel the repercussions. For example, water availability in Southern Europe would decrease by 5 to 35%, in case there is a temperature rise of 4C. Thus, negatively impacting not only agriculture, but also the production of electricity. Not to mention that, Latin America which heavily depends on the agricultural sector, is heading towards desertification of its lands due to increased episodes of droughts and changes in rainfall regimes.

Furthermore, climate change would also impact the quality of water intended to be consumed by humans. Considering the rise in the temperatures of rivers and lakes, it leads to deterioration in their quality, whether that is on the biological or chemical level. In addition, the abnormal increase in precipitation in some areas could cause contamination of water with pollutants, leading them to underground aquifers, also to flooding and thus saturation of wastewater treatment systems. Moreover, the precipitations, combined with erosion, could cause the mobility of these substances, as well as increase the turbidity of the water.

Part II: Climate change in the Mediterranean

General overview

There is no doubt now that climate change is a reality on the planet. Indeed, there is a multitude of effects: the increase in the Earth's average temperature, the melting of glaciers, the variation in precipitation, the multiplication of extreme weather phenomena as well as the shift in seasons. According to the World Bank report (Turn down the Heat, 2014) and the various IPCC reports, the Mediterranean is considered among the regions in the world most vulnerable to climate change. The situation continues to worsen, and the vulnerability of these spaces continues to increase as illustrated in Figure 6 below. This deterioration has started in the region for at least 30 years.

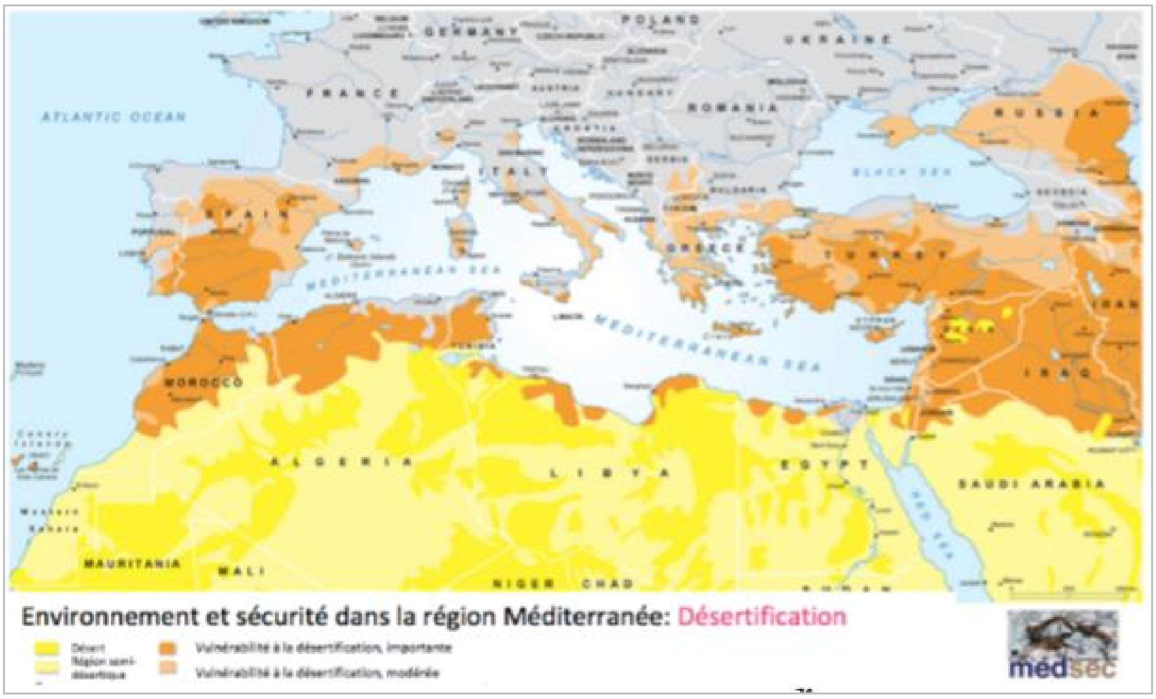


Figure 6 Vulnerability of the Mediterranean region to desertification (MedECC, 2018)

The Mediterranean Basin is a transition zone between the tropical climate and the temperate climate of mid-latitudes (Raymond et al., 2016). Despite the target set by the European Union not to exceed an average global temperature increase of 2 °C, in the Mediterranean, temperature increases will likely be greater than 2 °C. Moreover, due to the ecological and socio-economic characteristics of the area, the impacts will be greater than in many other regions of the world; The Mediterranean has therefore been described as a "hotspot for climate change".(Lionello P. and Giorgi F.,2007)

The countries around the Mediterranean are heavily impacted by the disruption of the climate system. According to the network of Mediterranean Experts on Climate and Environmental Change (MedECC), the

Mediterranean region is one of the areas that present major risks of climate and environmental change. This region is warming 20% faster than the global average temperature, given that the increase in temperature in the Mediterranean basin has already reached 1.5 ° C for a global average of 1.1 ° C. MedECC also assumes that the current problems will exacerbate further, as well as the current trends will further accelerate such that they estimate that, by 2040, regional temperatures will increase by 2.2 ° C (MedECC, 2018).

In the very distant past, there were important climatic changes in the Mediterranean, with temperatures being able to be, on average, lower than those of today by 8 ° C (20,000 years ago) or else above 1 to 3 ° C (6,000 years ago). However, the speed of the rates of change characterizes the current situation and that expected in the coming years. This phenomenon has become one of the biggest concerns of the 21st century. The Intergovernmental Panel on Climate Change (IPCC) says the observed changes are unprecedented. A new scientific report from the World Bank, published in 2014, warns that the international community could well suffer the catastrophic consequences of a 4 degree increase in the average temperature by the end of the century, including extreme heat waves, declining global food stocks and rising sea levels that could affect hundreds of millions of people. This increase in temperature would probably be greater at the level of the Mediterranean. It is expected to reach a value between 2 ° C and 6.5 ° C by the end of the century. Seasonal variations will be more marked in winter than in summer, with subregional variations (Magnan et al., 2009).

According to the IPCC (2007) report, the average sea level increased on average by 1.8 mm/year between 1961 and 2003 and by about 3.1 mm / year between 1993 and 2003. Across the Mediterranean, there is a great disparity between the shores; the most marked elevation being located in the eastern part of the basin. For example, it ranges between + 5 and + 15 mm / year against less than + 5 mm / year in the western part. (The Mediterranean in the future, 2014)

Furthermore, the spatial distribution of precipitation over the Mediterranean is very heterogeneous, as illustrated in Figure7. (Magnan et al., 2009). Indeed, certain regions such as the Middle East and North Africa should experience a drop in precipitation of the order of 20 to 50% if warming reaches 4 ° C. Unlike other regions such as central and eastern Siberia and northwestern South America, precipitation is expected to increase by about 30% (World Bank Report, 2014).

Agriculture, which occupies an important place in the Mediterranean economy, is largely influenced by climatic conditions. These climate changes are likely to affect yield, the proliferation of weeds and pests,

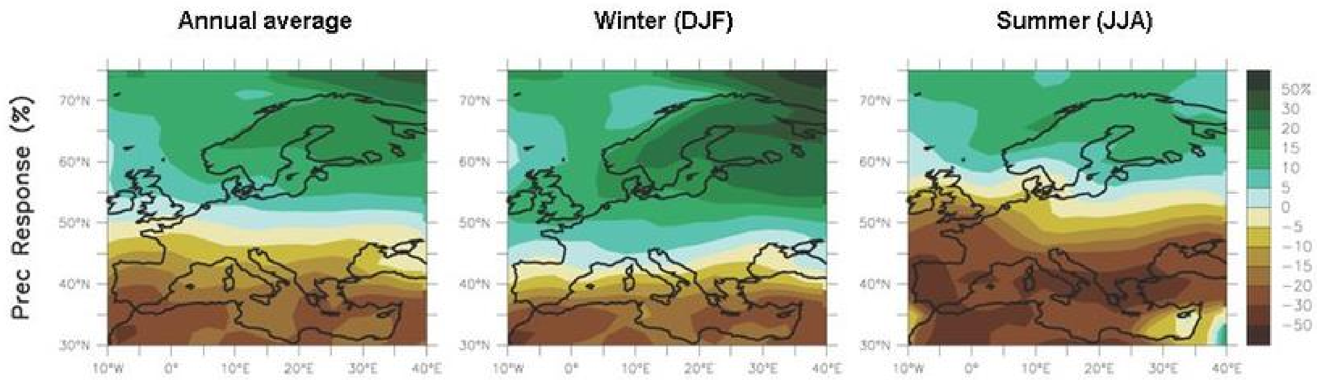


Figure 7 Evolution of precipitation in the Mediterranean and Europe in 2080-2099 compared to the period 1980-1999, according to an A1B emissions scenario

productivity and water resources. According to MedECC experts, the availability of fresh water will decrease by 15%, and the consequences will be heavy on various human activities, more particularly, the agricultural sector, fishing, and tourism. These impacts combined with the considerable increase in the population on the Mediterranean coasts threaten food security, such as food demand will increase while crop yields, as well as fish and livestock, will experience a decline.

Faced with this alarming situation, the Mediterranean strategy for sustainable development is being revised, the participants in the 16th meeting of the Mediterranean Commission for Sustainable Development (MCSD) revealed the need to integrate the agricultural question among the objectives of the framework conference on adaptation to climate change in the Mediterranean. Therefore, adaptation to climate change has become imperative to reduce the socio-economic impacts on already very vulnerable rural populations.

Twenty thousand years ago, the area between southern Spain and the Caucasus was covered with cold steppes (and scattered forests). In the northern part of the Mediterranean basin, the temperature of the coldest month was then 15 ° C lower than today.151. The water available for vegetation was less, and the winter cold was (-5 ° C instead of -15 ° C). Much more reliable results have been obtained for 18,000 years before the present (see Figure 7, showing isotherms and coastal areas; from Doumengue, UNU conference, 1997) or for the Middle Holocene, 6,000 years ago. For that period, vegetation and climate maps have been issued.152. Deciduous and mixed forests which gradually progressed northwards were also present in the Maghreb and the Sahoura valley for example. The climate was milder (+1 ° C to + 3 ° C during winter), while more water was available for vegetation growth (+ 8% to + 15% estimated). A more marked seasonal contrast than today has been highlighted with warmer summers (+2 ° C) and colder winters (-1 ° C to –2 ° C), resulting in a similar annual average. However, there is a tendency in these models to underestimate the mechanism of increased rainfall. An increase in temperature of 1 ° C can cause vegetation to move 100 km north. Based on a temperature increase of 2 ° C and a doubling of the CO2 concentration, simulations were carried out.153. The results did not show an extension of the arid Mediterranean zones of the north of the basin but rather a development of deciduous forests, as during the Holocene.

Impacts of climate change in the Mediterranean region

The problems linked to climate change are due, among other things, to the pressure of society on natural Mediterranean environments (Magnan et al., 2009). Indeed, the current state is closely linked to anthropogenic activities and the identification of species is not yet finished. Figure 7 shows the main impacts of climate change (Magnan et al., 2009).

Generally speaking, the increase in air temperature influences the circulation of air masses. It intensifies the winds which could cause a change in their directions. The episodes of high heat, associated with precipitation have a remarkable influence on the stability of the soil and the plant cover. They also generate landslide phenomena as well as increased evapotranspiration. Additionally, an increase in the amounts of precipitation favors the disturbance of the hydraulic regimes. This phenomenon results in a change in the volume of water received by the territory. It also affects river flows and water retention areas. Moreover, irregular and brutal precipitation favors the phenomena of flooding, soil erosion, and drought. Further, following the rise in sea level, phenomena of submergence of the low coasts and intrusion of marine water into aquifers will occur. The salinity of the water tables will also increase following the appearance of urbanization problems in the Mediterranean coastal regions. Furthermore, natural resources, namely ecosystems, such as water, soil, and wildlife are affected by climate change. The shortage of these ecosystems is directly linked to human activity. Indeed, the problems of submersion and or salinization of the soil will generate the loss of certain coastal portions. These places will be deserted by the population and other species (loss of biodiversity: species and landscapes). Increasing temperatures and varying precipitation patterns cause lag and reduced plant growth periods. Land degradation following climate change has a significant impact on the areas of productive land. Besides, periodic droughts, sea level rise associated with temperature variations will influence water availability and consequently increase the needs of rain-fed and irrigated agriculture.

The most important economic sectors of the Mediterranean such as agriculture, industry, tourism, and energy production are clearly affected by human activity. Therefore, socioeconomic inequality issues arise from the evolution of the region's economy and issues related to population migration and geopolitical relations will now appear

"*It is people suffering from poverty and social exclusion who will feel the effects of climate change the most, as their ability to adapt to rapid and gradual climate change is more limited*" (World Bank Report, 2014). Figure 8 below highlights the consequences of major future climate changes on human activities.

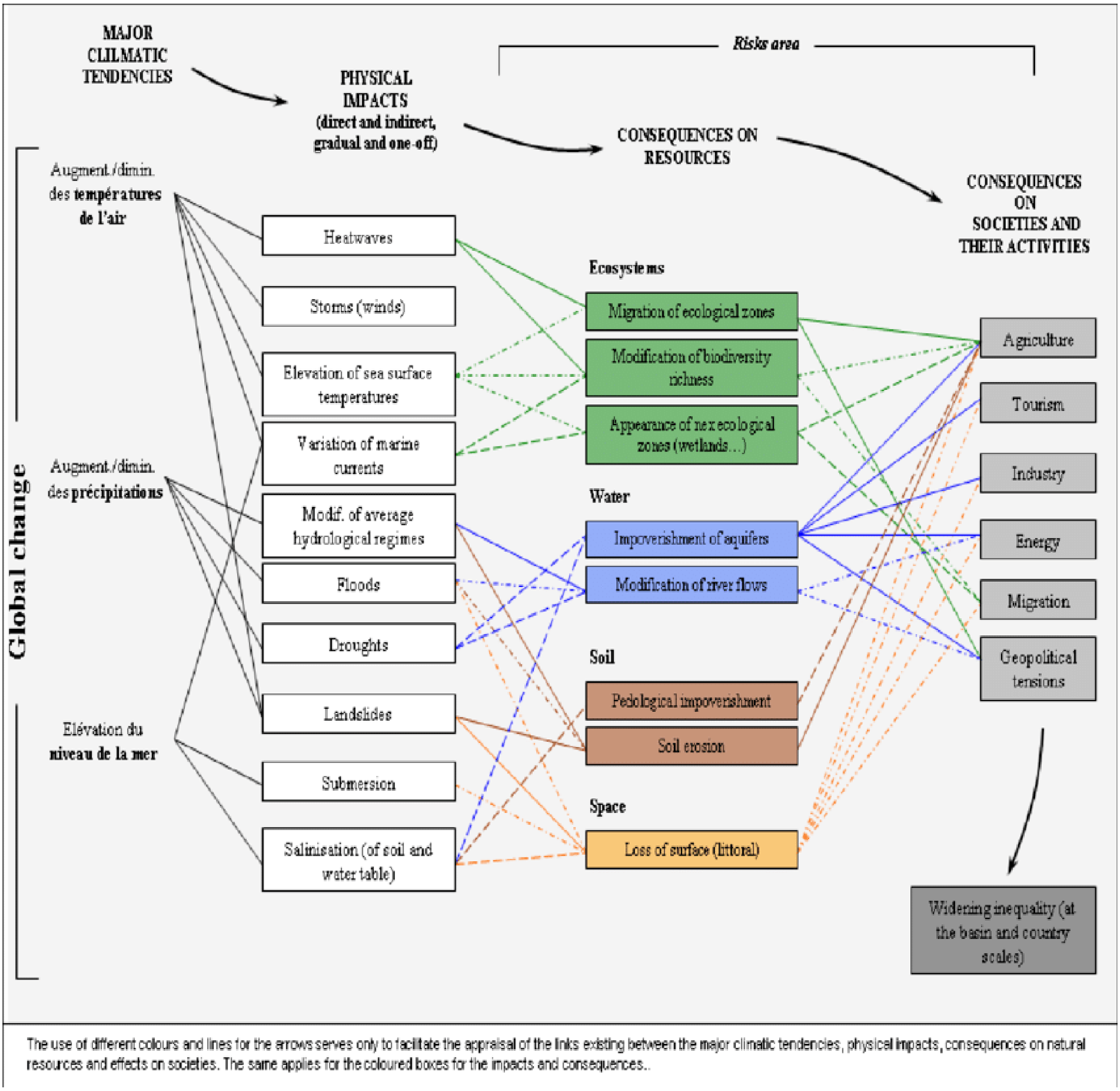


Figure 8 Some examples of "impact chains" highlighting the consequences of major future climate changes on human activities.

The impacts are the result of the confrontation between the major trends concerning temperatures, precipitation, and sea level and the conditions specific to the affected area, concerning the natural and anthropogenic characteristics of the Mediterranean area. However, it is important to remember that the Mediterranean is already characterized by natural environments strongly marked by the pressures of the societies which develop there. However, these pressures will only reinforce the problems inherent in climate change, and vice versa. Various climatic and environmental specificities which notably include structurally low availability of water resources characterize the Mediterranean basin. This situation is largely due to a climatic context which sees the clash over the year of three large air masses with very different characteristics: a dry tropical air from Saharan Africa; a dynamic air mass over continental Europe; and a moisture-laden air mass from the Atlantic (Villevieille A. et al., 1997). And this configuration of the rainfall regime is very irregular both in space and in time. As well as the riparian countries of the South only receive 10% to 13% of the average annual rainfall in the basin. Like the countries on the eastern shore, they are therefore characterized by very marked aridity, particularly in Libya and Egypt. The northern shores, for their part, offer more temperate conditions and the contrasts between the coastal zones and inland areas are more marked in the countries of the South. It is interesting to point out that the Mediterranean climate has a range of nuances as a result of several reasons; the latitudinal and longitudinal extension of the basin, the entanglement of the land and the sea, the presence of many islands and the softening effect of a relatively warm sea (Lanquar R. et al., 1995). Thus, the contrasts can be particularly marked between places like Djerba in Tunisia (rainfall of about 100 mm/year) and a city like Genoa in Italy (1,200 mm / year). However, these natural constraints only constitute real problems through their confrontation with the effects of development - direct pressure on resources, and increasing exposure of societies to hazards. The result is a constant growth in natural risk in the Mediterranean. As an example, it is possible to recall that demographic pressure, agricultural intensification, industrialization and urbanization, which is both intense and poorly controlled, today exert considerable pressure on ecosystems and water resources (Benoit G. and Comeau A., 2005). And the water demand, as estimated, doubled during the second half of the twentieth century, placing regional consumption at 290 km3 / year and increasing threats of scarcity.

Climate change and agriculture

Agriculture is a key pillar of the Mediterranean economy. It is particularly vulnerable to climate change. Indeed, it depends directly on climatic conditions which expose it to the threats of different climatic changes (Iglesias, 2008). Indeed, agricultural production in the Mediterranean region will tend to decrease (Olesen et al., 2007). Moreover, by 2050, it is estimated that the productivity of vegetables will drop by - 30 to + 5%. As for water demand, it is estimated that it will increase by 2 to 4% for corn and from 6 to 10% for potatoes in 2050 (Audsley et al., 2006).

According to Le Houérou (1992, cited by Rousset et al., 2006), the Mediterranean will experience a shift in bioclimatic stages to the north following the effects of climate change. This phenomenon will cause the rise of arid zones in North Africa. The increase in temperatures combined with water scarcity and soil degradation in the Maghreb region explains this decrease in agricultural potential for rain-fed and irrigated crops (Rousset et al., 2006). Moreover, the displacement of the bioclimatic stages implies a displacement of the geography of the agricultural potentials towards the north. An increase in the productivity of certain crops is then justified. The northern part of the Mediterranean could become the ideal environment for typically Mediterranean cultures such as olives or lemons. An intensification of market gardening is possible according to Le Houérou (1992, cited by Rousset, 2006).

Besides, Seguin et al. (2004) state that for fruit trees and vines, an advance in the phenological stages and a late breaking of dormancy due to lack of cold will take place. For other species, physiological disorders like falling buds and fruit abortion will be linked to mild winters. The high heat can cause the flowering date to advance and promotes the risk of frost. The latter prevents fertilization and pollination. For the vines, the maturation period will be advanced which will affect the quality of the harvest, thus will be more loaded with sugar and less with acid (Lebon 2002). Additionally, Bessaoud and Tabet-Aoul (2009) cite water scarcity, high variability in inter- and intra-seasonal precipitation, increased salinity and the development of pests as the main factor linked to climate change. According to Seguin and Soussana (2006), the pine processionary caterpillar moves in the north and in latitude, or the observation of a third generation of the codling moth.

It should be noted that the phenomena linked to climate change such as drought, floods and cold winds as well as the resulting consequences (loss productivity from grazing, etc.) induce a loss of livestock and generate diseases (Bessaoud and Tabet-Aoul, 2009). This, for example, will affect the ecological balance of the Maghreb forests. Secondly, the loss of soil due to erosion, in a region where 80% of all farms have an area of less than 10 ha in most countries (Blue Plan. 2009) will encourage the rural exodus of young people (Bessaoud and Tabet-Aoul, 2009). A phenomenon of "climate migrants" has been identified by several recent studies, which is defined by migratory movements both, within the same country or from North Africa to the north (Magnan et al., 2009). In addition, while food demand continues to increase in the region, the Blue Plan reports (2009) mention a reduction of around arable land per inhabitant in the Mediterranean since the early 1960s, which implies increasing overall food dependence in the Mediterranean. As well, the supply of cereal crops, an essential food for the Maghreb countries, will decrease by 2050. A problem of accessibility and volatility of food prices will also be raised due to storage difficulties under high heat (Bessaoud and Tabet-Aoul, 2009).

Climate change and water

Changes in sea level can strongly depend on the factors that influence the formation and melting of glaciers. (E. Rohling et al , 2008) The Mediterranean Sea has a rugged coastline, cut into several smaller seas: the Adriatic, the Aegean, the Alboran, and the Ionian. From the sixties to the nineties, it was the cooling of the upper waters of the EM which caused a reduction in steric heights, while after 1993, the warming caused a rise in the level of sea. NAO is also correlated with changes in steric sea level in the upper waters of the Adriatic and Aegean. However, a very small contribution to the observed rapid rise in sea level in the ME is made by steric effects, which suggests that changes in ocean circulation are also related to the transient phenomenon of ME (c ' i.e. variations in the region of deep water formation, from the Adriatic to the South Aegean) could be associated with the recent changes observed (rapid rise in sea level in the ME since the mid-90s).

Part III: Climate change in Lebanon

General context of the study area

Topographies and climate

Lebanon, located on the eastern shore of the Mediterranean Sea, is a small country with an area of 10,452 m2. It is a mountainous country, which stretches for a length of about 225 km and a width that varies between 40 and 70 km. In terms of topography, it presents a variation of relief and climates. Moreover, Lebanon is formed of 4 parallel surfaces which spread from north to south and are from west to east: A flat and narrow coastal strip parallel to the Mediterranean Sea constituting the coastal plain, the mountains of Lebanon which are medium and high mountains reaching up to 3087 m above the sea, the fertile Bekaa Valley located between the two mountain ranges and the Anti-Lebanon mountain range which extends on the eastern border with Syria (Figure 9). Its relief is complex and composed of sloping and steep terrain. This creates difficulties in exploiting the land, especially on steep slopes.

Regarding the texture of the soil, the land of Lebanon is mainly made up of limestone rocks (nearly 70%). However, one can find sandy soils formed by basalt strata (Akkar plain) as well as fertile alluvial soils in the middle and western zone of the Bekaa.

The Lebanese Climate is characterized by a cold and rainy winter which extends from November to May and a hot and dry summer the rest of the year. The climate varies between the warm Mediterranean and the desert (Verner et al., 2018). In fact, the Lebanese territory is characterized by a variety of microclimates which depend on the topography of the territory (MoE / UNDP, 2011), the influence of the Mediterranean Sea and the Syrian Desert in the north of the country. The amount of precipitation in this territory is highly variable and decreases as it passes from south to north (from more than 1400 mm to less than 200 mm) (MoE

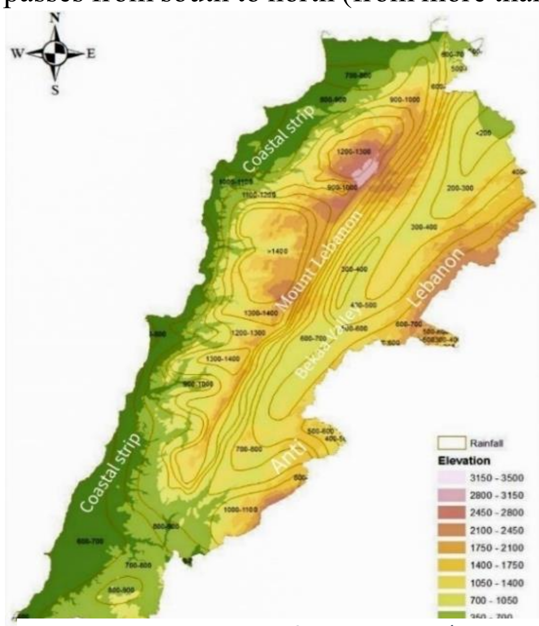


Figure 9 Topographic map of Lebanon MoE / UNDP, 2011

/ UNDP, 2011). Thus, referring to the National Meteorological Service, we can distinguish eight Eco-climatic zones based on rainfall, which are: the coastal strip which includes the north, central and south coast; the low and medium altitudes of Mount Lebanon; the Bekaa plain divides into 3 main zones, the north (interior Asi-Orontes), the central (interior Litani) and the south (interior Hasbani) (Figure 9).

Climate change in Lebanon: Impact on water resources

Lebanon is one of the water-rich countries compared to neighbouring countries because of its favourable position for rains. It is characterized by the presence of 40 main currents, mostly seasonal, with 17 perennial currents. This country depends mainly on the contribution of rain and not on water brought from other countries. In addition to this, snowmelt is an advantage since it provides water supply to aquifers and prolongation of runoff during dry seasons. However, several constraints arise for their development, such as the limitation of water resources during the hot season due to drought conditions (low storage capacity) and the proximity of the mountains to the sea causing difficulty in collecting water (FAO, 2013).

Over the past decades, several studies have shown an increase in average global temperature of 2 ° C between 1986 and 2050 (figure 10) and a remarkable reduction in rainfall (Nasser et al., 2020; Verner et al., 2018) (figure 11). Temperatures will increase by season and a variation in the length of the seasons is expected. These changes will have an impact on the snow cover which will decrease by 30% coverage and 50% thickness with an early melt of 15 to 20 days. The spring flow will then decrease especially between May to December (hot and dry season).

Climate change will therefore have an impact on agricultural activity, which largely depends on weather conditions, in particular rainfall and wind temperature (Verner et al., 2018). It is the main sector of water consumption (Frenken, 2009) and more than half of water waste comes from groundwater which depends largely on rainfall and snowmelt, hence the importance of a revision continues strategies and management plans for the water sector in Lebanon.

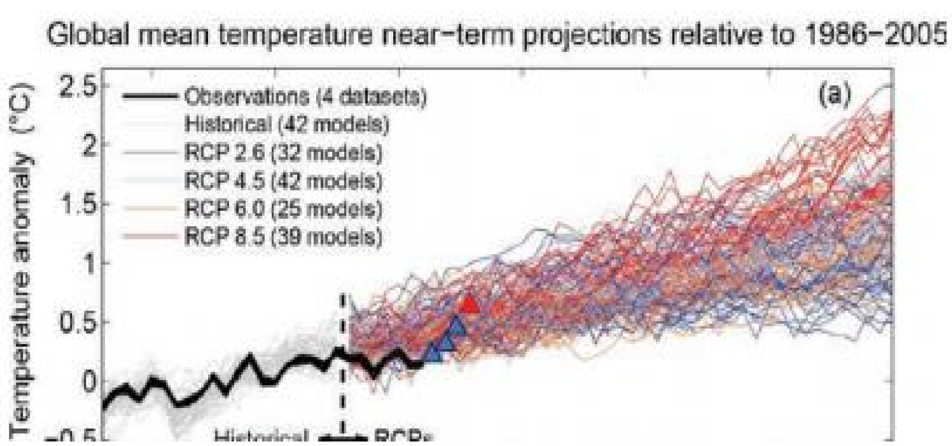


Figure 10 Projections of the global average temperature between 1986 and 2050 in Lebanon Verner et al.,2018

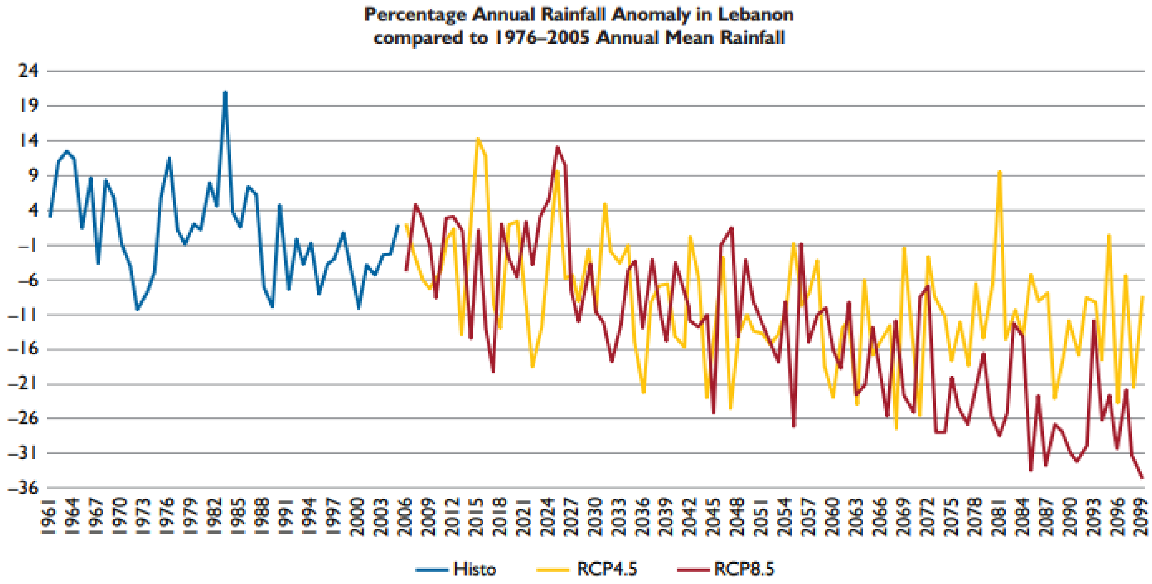


Figure 11 Variation in the percentage of precipitation between 1961 and 2099 in Lebanon Verner et al., 2018

Agroeconomic aspects of Lebanon

Agricultural sector

The main agricultural areas in Lebanon are:

- The coastal plain with mainly citrus crops, horticulture and bananas;
- The plains of Akkar cultivated with cereals, potatoes, grapes and vegetables;
- The Bekaa Valley is dominated by potatoes, vegetables, vines, stone fruits and cereals;
- The mountainous region is characterized by its valley terraces where orchard fruits and vegetables are grown;
- The western slopes of the Mount Hermon and Anti- Lebanon range where grapes, olives and cherries are grown;
- The southern hills where olives, cereals, tobacco and almonds are most cultivated.

According to the last agricultural census (2010/11), Lebanon has an estimated agricultural area of 332,000 hectares (32 percent of its area). A total of 230,000 hectares are cultivated, half of which is irrigated. The distribution of the UAA by governorates shows that almost half is located in the Bekaa (43%) followed respectively by the North, the South, Nabatiyeh, and Mount Lebanon (figure 13). The average farm area reached 1.4 hectares with a peak in Bekaa of 2.9 hectares per farm and a minimum in Mount Lebanon with 0.6 hectares (MoA, 2012). Almost three-quarters of the total UAA of farms are governed by the mode of direct assertion (land management rights by the owners of land) (MoA, 2012). Land use s is gradually being moved from cereal-based production systems to value-added crops (mainly fruits and vegetables). In recent years, there has been little change in the total value of agricultural production.

Irrigation is expected to increase from 90,000 ha currently to 150,000 ha in 2035, which may pose risks of soil degradation and the disappearance of vegetative cover in this region (Darwish et al., 2005) due to the water limit. In fact, Lebanon's water demand is estimated at 1.5 BCM / year, while the current supply is only 1.2 BCM / year (MoE, 2010). In addition, weak government support for the agricultural sector and the lack of effective management and planning policies can worsen the situation, especially in these most vulnerable regions (Darwish, 2004).

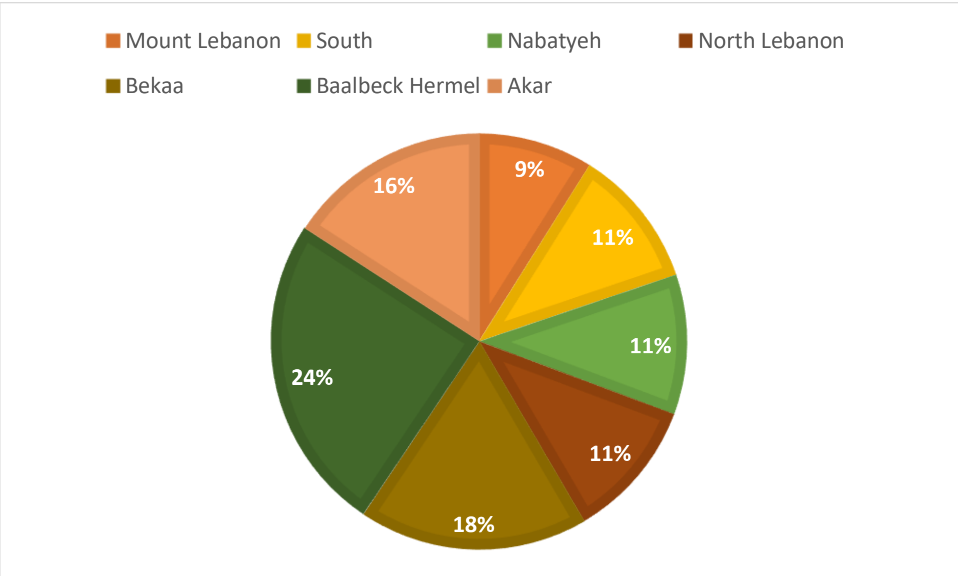


Figure 12 Distribution of the agricultural area used by Mohafazat in 2010 MoE / FAO, 2012

Agricultural economics

The agricultural value added per km² in Lebanon is higher than in many neighboring countries due to its capacity for agricultural diversification and its wealth of resources favorable to agricultural activity, thus reflecting higher production intensity and a concentration on more valuable fruits and vegetables. Nevertheless, the share of agriculture in the Lebanese economy is small around 2.9% of its annual GDP in 2018.

Lebanon is a country a net importer of food products (Figure 13). In 2019, according to the General Directorate of the Treasury, Lebanon's total agricultural and food imports amounted to USD 2.987 billion while agricultural and food exports were valued at USD 0.546 billion. The country is thus very vulnerable to the volatility of the prices of foodstuffs and other agricultural products, especially since there is currently a scarcity of access to dollars with an increase in its rate on parallel markets (up to $ 1 = 3500 LBP instead of the official rate of $ 1 = 1507 LBP) and security and health crises (explosion, pandemic ...).

The significance of this sector is that it employs 25 percent of Lebanon's labor force, including full and part-time workers as well as seasonal family work. Women represent about 9 percent of total farmers and are mainly involved in the production of industrial products (dairy products and canned food, etc.). Agriculture is a main source of employment for a large number of Lebanese families, especially the poorest among them. In many villages in the south as well as in Baalbeck and El Hermel, which are also the poorest sections of the country, agriculture accounts for up to 80 percent of local GDP and represents the main income and employment opportunity.

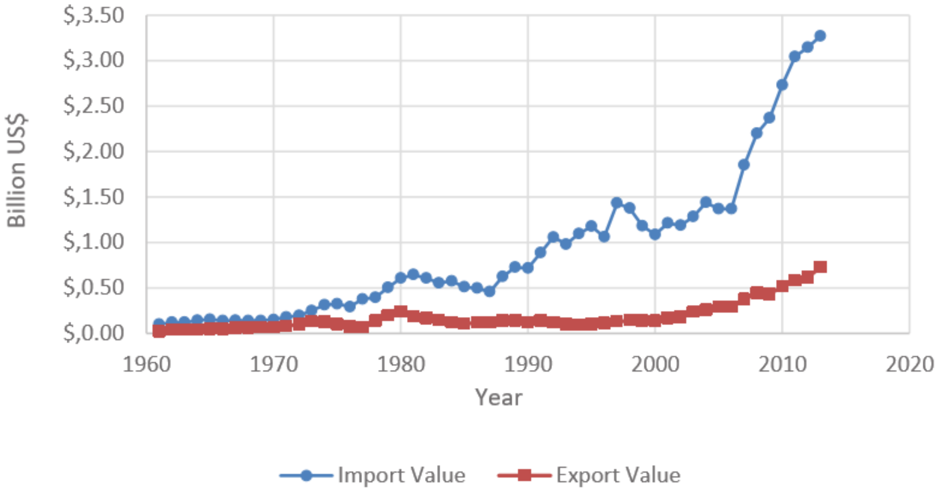


Figure 13 Values of Lebanese agricultural imports and exports between 1960 and 2013 FAOSTAT

Constraints and opportunities of the agricultural sector in Lebanon

The agricultural sector in Lebanon is impacted by the economic decline and the unstable security situation. The agricultural work has become incapable on its own of ensuring a sufficient yield for a favorable standard of living of the peasants, especially in the poorest rural areas in particular the border areas of Hermel, Baalbek, and Akkar which depend on agriculture as the main income source. Moreover, several constraints in institutional, political, technological, and financial resources interact, impacting the performance of agricultural systems (FAO, 2013):

Small fragmented land holdings:

According to the last census, the average UAA in Lebanon is 1.4 hectares so it is a dominance of small farms. In addition, these lands are increasingly fragmented because of the transitional activity between farmers and their children, especially as farm households have an average of 5 members each.

Lack of access to infrastructure:

One of the common problems in Lebanon is the poor quality of infrastructure which is damaged and inefficient requiring rehabilitation, especially in rural areas (irrigation canals, roads and sub-roads, etc.).

Widespread use of foreign labor:

Many Syrian refugees settled in rural Lebanese areas after the Syrian crisis (especially border areas) and constitute the main foreign workforce in Lebanon. Farmers resort to these generally unskilled laborers who are increasingly replacing skilled Lebanese workers who are relatively more expensive. In Bekaa, for example, wages have fallen by up to 60% in some villages due to a high number of foreign workers.

High production costs (inputs, labor and energy):

The degraded economic and financial situation in Lebanon has caused an increase in the prices of factors of production in agriculture (fertilizers, pesticides, labor, etc.). For example, the price of urea fertilizer has doubled ($ 600 / tonne) and sulfur used for pest control has more than quintupled (from $ 0.18 - $ 1.0 / kg). Farmers are therefore increasingly unable to maintain and invest in their livelihoods.

Insufficient knowledge of innovative techniques and environmentally friendly practices and excessive use of pesticides:

Most of these lands still use traditional irrigation methods in addition to the use of tractors. The quality of production is not systematically taken into account at the market level where the low technical level of Lebanese farmers makes them dependent on sellers of agricultural inputs (fertilizers, pesticides, insecticides, etc.). This leads to the frequent misuse of inputs that sometimes make the production unsaleable on international markets because of its high cost and its non-compliance with international laws for the healthy use of pesticides and fertilizers. The lack of knowledge of these standards by insufficiently trained and informed farmers exacerbates this situation.

Political constraints and limited government support:

This is a lack of agricultural policies and plans as well as government quality control and marketing regulation programs. No agricultural policy, in the sense of coherent public action oriented towards sustainable development of the agricultural sector, has ever been developed.

Degradation of natural resources

In the rural areas of the North (Akkar and Baalbeck el Hermel) where the Syrian refugees are based, there has been overexploitation of natural resources to ensure the need for water and food. In addition, this large number of refugees generated pressure on resources and accentuated the pollution problem which was already present (water pollution, soil degradation, destruction of flora and fauna, etc.). The increased use of water has intensified the depletion of underground aquifers and farmers in Al Qaa have confirmed that the water table has dropped by 10 to 20 meters.

Lack of specialized agricultural credit

Bank loans are the only sources of financing for farmers to invest in. These loans with high interest (10.3% interest rate in dollars) and short term are not favorable for farmers who find it difficult to pay them especially since the agricultural yield does not have the same elasticity as that of the commercial performance.

In addition, Lebanon has competitive advantages compared to neighboring countries such as:

- Lebanon has the highest proportion of agricultural land in the Middle East;
- Lebanon's climate, soil, and abundant water resources exhibit characteristics that enhance Lebanese agriculture;
- Microclimatic variability allows Lebanon to grow a wide range of crops which can occur in both cold and tropical climates;
- The existence of some institutional support to the sector capable of supporting exporters financially and non-financially in an attempt to increase the level of exports in order to access new markets (IDAL, 2017).

Description of the study area

Structural and social characteristics

The study area concerns the governorate of Baalbeck-El Hermel which is part of the Bekaa plain (figure 14). This governorate is divided into two large districts, El Hermel located in the north of Bekaa, with an area of 136 km2, composed of 9 municipalities, and Baalbeck which is the largest district of Lebanon with a total area of 2319 km2 and comprising 102 municipalities. The population is made up of 416,427 inhabitants, of which 26% are non-Lebanese (Syrian and Palestinian refugees).

This region, by its geographical position between the two mountain ranges, presents two types of geomorphological units: first, the slopes of the Lebanon and Anti-Lebanon mountains with a high slope value, having a differentiated lithology, and outcropping in certain places caused by the water erosion with shallow soil. Secondly, the plain is characterized by its flatness, by the thickness of the soils and the absence of geological outcrop and above all by the presence of agriculture (figure 15). The soil texture in this area varies between loamy and clay loam and is characterized by the presence of volcanic basalt rocks in the Hermel region of high values. The land is characterized by a petro-calcium layer that farmers break up to cultivate the soil with high productivity (Darwish et al., 2005).

The villages of Baalbeck El Hermel are the most vulnerable and poorest in the Lebanese territory. This vulnerability is due on the one hand to the political and social problems in this area, which worsened after the Syrian war and the flow of refugees. On the other hand, farmers in this region rely on agriculture as their main source of income and given the semi-arid climate and the lack of support from the state as well as poorly adapted agricultural policies, the farmer is faced with shocks and risks that increase this vulnerability. According to the analysis carried out by the UNDP in 2018, concerning the living conditions of Lebanese inhabitants, the inhabitants of the two Cazas Baalbeck and El Hermel are below the average satisfaction threshold with respectively 49% and 66% of low satisfaction.

Figure 14 Location of the Caza of Baalbeck El Hermel in Lebanon Atlas of Lebanon, 2007

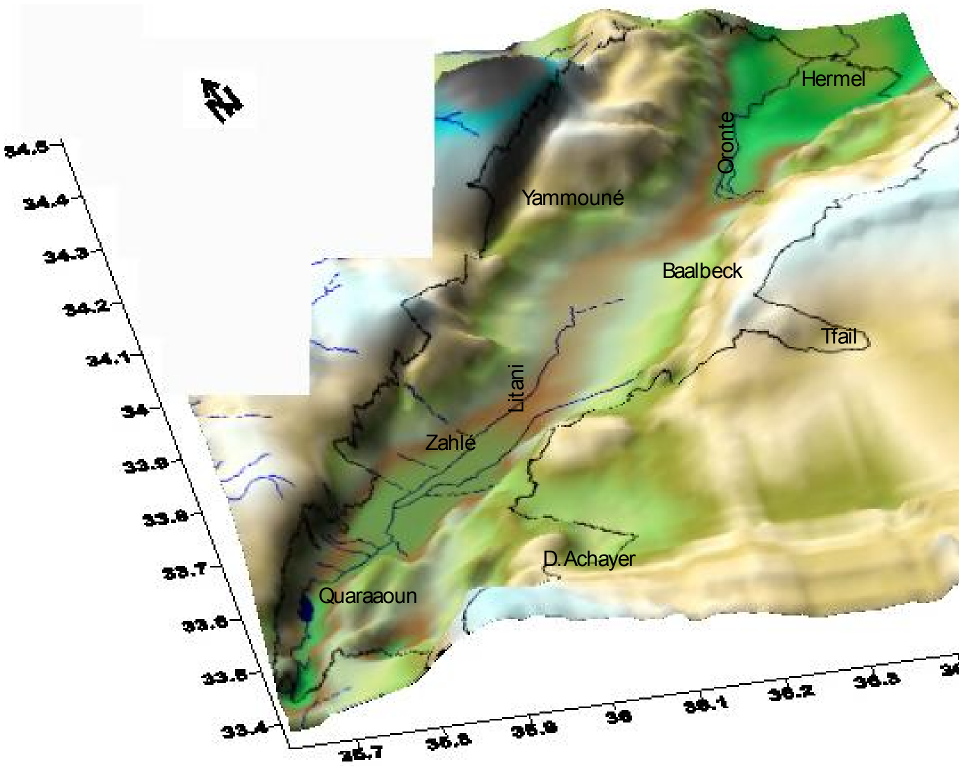


Figure 15 Topographic position of Baalbeck El Hermel El Hage Hassan, 2013

Climatic characteristics

Baalbek El Hermel is a semi-arid zone influenced by the continental climate. It is characterized by a cold and rainy winter that lasts from October to May and a hot, dry summer that lasts from June to September. In summer, the influence of high subtropical pressures prevents any airlift on the Bekaa plain and causes absolute drought from June to September (Nasser et al., 2020). The plain is characterized by significant spatial variability in annual rainfall with totals ranging between 100 mm to 1,200 mm. Thus, depending on the distribution of rainfall on the plain, we can distinguish three distinct agro-climatic zones (El Hage Hassan et al., 2013) (figure 16):

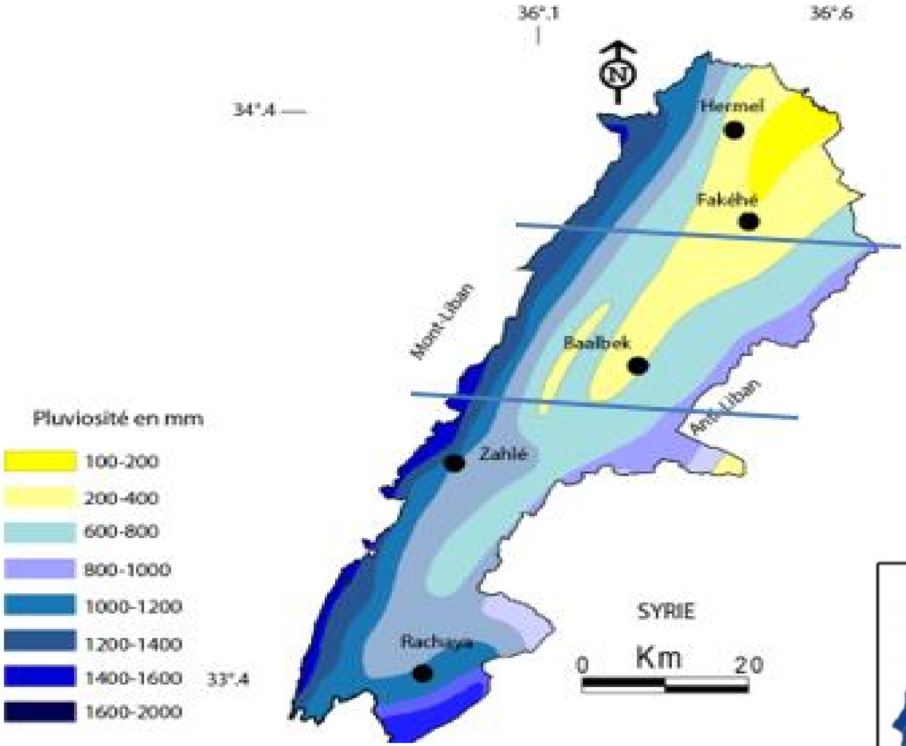
- The northern Bekaa, in the northern part of Baalbeck ELHermel, is the driest with a rainfall of between 100 and 300 mm;
- The central Bekaa which stretches from Bar Elias to Baalbek receives varying rainfall between 300 and 700 mm;
- South Bekaa, is represented by the Rashaya area which receives between 700 and 1000 mm of rains per year.

Baalbeck ELHermel is mainly located in the first two zones and receives the lowest amounts of precipitation on this territory, which do not exceed 700 mm.

Concerning the rainfall regime, Figure 10 shows the variability of the average annual rainfall over 10 years measured by the different climatic stations located in the 3 zones of the Bekaa.

Hoch el Omara and Tal Amara, located in the upper part of South Bekaa receive the highest rainfall amounts in our study area compared to other stations[1] but with significant variability between the minimum average and the maximum received, unlike other stations.

Baalbeck El Hermel is an area vulnerable to climate change due to its topography and low rainfall. Drought conditions in a semi-arid climate cause soil deterioration and threaten groundwater considered the main source of irrigation in this semi-arid region (Darwish et al., 2005).



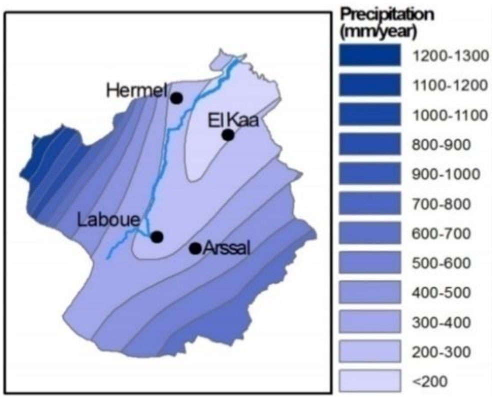


Figure 16Annual rainfall in the Bekaa plain and in its northern zone and agro-climatic zones. Jomaa et al, 2015

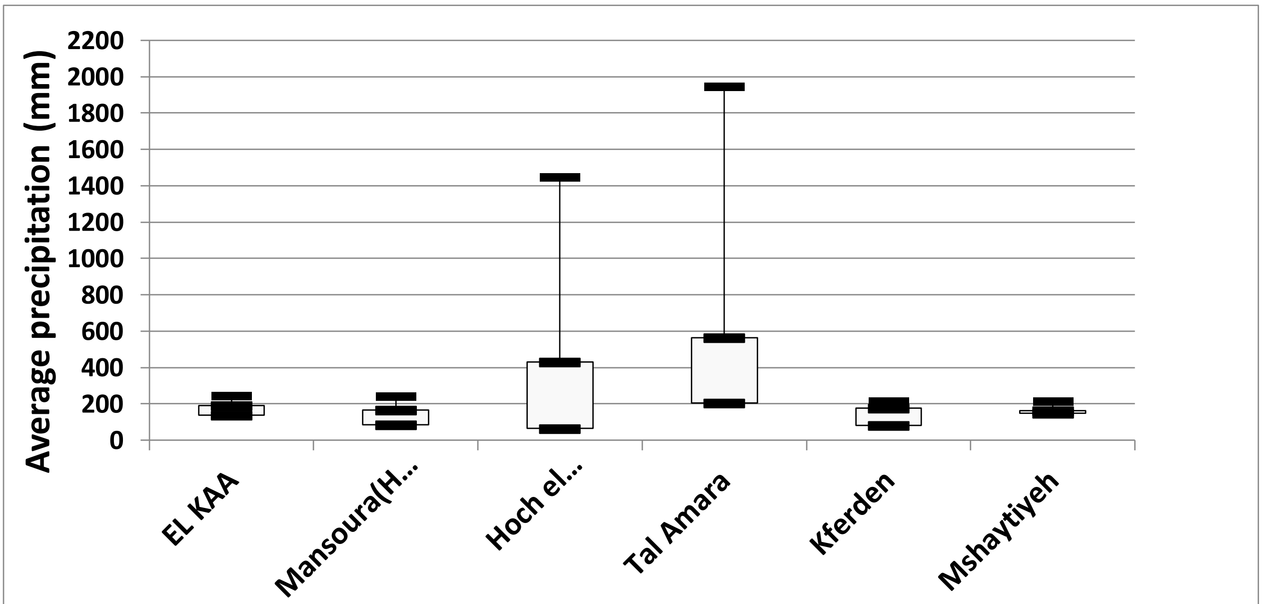


Figure 17 Average precipitation in several stations at Baalbeck El Hermel data collected from LARI

A. *Land structure*

The utilized agricultural area of Baalbeck El Hermel of 576.3 ha represents the largest cultivated area of the Lebanese territory (25% of the total UAA) (MoE / FAO, 2012). It is mainly characterized by rain-fed crops, irrigated crops and fruit trees where water resources are available. According to the last census carried out in 2010, the majority of irrigated UAA in Lebanon is concentrated in Bekaa with its two districts and it is mainly additional irrigations (MoE / FAO, 2012) (figure 18).

In northern Bekaa, new irrigated plots were introduced in the last decade after farmers discovered the high productive capacity of these areas and easy access to groundwater for irrigation. This high productivity is due to a specific climate for semi-arid crops and the availability of water (groundwater). In addition, it is possible to produce earlier than in other regions due to the specific climatic conditions of this region (Jomaa et al, 2015). Thus, several new crops were introduced such as vegetables, market gardens, especially watermelons and new varieties of fruit trees.

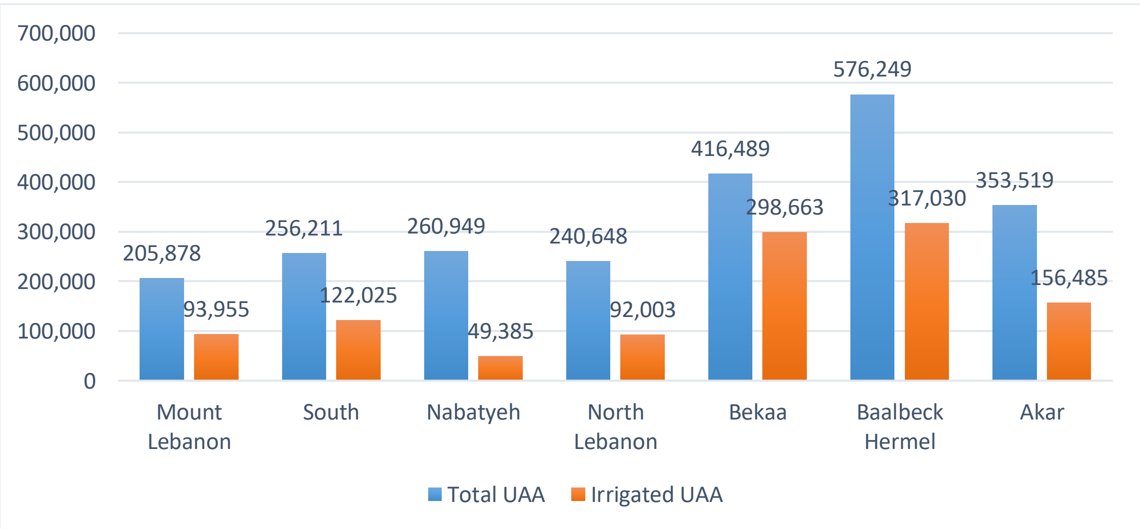


Figure 18 Distribution of agricultural areas irrigated by governorates

Diversified and subsidized crops in Baalbeck El Hermel

Baalbeck El Hermel is characterized by several types of crops divided into cereal crops, market gardens, olive trees and fruit trees.

Cereals

Wheat and barley are the most cultivated cereals in the Bekaa region (MoA, 2011). The majority of these crops, the yield of which depends on the amount of rainfall, are concentrated in the governorate of Baalbeck which receives the most rainfall. Wheat is a crop subsidized by the Lebanese State. The institution which is in charge of purchasing wheat from producers is the General directorate of Cereals And Sugar beets under the supervision of the Ministry of the Economy and Trade. In this region, wheat farms are large and all the wheat produced in Lebanon and sold to OCBS comes largely from this region. Cereal production is essential for food self-sufficiency. Durum wheat is the most widely cultivated type of cereal crop although it is not suitable for bread production. It is used in the local food industry. Barley is mainly grown as fodder for animals. Its yields vary depending on rainfall.

Vegetables

Vegetables are dominant crops in the Bekaa region including Baalbeck El Hermel. The Bekaa plain is the main producer of legumes for the Lebanese market, part of which is exported abroad. There is intensive cultivation especially of potatoes, tobacco, onions and tomatoes. The potato is the main market gardening crop cultivated on the plain followed by the tomatoes. Tobacco production is entirely purchased by the Regie Libanaise de Tabacs et Tombacs (RLTT) which buys this production at favorable prices and controls the quality of this production.

Fruit trees and olive trees

The cultivation of fruit trees is one of the most common crops in Baalbeck El Hermel. These are pome fruits, stone fruits, tropical fruits including locust beans, almonds and walnuts. Fruit growing is one of the most important elements of agricultural income with 40% of the total amount of agricultural production (in 2005) (MoA, 2012). The majority of these crops are sold on the local and national market but with few exports because of the problems of non-compliance with international standards (high residual, old categories, etc.).

The significant decline in cereal cultivation was offset by strong growth in perennial crops and in particular olive growing. The latter occupies some 57,000 hectares (or 20% of cultivated land) where oil production is from 130,000 tons of olives (on average), 70% of which are processed into oil, making it the most common tree species in Lebanon. The olives are largely non-irrigated but in the Bekaa plain they are mostly irrigated.

These crops are characterized by their capacity to adapt to drought and their resistance to diseases, hence their importance in the study area.

Hydrological characteristics and irrigation sources

Water resources

Our study area is characterized by the presence of two main basins on its territory. The first is the upper Litani basin, coming from sources close to Baalbeck and crossing the Bekaa plain to the south. It represents the largest current in Lebanese territory with an average annual flow of 475 million m3. The central area, especially the governorate of Baalbeck, benefits from the source waters of the Litani and a hill lake "Yammouneh" has been built for several years on these spring waters (Nabaa Yammouneh), refreshing the area and ensuring water supplies to farmers who are not so much sufficient but can contribute to an improvement in productivity. It is an industrial lake developed in 1936 by the French proxy authorities in the region of Baalbek, but the work was only carried out in 2009. The lake is a dish of water reserved for a low-lying dam that stores 1.5 million cubic meters of water (BWE, 2014). The water from the lake is used to irrigate large tracts of land in the Baalbeck valley, particularly the land between Deir al-Ahmar in the north and Saaideh in the south. The water is distributed via the canals of the public irrigation system and the

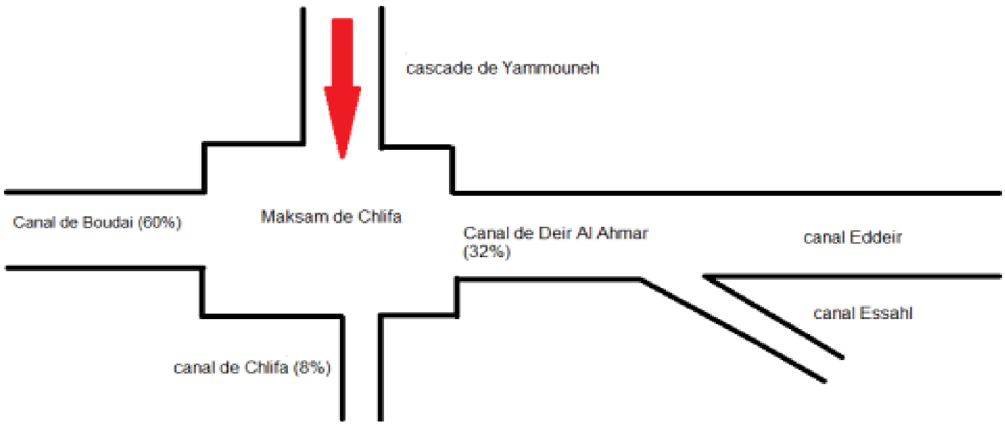


Figure 19 The distribution of water from Yammouneh

distribution over the villages of the region is as follows: 60% of the flows supply the village of Boudai and 40% go into the canals of Deir Al Ahmar and Chlifa (figure 19).

The second is the Asi-Orontes basin which originates from the Hermel mountains in the North Bekaa region of Lebanon, flows north through Syria to empty into the Mediterranean Sea after passing through Turkey. It is mainly fed by groundwater which comes from the snowmelt of Mount Lebanon and Anti-Lebanon. Its main sources are Al-Labweh, Ain Zarqa (main contributor of flow) and Daffash Springs in the Bekaa Valley. The presence of this basin does not offer a great opportunity for agricultural households despite their importance and the region does not present a vast natural cover. This is due to the lack of irrigation projects that farmers need to take advantage of these rivers and the lack of proper planning for the construction of dams and hill lakes (Darwich, 2004). A development project (Assi program) was developed in consultation with the Syrian government aimed at developing the basin's water resources for irrigation, domestic use and hydropower. It consists of the construction of two dams north of Baalbeck El Hermel, one near Ain Zarqa (phase 1) and the other upstream of the Hermel bridge (Phase 2) (BWE, 2014). This project was initialized in 2005 but security (2006 war) and political problems caused a delay in the completion of this project, which is currently in the construction phase (Table 1).

Table 1 Dam projects on the Al-Assi River

River	Characteristics	Dams	Status	Dynamic Storage
Al-Assi River	Debit : 1.2 BCM (410 MCM in Lebanon)	-Assi Phase 1 -Assi Phase 2	Construction phase	-Phase 1: 27 MCM -Phase 2: 37 MCM
	Length: 404 km (40 km in Lebanon)			
	Area : 26,530 km2 (2016 km2 in Lebanon)			

Source: https://water.fanack.com/lebanon/shared-water-resources/

The region of Baalbeck El Hermel is also known for its richness in groundwater (Jomaa et al., 2015; Darwich, 2004). There are three types of groundwater exploitation in Baalbeck El Hermel, either by public wells under the responsibility of the Bekaa water establishment (presence of 15 wells in Baalbeck and 3 wells north of Baalbeck) either through licensed private wells drilled by farmers only or illegal private wells of unknown number (BWE, 2013). The overexploitation of the wells to meet the growing demand caused a drop in the piezometric level and a deepening of the drilling (Table 2).

Table 2 Variation in the depth level of the boreholes in Bekaa Risk G., Bekaa water establishment

Drilling depth	**1980**	**2006**	**2018**
Zahle	100 m	150-200 m	400- 450 m

Regarding water consumption in the Bekaa region including Baalbeck El Hermel, it is expected that the water demand will increase due to demographic pressure and the growing water needs for irrigation (70% of the water consumed in this area is related to irrigation). Water supplies in this region remain limited and the water deficit will reach 316 million cubic meters in 2035 (BWE, 2014).

Irrigation sources:

The sources of irrigation in the Baalbeck El Hermel region are:

Lake and canals:

The water of Lake Yammouneh is distributed by schemes that distribute the water in canals at the agricultural zone level. The Bekaa Water Establishment manages the distribution of Yammouneh water, and farmers pay the establishment a fee for service and cleaning the canals (nearly LL 75,000 per year / $ 50). The absence of water meters on farms makes it difficult to determine the amount of water consumed per farm and farmers estimate the average volume consumed per year depending on the type of crop. In some villages, a water distribution schedule is applied (Boudai, Deir Al Ahmar, etc ...) but there is no precise information on this program since there is a lack of supervision and works illegal controls.

Other canal systems are present from water sources such as the Nabaa de Labweh between the villages of Labweh and Nabi Osman. Water is distributed free of charge in the canals and farmers have access to water which varies according to the flow of the source.

Well:

The artesian wells at Baalbeck El Hermel present the main source of irrigation in the region. The characteristics of these wells are unknown due to lack of monitoring and illegal activities. Usually farmers pay pumping and fuel tariffs to be able to irrigate their farms.

Chapter II

Typology of agricultural holdings: a starting point for understanding the performance of irrigated systems in Baalbek Al Hermel Lebanon.

Abstract

The Mediterranean region is one of the most vulnerable regions to climate change (CC) which raises important problems for Mediterranean agriculture. In fact, climate disruption creates some uncertainty in the decision-making of farmers in the management of their farms. This understanding can help researchers to better orient agricultural research on adaptation at the farm level and can help policy makers to develop adaptation policies. The semi-arid region of Baalbeck El Hermel is increasingly threatened by climate change. The agricultural systems constituting the main source of household subsistence in this zone show a significant vulnerability to these disturbances, especially about the limit in water resources. In this research we propose a framework to represent agricultural activities using typologies of farms and production units aggregated at a regional scale. We used empirical data from a local case study of the five most representative farming systems in the Baalbek-Hermel Governorate. Analysis of the results showed several behaviors and several levels of resilience of these farms:1-farms specializing in market gardening or perennial crops are very sensitive to drought conditions and are not resilient in the face of water limit conditions;2-the diversified farm with olive tree dominance is less sensitive and more resilient.

Key words: Baalbek Al Hermel, typology, climate change

Introduction

The climate on our earth has always undergone changes, but due to human activities, these changes are becoming more pronounced, and evolving more rapidly than before (Aspar, 2019). This is the phenomenon that scientists and politicians are referring to when discussing the topic of climate change. Before, climatic changes were mainly due to natural phenomena, but since the beginning of the industrial revolution in the 18th century, Man contributes more and more to these by releasing enormous quantities of greenhouse gases in our atmosphere or by burning fossil fuels such as petroleum to generate electricity or by clearing forests to produce crops as an example. At the same time, these emissions further increase the natural greenhouse effect, thus leading to increasingly intense global warming. (OCDE 2016)

Climate change is a large-scale scourge, as no country can escape its repercussions at various levels, whether developed or developing. To face it, there have been the adoption of many policies at the international level, such as the Kyoto Protocol, which was signed on December 11, 1997 and of which 37 countries were committed to reduce their emissions of gas. greenhouse effect of at least 5% over two periods (2008-2012) and (2013-2020) and for which the objective for the first period has been reached, such that the 37 countries involved have reduced their emissions by more by 20%. There was also, recently, the signing of the Paris Agreement which constitutes the first universal agreement bringing together all nations around a single cause which is the fight against climate change and adaptation to its consequences, the main objective of this agreement is that the global average temperature does not increase above 2 degrees Celsius compared to pre-industrial levels.

According to the 5th report of the Intergovernmental Panel on Climate Change, several scenarios between 2016 and 2035 show an increase in the average temperature of the earth between 0.3C and 0.7C (IPCC, 2014), This increase has impacts at different levels, such as rising sea level, weather conditions become more and more unpredictable, phenomena like droughts, floods increase even more. This upheaval in the climate also has impacts on crops, on the water supply, as well as on various organisms as well as it can also have impacts on infrastructure. The combination of all these impacts gives rise to new impacts at three levels: social, economic, and political.

The agricultural sector, which is a key sector for many countries, especially developing countries, is affected by climate change, which leads to a decrease in crop yields, given that it is highly dependent on the climate and conditioned by specific meteorological conditions of rainfall and sunshine to have a good yield. On the other hand, it contributes to the emission of greenhouse gases, such that, on its own, it concentrates 13.5% of emissions (IPCC, 2014). But despite this, the agricultural sector has a great capacity for adaptation and mitigation, with a good cost-effectiveness ratio, mainly from carbon sequestration thus decreasing carbon sequestration in the atmosphere.

The agricultural sector in Lebanon in general, and in the Baalbek-Al Hermel region particularly, is largely made up of small farms, which face several constraints, and consequently, are exposed to dangers and shocks.

The Baalbek-Al Hermel region is characterized by irregular rainfall with periods of drought. In addition, climate change further aggravating the situation, however, the recourse to irrigation from groundwater is proving to be impossible (Lefeuvre, 2018).

What is more, certain agricultural practices adopted by farmers consume water such as vegetables, which leads to the overexploitation of water resources, and therefore, the reduction in the level of aquifers.

Reflection around this situation prompts us to ask the following question:

How to increase the resilience of farms and reduce their vulnerability, in the short and long term, of the Baalbek-Al Hermel region to the repercussions of climate change by reducing their dependence on water resources?

In this research, the use of diagnostic analysis in relation to irrigation water management helps structure the analysis of problems and the identification of potential solutions related to water management (Dorian et al., 1999). It is within this framework that this first stage of the research action takes place, the aim of which is to take stock of the current situation of water management at the level of an irrigated field in Baalbek Hermel.

Materials and methods

The variations in climatic factors in Lebanon such as temperature, precipitation, and relative humidity, will have impacts on water resources which constitute the main element of life. The decrease in precipitation and the rise in temperatures, with the increase in drought and the decrease in relative humidity would have impacts on agriculture in the Bekaa Valley and would encourage farmers to irrigate by using artesian wells. Therefore, the climatic change would have negative effects on the groundwater level and would increase the risk of its pollution.

The Bekaa Valley, lying on the East of the Lebanon Range, is a very fertile High Land about 16 km wide and 129 km long, representing 42% of Lebanon's area, gently sloping from North to South from an altitude of 900 to 1,100 m. It is divided into three main zones: North Bekaa composed of Baalbek and Hermel, Central Bekaa which has Zahle as its Governorate and West Bekaa.

The Baalbek-Hermel governorate illustrated in Figure 20 is located between the two mountain ranges (Mount-Lebanon and Anti-Lebanon), more precisely in the north of the Bekaa Valley. It occupies 25% of the total area of Lebanon (2640 km2) and is composed of two districts, Baalbek and Hermel. The altitude in this governorate varies from 1100 m to 600m which runs along from Baalbek to the northern border of Syria, with a length and a width of 60km and 13 km respectively. Moreover, Baalbek-Hermel represents 64% of the total area of the valley. Even though Baalbek district is composed of a large part of lowlands, 94.6% of the Baalbek-Hermel regions are highlands.

Figure 20 Case study area Baalbek-Hermel (Bekaa, Lebanon)

Although this governorate has a significant agricultural activity, it faces a certain number of constraints (Darwish. 2004), of which we can enumerate among others: small population, low income, and the large size of families.

Baalbek-Hermel has 2 types of climate that depend on the geographical location: a continental climate in Baalbek district with a good amount of precipitation which varies from 600 mm to 800 mm per year, and a semi-arid climate in Hermel district with precipitation not exceeding 200 mm. Besides, the temperatures know a great variability between the warm season and the winter, such as it reaches 40°C in dry period and below 0°C in the cold period. This variability generates agricultural problems, especially for flowering fruit trees and some early crops. Moreover, spring frosts cause farmers to switch to illicit cultivation which is less demanding (Darwich, 2004). In sum, Baalbek-Hermel is the most desert area of Lebanon where the rainfall is around 400 mm/y (MoA, 2003).

The nature of the soil in the Baalbek region is not the same; it varies according to the geographical location (Darwish, 2004). For example, in the center and south of Baalbek, the soils are of the colluvial type with a depth of about 2-3m, therefore they are poor in organic matter. However, in the North of Baalbek and a large part of Hermel, the soils are of the limestone type, they are not very deep, and not very clayey, which poses a problem for irrigation as well as for mechanization. Nevertheless, next to the Orontes and its effluents, the soil type is mainly alluvial.

The Baalbek-Hermel region is characterized by low rainfall which is irregular, and occurs between November and March, therefore irrigation from groundwater is essential (Darwish. 2004). Additionally, two river basins stretch throughout the Bekaa Valley, which are the Orontes in North Bekaa and Litani in Central and South Bekaa. These two basins have the same source which is north of Bekaa however, they do not flow in the same direction. The Litani, with a length of 160 km, flows towards the south, while the Orontes flows north towards Syria. The Orontes constitutes the most important source of Lebanon with a flow that varies from 7 to 16 m^3/ s (Darwich. 2004).

Typology

Data collected and survey carried out

This work is based on a sample of 101 surveys carried out at the level of crop production farms in Baalbeck El Hermel in 2019. These farms were chosen at random from different villages in the Baalbeck ELHermel region, taking into account two main criteria: the diversity of crops and the climatic variability of the study area.

The questionnaire addresses several main issues which are:

- Characteristics of the farmer (age, status, origin, pluriactivity, level of education, etc.)
- Characteristics of the farm (location, total UAA, UAA by type of crop, date of installation, mode of acquisition, etc.)
- Labor (family labor, cost of permanent labor, cost of seasonal labor, origin of labor)
- Structure of the agricultural area and type of crop (name of the crop, yield per crop, quantity of irrigation, estimated cost of irrigation, source of irrigation, method of irrigation, total production cost, income by type of culture, marketing channels, etc.)
- Agricultural machinery and equipment (number of tractors, generators, pumps, PVC, private wells, etc.)
- Investment and non-agricultural external resources (value of the external income of the farmer and other members of the family, etc.)
- Analysis of climate change and perspectives.

The data obtained from the questionnaire allowed us to calculate the production costs and the gross margin resulting from the agricultural activity for each farmer. The main variables derived from this questionnaire are:

- The cultivated agricultural area (dnm): the total area per farm, the area per type of crop (cereals, market gardening, olives and fruit trees).
- Yield per crop (Kg / dnm): the yield of each crop in kilograms per denomination from which we calculated the average yield per type of crop per denom.

- The total income of the farmer (LL): from the yields by type of crop we calculated the total income of the farm in Lebanese pounds
- Total labor cost per farm (LL): the permanent and seasonal labor cost for each farm from which we calculated the total labor cost per name for each farm.
- The amount of irrigation water applied per crop (m3 / dnm): from the amount of water consumed by each crop in one season, we were able to calculate the average total water consumption for each farm.
- The cost of irrigation per crop (LL / dnm): from the cost of irrigation per crop we were able to calculate the average cost of irrigation of the farm per dnm in a season.

Note that the cost of irrigation does not represent the cost of the cubic meter of water per name since farmers pay either a cost per year which varies according to the region (nearly 75,000 LL per year) or irrigation charges (pumps, fuels), especially for those who irrigate by wells and canals.

Concerning the characterization of cropping systems, the analysis of the samples showed a dominance of market gardening crops which cover more than half of the total cultivated agricultural surface followed by cereals, arboriculture, and olive trees. The identification of the dominant crops was not possible in terms of the area since the questionnaire did not include the question concerning the cultivated area per crop. So we were just able to identify the different varieties of crops present for each type of crop and the typology was built according to the types of crop.

Programs and software used

Typology is a method of analyzing the diversity and complexity of agricultural systems. It is a method used in development research projects to take into account the heterogeneity of agricultural systems in a region. It is carried out by classifying groups of agricultural holdings according to homogeneous criteria. This allows us to obtain typical farms that answer the question of agricultural development research following a specific objective (Chenoune, 2014).

There are several typology methods which are: The "step by step" comparison of farms (Landais, 1998), the “expert opinion” typology (Landais, 1998; Pacini et al., 2013), the participatory classification (Kebede, 2009), and the multivariate analysis (Chenoune et al., 2016). In this work, we will follow a quantitative typology of multivariate statistical analysis using the Tanagra statistical software.

A principal component analysis (PCA) was used to draw up the typology of farms by identifying classes of farmers according to trend axes. PCA is an essentially descriptive statistical method that allows the maximum amount of information contained in a data table to be represented in graphical form (Philippeau, 1986). It makes it possible to see more clearly the link between the characteristic variables of the holdings and to observe their distributions.

The diversity of farms in the Baalbek Al Hermel region makes studying this area complicated; however, a typology makes it easier to understand. A typology of a farm represents the diversity of systems that are based on the distinction between a set of types of farms based on a certain number of criteria that are defined according to the objective of this typology. It makes it possible to represent a complex reality. In other words, the development of a typology of farms aims to bring together in the same group, a set of farms who have almost the same characteristics, and thus reduce their diversity to represent them as easily as possible.

According to AGRESTE (2013), the development of a typology of farms aims to:

- Have a grid to better understand the different agricultural systems;
- Define the most important characteristics of the different farming systems;
- Locate as well as quantify agricultural production;
- Concoct tools for study and decision support.

In the case of our study, the development of the agricultural typology in the three Lebanese villages, Bouday, Hermel and Saarin will allow us to group the farms that have the same characteristics in the same system. Thus, to meet the objective of this study, which is to propose strategies for adapting farms in the Baalbek-Hermel region to climate change as well as their dependence on water resources to increase their resilience and reduce their vulnerability.

To develop this typology, three criteria of classification are proposed:

- the resource allocation:

The resource allocation by the 3 villages includes a wide range of resources, but in our study, we will investigate two resources that we consider more important since they are the most likely to influence the decisions of production and productivity of the farm; they are the production potential and the financial resources. The production potential in an arid zone is associated with the level of access to natural biophysical resources, for example land and water. Concerning the financial resources of the farmers, we can estimate them for example by the capacity of the farmer to buy and use the different production factors to improve the productivity of his farm (labor, fertilizer ...), and the level of total agricultural income.

- the production objectives:

These criteria include several factors, of which we can cite among others: the choice of cultivation (crops versus livestock); the choice within the plant and animal systems, and the orientation of agricultural production (if it is oriented to be sold on the market and thus generate income, or it is oriented to meet the needs of farmers); and the share of each crop in agricultural income.

- the intensification levels of production

The two criteria mentioned above can have an impact on the decisions of the farmers concerning the types as well as the quantities of the factors of production, which can either be respectful of the environment (fertilizers, labor ... .) or the reverse (the non-respect of the doses of chemical fertilizers, irrigation water ...). We can summarize the variables that we can use in order to bring together the farms which are somewhat similar in point view of these in the same system in the following table:

Table 3 Factors of production

Criteria taking into account the resource allocation	**Production potential**	-Agricultural land (ha) - Irrigated area per farm -The share of each crop in UAA -Topography (plain/mountain)
	Availability of financial resources	-Gross margin per farm on crops - Non-operating income
Criteria taking into account the production objectives		-Size of the active family population -Time spent on the farm -Production of each crop / ha -Production (breeding)
Criteria taking into account the intensification levels of production		-Total amount of irrigation water per farm (m3 / ha / crop) - Irrigation source - Irrigation mode -Cost of fertilizers (LL / ha) -Cost of seeds (LL / ha) -Cost of pesticides (LL / ha) -Cost of water (LL / ha) -Labor cost (LL / ha) -Cost of seasonal and permanent labor (LL / ha) -Cost of inputs into the plant system -Cost of inputs into the animal system

Analysis of types of farms at the agro-climatic level

After classifying farms according to their criteria at farm level, we built a classification according to agro-climatic zones based on the location of farms. This analysis will allow us to characterize the agricultural production of each agro-climatic zone, to identify the diversification of these zones and to identify the homogeneous production systems present in the different zones. The grouping of farms according to the climate criterion is important in a semi-arid zone where the main factor that impacts the performance of farmers is the amount of rain on its territory (Verner et al., 2018).

SWOT analysis

The SWOT matrix is a universal decision support tool, developed since the 1960s (Schendel, 1994). At the level of a SWOT analysis, strengths, weaknesses, opportunities, and threats are to be identified. The purpose of this analysis is to rely on internal and external analysis to make strategic decisions. This will therefore make it possible to counter threats and seize opportunities, while starting from improving the internal functioning of the system. Indeed, through the SWOT matrix, strategies of attack, adjustment, defense, and survival will be identified

Results

Preliminary analysis of survey results

The farms surveyed in the Baalbeck EL Hermel area have different surface areas ranging from 4 dnm to 800 dnm with an average of 80 dnm. The frequency analysis shows that the majority of farms have a surface area of less than 100 dnm (77%) with 69% less than 60 dnm and 10% less than 10 dnm (figure 21). In addition, just 11% of farmers own surface farms greater than 200 dnm with only 3% greater than 500 dnm, which is common in arid regions such as Tunisia (Elloumi, 2006) and Egypt (Radwan et al. ., 2011).

In addition, one notices a great variability in the income of the farmers which is 59 million LL / ha for some farmers and 0.84 million LL / ha for others.

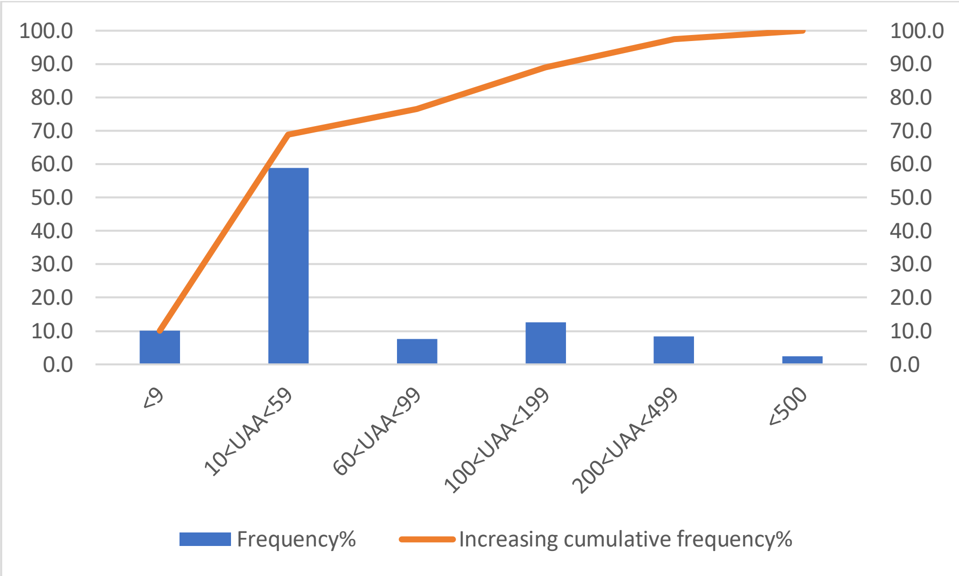


Figure 21 The frequency of farms by UAA

Typology of agricultural holdings

The statistical analysis of farms based on the two techniques PCA and HAC on the Tanagra software allowed us to classify the farms surveyed into 5 types of agricultural systems having the same characteristics and respecting the variables chosen in Methodology-I-2. To measure the association, two correlation axes were chosen using the Kaiser criterion which implies the choice of axes whose "Eigen Values" are greater than 1 and which explain a "good proportion" of the total variation. This means that the sum of the inertia (variation) explained by each of the axes must represent a significant part of the total inertia. The results of the PCA and HAC revealed that the distribution of categories of agricultural households according to the selected criteria (called discriminant variables) represented by two axes of correlation, explain 46.72% of the total variability. Axis 1 (28.98%) is associated with vegetable production and the cost of inputs. This correlation confirms that the vegetable farms present on the market are those which use the most inputs.

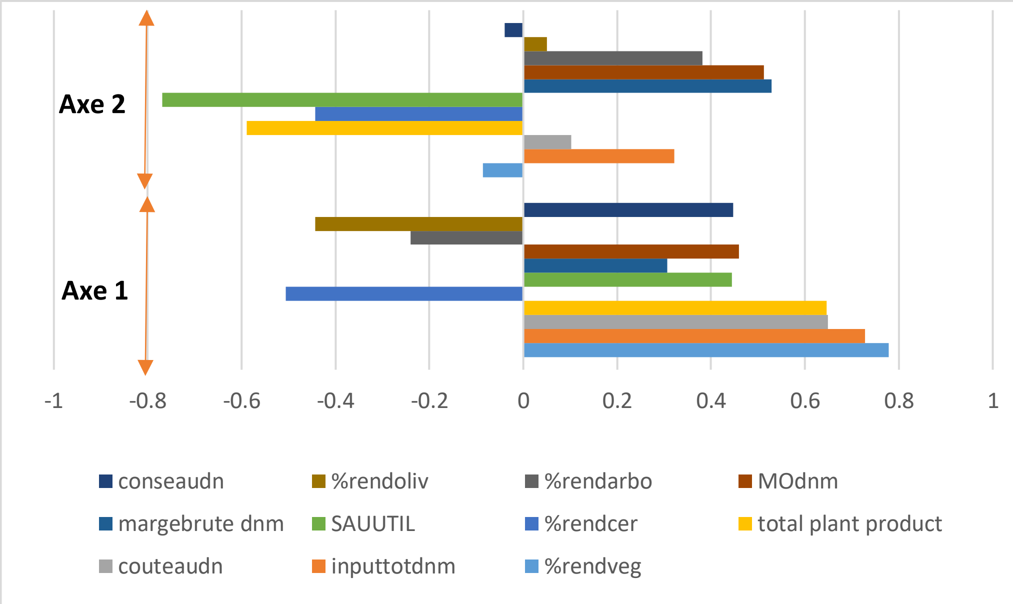


Figure 22 The two correlation axes linked to the tested variables (correlation scatter plot)

Axis 2 (17.74%) is associated with the agricultural area used, the agricultural income per holding and the gross margin (Figure 22).

Typology of farms

The variables in this analysis are:

SAUUTIL used agricultural area

PCEREAL Percentage of cereals

PVEGTA Percentage of plants

POLIV percentage of Olives

PARBO Percentage of arboriculture

QTEAU dn Quantity of water per dn

ValPVM3 Plant production value per m3

MBTVM3 Total plant gross margin per m3

Determination of the main axes

The eight inter-correlated quantitative variables are transformed into eight new uncorrelated quantitative variables (principal components or principal axes). The main axes are defined by the matrix of the eigenvectors of the matrix of the correlations of the initial variables. The elements of the matrix of the eigenvectors are the coordinates of the initial variables on the principal axes (table 2). This matrix makes it possible to represent the initial variables on 1, 2 or 3 axes or even more.

Table 4 Matrix of the eigenvectors: (coordinates of the initial variables on the first five main axes).

Variable	Axe1	Axe2	Axe3	Axe4	Axe5
ValPVM3	0.95377	0.09837	0.18548	0.14113	-0.05246
MBTVM3	0.93591	0.13042	0.19999	0.14746	-0.01487
PCEREAL	-0.54757	0.12529	0.66762	0.29901	0.31143
PVEGETA	0.41936	-0.86101	0.04108	-0.15456	0.08008
QTEAUDn	-0.18006	-0.66653	-0.56466	-0.04441	-0.00030
POLIV	0.00658	0.52601	0.01699	-0.80941	-0.22095
PARBO	0.00369	0.49752	-0.66645	0.51118	-0.21145
SAUUTIL	-0.26378	-0.33543	0.43622	0.18433	-0.76990
Var. Expl.	2.36335	1.86470	1.47537	1.10735	0.79266

The elements of the diagonal matrix of eigenvalues represent the variance of farms on the corresponding axis, as shown in Table 5

Table 5 Variance of the initial variables on the main axes.

AXIS	VARIANCE	DIFFERENCE	PROPORTION (%)
1	2.363353	0.498650	29.54 %
2	1.864703	0.389332	23.31 %
3	1.475372	0.368022	18.44 %
4	1.107349	0.314693	13.84 %
5	0.792657	0.409239	9.91 %

Examination of this table shows that the farm variance is 2.363 on the first axis (this is the maximum variance), and is 1.8647 on the second. The share of all initial information visible on the main plane is in the order of 50%.

The software provides a hierarchical classification tree for farms. To choose a cut from this tree into classes, we study the progression of interclass inertia for different cuts. By examining the results of the software concerning the progression of inter-class inertia, we notice that the values of the latter before and after iterations are the same starting from the division of the hierarchical tree into 5 classes.

Identification of typical farms

Five distinct typical farms were identified based on the statistical analysis of ACP and HAC. These farms are distributed homogeneously, having the same characteristics, and respecting the variables chosen in establishing the typology. The types of farms obtained are as follows:

A. ***Large farms dominated by plants (LP):***

These farms represent 8.4% of the sample and they are the farms with the highest surface area with an average surface area of 417 dnm. Market gardening is the dominant crop with 75% of the cultivated area and a 96% share of the total yield. The remaining area (25%) is cultivated with cereals and generates only 4% of the total income of the farmer. These farms consume the highest amount of water per hectare (on average 499 m3 / dnm). This result is in line with previous studies carried out in the same region (Khansa et al., 2017) which show that plant farms are irrigated excessively. This group has high production costs of an average of 681,000 Lebanese pounds per denom and the highest water cost of nearly 100,000 LL per denom.

Small intensive plant-dominated farms (SP):

Small, intensive plant-dominated farms represent the largest group in the sample (37%) and are generally small in size with an average of 37 dnm. The main crop for this type is market gardening which represents 91% of the total area with a share of 96% of the total yield. The quantity of water consumed per hectare is significant but lower than the previous group (464 m3 / dnm on average). Labor and production costs of this type are the highest compared to other types respectively 408,000 and 729,000 LL per denom. This group represents the highest gross margin averaging LL 1,670,000 per denom.

Small farms with arboriculture dominance (SA):

This group represents 14.3% of the sample, and small farms with an average surface area of 29 dnm. The main crops of these farms are fruit trees which represent 97% of the total area and 98% of the farmer's income. Water consumption for irrigation for this group is high (411 m3 per denom) but with moderate consumption of labor and input (on average 212,000 and 371,000 LL per denom respectively). The gross margin of this group is an average of LL 803,000 per denom.

Small farms with olive growing (SO):

These farms with an average surface area of 40 dnm represent 10.1% of our sample. The dominant crop for this group is the olive tree which represents 81% of the total area and contributes 89% of the total average income. Other crops (market gardens, arboriculture) represent a very low share in this group. Water consumption for irrigation by these farms is the lowest at 282 m3 per dnm. This result is expected since olive crops are crops that consume little water (rain-fed crops) and are resistant to drought. The consumption of input and labor is relatively low, with respective values of 236,000 and 110,000 LL per denom. This type generates a gross margin of LL 734,000 per denom.

Medium-sized diversified grain-dominated farms (MDC):

Diversified farms represent 30.3% of our sample. These farms have an average surface area of 76 dnm and are characterized by the presence of several types of crops, mainly cereals and market gardens (respectively represent 61% and 30% of the total cultivated area and respectively contribute 37% and 59% of total income). The production and labor costs for this type are the lowest (respectively 100,000 and 160,000 LL per denom). Its gross margin is also relatively low compared to other types of operations of LL 354,000 per denom.

Table 6 below represents the average characteristics of the five groups of typical farms according to the variables chosen.

Table 6 Average structural characteristics of the 5 types of farms

Criteria	Variables	LP	SP	SA	SO	MDC
Number of farms		10	44	17	12	36
Environmental potential	Cultivated area (dnm)	417	37	30	40	75
Availability of financial resources	Gross margin (LL / dnm)	648,000	1,270,000	803,000	734,000	354,000
Production goal (Contribution of each crop to yield)	Cereal production in%	4	0	0	1	37
	Market garden production in%	96	96	0	5	1
	Arboriculture production in%	0	3	98	5	59
	Olive tree production in%	0	1	2	89	3
Factors of production intensification	Water consumed (m3 / dnm)	499	464	412	282	382
	Production cost (LL / dnm)	661,000	729,000	371,000	236,000	160,000
	Labor cost (LL / dnm)	208,000	408,000	212000	110,000	100,000
	Water cost (LL / dnm)	99,000	83,000	70,000	27,000	25,000

Identification of the characteristics of agro-climatic zones

The aggregation of the five types of farms according to their location in the 3 agro-climatic zones allowed us to identify the dominant agricultural systems for each zone.

For the North zone, characterized by the lowest rainfall, only three types of agricultural systems are identified, namely SP (15 farms), SA (6 farms) and SO (6 farms). It is above all small-scale farms which produce the majority of plants and fruits (fruit trees and olive trees). In this zone, there is almost no cereal crops. This is expected since they are rain-fed crops that depend on the amount of rain and require large areas to produce enough. Crop rotation for these farms is almost absent and they adapt the same cropping systems every year. Most of these systems are irrigated by artesian wells and the rest by canals from water sources.

For the Center zone, the results of the typology showed that 4 different agricultural systems are present. These systems are LP (7 farms), SP (17 farms), SO (4 farms) and MDG (34 farms). The presence of these farms in the center of the plain offers them the opportunity to cultivate large areas. They are irrigated from the Yammouneh Lake. Moreover, the majority of diversified grain-dominated farms are present in this zone. This type is characterized by the lowest gross margin and the lowest intensification factors.

For the South zone, the results of the typology showed the presence of the five types of exploitation. The dominant types according to our sample are SP (12 farms) and SA (11 farms). The majority of these farms are irrigated by wells. The presence of various production orientations in this zone can be explained by the significant contribution of rainfall, the wealth of water resources and the availability of large agricultural areas.

The characteristics of these subgroups are shown in Table 7 below.

Table 7 Average structural characteristics of sub-groups distributed by agro-climatic zone

	Type	NB	UAA	UAA cereals	Vegetable UAA	UAA Olives	UAA arboriculture	Water consumption	Irrigation source
North	SP	15	30.2	0	26.8	2	1.4	375	Well
	SA	6	27.3	0	0	5	22.3	348	
	SO	6	67.5	16.7	3.3	40	7.5	264	
Center	LP	7	353.4	50	303	0	0	513	Lake
	SP	17	32.5	0	32.5	0	0	577	
	SO	4	15.8	0	0	13.3	2.5	350	
	MDC	34	68.5	41.8	21.9	2.4	2.5	393	
South	LP	3	566.7	283.3	283.3	0	0	467	Well

	SP	12	50.3	4.2	43.2	0	2.9	415	
	SA	11	31.1	0	0	0	31.1	446	
	SO	2	8	0	0	8	0	200	
	MDC	2	200	150	50	0	0	189	

Table 8 SWOT analysis of the different operating systems

	LP	SP	SA	SO	MDC
Strengths	-Use of a lower irrigation dose within the group compared to the average dose for all farms. -The farmers have non-farm income; they are pluriactive so as not to depend only on their productions. -The farms are close to the market, which would facilitate the sale of their production. -Diversification of cultures -Good yield of cereals, vegetable crops and tobacco compared to the average yield of all farms.	-Use of a lower irrigation dose within the group compared to the average dose for all farms. -Adoption of drip irrigation, which is a water-saving method. -Diversification of cultivations. -The farms are, on average, close to the market, which would facilitate the sale of their production. -Good yield of vegetable crops, tobacco and fruit trees compared to the average yield of all farms. -Gross margin / ha is higher than the average margin of all farms, which shows good management of the farm. -The farms have non-farm	-Use of a lower irrigation dose within the group compared to the average dose for all farms. -Adoption of drip as the method of irrigation, which is a water-saving method. -Diversification of cultivations. - Good yield of fruit trees. -The costs of inputs into the plant system are low compared to the average costs.	-Diversification of production systems. -Diversification in the plant production system. -Diversification in the animal production system. -The farmers have non-farm income; they are pluriactive so as not to depend only on their productions.	-Diversification of production systems. -Diversification in the plant production system. -Diversification in the animal production system. -Use of a lower irrigation dose within the group compared to the average dose for all farms. -access to the market is almost similar to the average distance of all the farms which makes the marketing of productions less difficult -The costs of inputs in the plant and animal

		income, they are pluriactive so as not to depend only on their productions.			system are low compared to the average costs. -Good yield for the productions of the two systems (animal and vegetable).
Weaknesses	-The costs of all the inputs in the plant system are higher than the average costs of all the farms, while the gross margin / ha is low compared to the general average. -No diversification of production systems. -The source of water used in an important way is the wells, which could have a negative impact on the groundwater. -The costs of labor, whether seasonal or permanent, very high compared to average costs.	-The source of water used in an important way is the wells, which could have a negative impact on the groundwater. -No agricultural monitoring. -Absence of agricultural aid.	-Very small farm size compared to the general average size of all farms. -No diversification of production systems. -The only source of water used is wells, which could have a negative impact on groundwater. -The gross margin / ha as well as the non-operating income are lower. -Access to the market far from the average for all farms which could make it difficult to market their productions. -No agricultural monitoring. -Absence of agricultural aid.	-No agricultural monitoring. -Absence of agricultural aid. -Access to the market far from the average for all farms which could make it difficult to market their productions. -Very small farm size compared to the general average size of all farms.	-No agricultural monitoring. -Absence of agricultural aid. -Very small farm size compared to the general average size of all farms.

	-no agricultural monitoring. -No agricultural aid.				
Opportunities	- Large farms could be an attraction for investments. -Export of agricultural products	-Export of agricultural products	-Export of agricultural products	-Export of agricultural products	-Export of agricultural products
Threats	-The negative impacts of climate change on this type of exploitation. -The overexploitation of water resources, especially groundwater. -High input costs in the face of a low gross margin / ha could subsequently lead to a financial crisis for this type of farm. - Very large farms could cause difficulties in their management.	-The negative impacts of climate change on this type of exploitation. -The overexploitation of water resources, especially groundwater.	-The negative impacts of climate change on this type of exploitation. -The overexploitation of water resources, especially groundwater. - Importance of fruit trees in terms of UAA than other crops, which could create a crisis for operators of this system in the event of low production.	-The negative impacts of climate change on this type of exploitation -The irrigation dose greater than the average dose for all farms.	-The negative impacts of climate change on this type of exploitation. -The source of water used is the lake, which can cause disease if it is contaminated.

Discussion and Conclusion

The future of agricultural systems in the Mediterranean area is threatened by several external factors. The scarcity of water resources and the climate changes affecting this area are according to several authors the most threatening factors, especially in semi-arid regions. These authors predict a significant decrease in water availability caused by rising average temperatures and variability in precipitation in the future. These conditions will influence the productivity of agricultural systems in these areas and lead to uncertainty about the performance and future of existing farms. However, it is an area characterized by its diversification in terms of production systems distributed in a different way depending on the climatic context of the area.

In this context, the objective of our study is to develop a framework for assessing the resilience and the capacity to adapt to climate change of agricultural systems in the semi-arid region of Baalbeck El Hermel, taking into account the diversification of agricultural systems in this area.

To meet this objective, we have developed a methodology based on characterization of the diversity of agricultural systems in this territory by carrying out a quantitative typology according to precise variables,

According to the typology produced Our work has brought out several results concerning the heterogeneity of the agricultural systems studied at the level of the governorate of Baalbeck El Hermel, the farms in the studied area present a diversity of agricultural production systems. The analysis of the diversity at the level of agro-climatic zones showed a low diversity of agricultural practices at the level of the North zone. Such a result is expected for an area receiving the least amount of precipitation and characterized by the highest average temperatures. We also found that despite the dominance of small agricultural areas, agricultural practices are diverse and several types of crops are present in Baalbeck El Hermel.

The "not very resilient" farm can maintain a slight decrease in its gross margin even if the quantities of water available are very low. That is, even for years of drought, this farm has the capacity to keep a good income. Nevertheless, this type is forced to modify its structure (labor and UAA) to maintain the gross margin and consequently does not keep its initial situation stable. It is the most diversified type of farm in the northern area on the one hand and in the Baalbeck El Hermel area on the other. For this type of farm, the diversification of agricultural practices and the adaptation of crops resistant to drought (olive trees) guaranteed farmers a more remarkable income than for other farms. These results are similar to those of studies conducted with agricultural systems to prove the importance of diversification in the resilience of agriculture (Aspar, 2019; Lefeuvre, 2018; Souissi et al., 2017).

"Non-resilient" farms are farms unable to maintain their net gross margin under conditions of limited water resources. These are specialized farms producing either arboriculture or vegetable crops. In this group, the significant drop in gross margin is mainly due to the decrease in yields of arboriculture and market gardens unable to maintain their productivity in the absence of irrigation (water stress). These crops, despite their high profitability, are very risky and require high amounts of water. The farmer is forced to change his rotation (limit crops by choosing the most profitable in conditions of water stress) and limit his production because of dry techniques since for perennial crops it will be very expensive to replace them.

In addition, the collective scientific expertise of INRA (2006) proposes, under such water-limiting conditions, the adaptation of alternative crop strategies that are less tolerant to drought, ensuring the sustainability of farms and an improvement in their resilience. In this regard, it will be relevant to adapt strategies to strengthen the investment capacity of these farms before the implementation of a water tariff. It is a question of proposing and developing support strategies for the farmer of the zone. Support can be in the form of policies offering premiums and subsidies on behalf of the government for the most vulnerable farmers especially since the crops present in the North are not subsidized crops (like tobacco and grains in Lebanon). So, this agricultural aid can help them invest in crops that are more resistant to drought.

In conclusion, these research results would help to design adaptation strategies for farming systems that are based on understanding farmers' and related impacts. This understanding can provide a solid foundation for the development of climate scenarios based on what farmers consider where appropriate. The results would also be beneficial for developing strategies that depend on the context as well as on the significance for farmers and, therefore, are probably more effective and sustainable.

Chapter III

Evaluating and developing scenarios for resilient farms: the case of the Baalbek Al Hermel Region (Lebanon).

Abstract

The agricultural sector in Lebanon currently accounts for about 5% of the total Gross Domestic Product. Its durability and the maintenance of its performance are crucial for the country's economy. However, climate change risks to hardly effecting agricultural durability and resource depletion in a long-run perspective. In this sense, the agricultural system needs to be resilient, i.e. able to absorb a shock while reorganizing itself to keep the same structure and functions. This study aims to evaluate the resilience of farms in Lebanon using some participatory methods and tools. Cognitive maps and evaluation grids are used to characterize current and future farms and to compare the resilience of farms. The analysis is applied to the region of Baalbek Al Hermel that presents different types of farms which have been classified into 5 types based on bibliography and individual interviews. All farms have diversified to cope with climate change and groundwater resources. The study shows that small-sized farms with olive growing and medium-sized diversified grain-dominated farms are the most resilient farms on the basis of their present and future assessed indicators.

Key words: Farm classification, participatory methods, cognitive maps, typology, climate change

Introduction

The climate has always changed worldwide, but in the last decades, these changes are becoming more pronounced and evolving more rapidly than before, especially due to human activities (ADEME, 2018). This is the phenomenon that scientists and politicians are referring to when discussing the topic of climate change. Before, climatic changes were mainly due to natural phenomena, but since the beginning of the industrial revolution in the 18th century, man contributes more and more to these by releasing enormous quantities of greenhouse gases (GHG) in our atmosphere or by burning fossil fuels such as petroleum to generate electricity or by clearing forests to produce crops. (Cassingerna-Trévedy F., 2015). At the same time, these emissions further increase the natural GHG effect, thus leading to increasingly intense global warming (ADEME, 2018).

Basically, climate change is a large-scale scourge, as no country can escape its repercussions at various levels, whether developed or developing (Henry C., 2016). To face it, many policies at the international level have been adopted such as the Kyoto Protocol which was signed in December 1997 (Henry C., 2016). According to this agreement, 37 countries were committed to reducing their emissions of GHG effect of at least 5% over two periods (2008-2012) and (2013-2020). The objective for the first period has been substantially reached, such that the countries involved have reduced their emissions by more than 20% (Taabni et Jihad, 2012). Recently, the signing of the Paris Agreement constitutes the first universal agreement bringing together all nations around a single cause, which is the fight against climate change and adaptation to its consequences. The main objective is that the global average temperature does not increase above 2 degrees Celsius (C) compared to pre-industrial levels.

According to the 5th report of the "Intergovernmental Panel on Climate Change", several scenarios between 2016 and 2035 show an increase in the average temperature of the earth between 0.3C and 0.7C (IPCC, 2014), This increase has impacted at different levels - such as rising sea level, floods increase even more, and droughts increase - implying that weather conditions become more and more unpredictable. This upheaval in the climate also has impacts on crops, on the water supply, as well as on various organisms as well as it can also have impacts on infrastructure. The combination of all these impacts gives rise to new impacts at three levels: social, economic, and political (ADEME, 2018).

The agricultural sector - which is a key sector for many countries, especially for developing countries - is strongly affected by climate change, which leads to a decrease in crop yields, given that it is highly dependent on the climate and conditioned by specific meteorological conditions of rainfall and sunshine to have a good yield (Martin et Vaitkeviciute, 2016). On the other hand, it contributes to the emission of GHG, such that, on its own, it concentrates 13.5% of emissions (IPCC, 2014). But despite this, agriculture has a great capacity for adaptation and mitigation, with a good cost-effectiveness ratio, mainly from carbon sequestration thus decreasing carbon sequestration in the atmosphere (IPCC, 2014).

In Lebanon, agriculture is largely made up of small farms, which face several constraints (economic crisis, the monopoly of big farmers….), and consequently, are exposed to dangers and shocks. The Baalbeck Al Hermel is one of the most important Lebanon regions where farming systems play a strategic role and that show relevant critical issues related to natural resources exploitation. Concerning the water, for example, this region is, indeed, characterized by irregular rainfall, with long periods of drought (FAO, 2018). However, certain agricultural practices adopted by farmers, such as vegetables, typically consume a huge amount of water, which leads to the overexploitation of water resources, and therefore, the reduction in the level of aquifers. In addition, the recourse to irrigation from groundwater is proving to be impossible and climate change is further aggravating the situation.

Reflection around this situation in the Baalbek Al Hermel region prompts us to ask the following question: How to increase the resilience of farms and reduce their vulnerability, in the short and long term, to the repercussions of climate change by reducing their dependence on water resources?

In this research, the use of diagnostic analysis in relation to irrigation water management helps structure the analysis of problems and the identification of potential solutions related to water management. It is within this framework that this first stage of the research action takes place, the aim of which is to take stock of the current situation of water management at the level of an irrigated field in Baalbek Al Hermel.

Especially,

• How to ensure a transition of farms in the region of Baalbek Al Hermel towards sustainable agricultural practices, profitable, and concomitantly, less water consuming? And what are the difficulties and challenges that may hinder this process?

• What national strategies can be envisaged in the face of climate change?

Background and Objectives

The definition of the term "resilience" varies according to its field of use (physics, biology, industry, ecology...). In terms of origin, it is derived from Latin "resilire", which means "to recoil or rebound". Typically, resilience is "the ability of an individual or system to absorb disturbances and reorganize while undergoing change in such a way that it easily and essentially retains the same function, structure, identity, and feedback" (Walker et al. ., 2004).

Resilience in agriculture can be defined as the capacity of a system to ensure and reorganize its functions and structures in the face of significant sources of stress whether economic, social, environmental or institutional (Meuwissen et al., 2019; Souissi et al., 2018). A complex and multifunctional agriculture system is formed of the interaction of different socioeconomic, biological and environmental components. The 3 capacities that characterize an agricultural system are “robustness, adaptability and transformation” (Meuwissen et al., 2019). At first, the system is robust by its structural and functional diversity which is proven as a strong point for resilience (Diakité et al., 2019). In the presence of several external disturbances (climate, market, policies, and innovation), this system finds the most effective means of adaptation facing these challenges. This adaptation can be through short-term resilience such for example in the case of a water resource deficit, adaptation of a more efficient irrigation system (drip), or through a capacity for long-term adaptability such as the adaptation of a cropping system less vulnerable to water stress (Rivington et al., 2007). This long-term adaptation is known as the transformative capacity of systems (Anderies et al., 2013) and will take place when the current system is no longer effective in the face of external disturbances and global challenges. This transformation requires a significant investment in the four capitals: natural, human, financial, and technical.

Therefore, to analyze the influence of climate change on any agricultural system, it is necessary to identify the limits of the resilience of that system, its capacity to improve this resilience, and the consequences of this change (Rivington et al., 2007).

The resilience of a farm is defined by three components (see figure 1): its vulnerability, the risks it may undergo, and its capacity to adapt (Gitz, 2015).

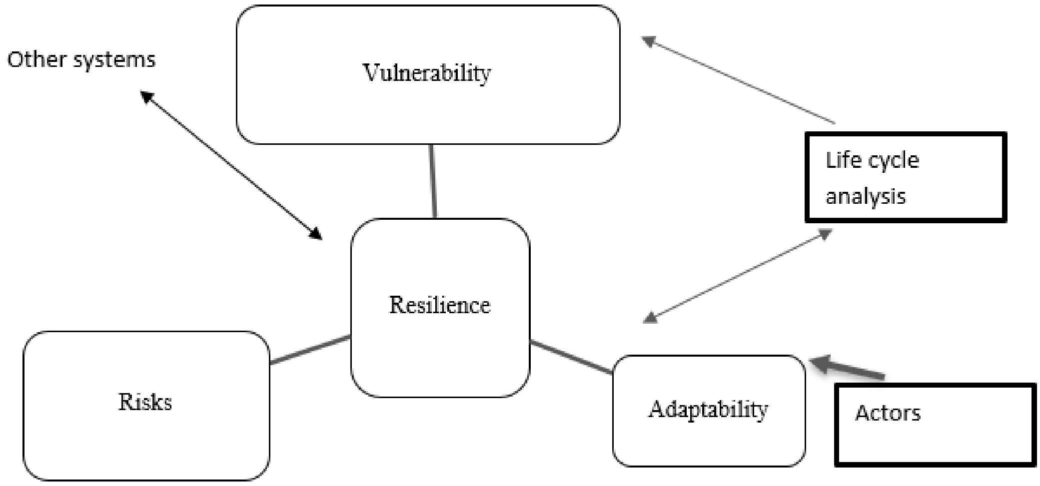


Figure 23 The components of resilience. Source: Gitz and Risks, 2015

At first, according to Allen and Prosperi (2016), vulnerability is an intrinsic feature of the system. It is the tendency or readiness of a system to be negatively influenced. It is a dynamic concept, varying according to its economic, social, geographic, cultural and institutional environment (Gitz and Risks, 2015). The more a system is subjected to the same disturbance, the greater its vulnerability to this disturbance (Gitz and Risks, 2015). Hence, the study of a farm's history via a life cycle analysis is relevant to know if a farm has already been vulnerable to a shock or not.

Secondly, the risk is an uncertain situation that can lead to potentially unfavorable results (Aumell, 2005). The different properties that characterize a risk are its intensity, frequency, probability, and uncertainty (Gitz and Risks, 2015). For farms, there are three categories of risks: return risks, price risks (inputs or sales), and risks related to family assets (Dercon and Krishnan, 2000).

Further, adaptability is the capacity of a system to learn and adjust to changes while developing with the same stability (Giraud-Heraud, 2016). The actions of actors (farmers and agricultural organizations) and their ways of managing risks individually or in groups directly alter this component of resilience (Walker et al., 2004).

Resilience is therefore the ability to resist a factor of change or what is called a shock. A factor of change is defined as “any natural or human element which directly or indirectly induces a change in an ecosystem” (Watson and Zakri, 2005). For example, the internal factors can be labor force, or the local market, while the external factors might be international prices, public policies, or climate change (Zurek and Henrichs, 2007). Nevertheless, the change factors selected to study resilience must have a strong link to the subject and must be independent of each other as much as possible (Van’t Klooster and Van Asselt, 2005).

According to Giraud-Héraud (2016), to study resilience, we need to define a current and future situation. Thus, a temporality is very important to be chosen because time steps greater than fifteen years are difficult to grasp, and the uncertainties about future policies and variations are too great. The fifteen-year time step was therefore chosen in order to be able to be creative while remaining realistic (Delmotte et al, 2017).

Further, indicators such as yield and income are also used to study resilience. Any clear and specific quantity that is observable and measurable represents an indicator (UN, 2011). Moreover, a qualitative study of resilience can be based solely on the state of the art (Allen et al., 2018). Nevertheless, to study resilience quantitatively, it is necessary to quantify future indicators that can be possibly calculated by a model. The resilience of the farm is determined by the variations between present and future indicators (Souissi et al., 2018).

Nevertheless, studying resilience qualitatively or quantitatively requires a participatory approach. It is defined as a process where individuals, groups and organizations choose to have an active role in the reflections that concern them (Reed, 2008). The stakeholders present during the participatory workshops are the actors concerned by the study or who can affect the decisions. It allows local actors to participate in the development and research process to respond to the issues of the local context. Implementing this approach allows local actors to share their opinions by expressing themselves freely (Ericson, 2006). Indeed, they are the ones who are best able to find solutions adapted to the climatic and socio-economic context of their region (Reed, 2008).

In this perspective, resilience is studied in several stages. First of all, it is a question of defining the study area (the boundaries of the human/environment couple), then the scale of analysis (local, regional, national), after which it is necessary to choose the main factors of changes (eg water, loss of biodiversity, price volatility, changes in dietary habits), identify the outputs of the system and finally develop a simple model from known interactions. This approach then makes it possible to examine the risks, vulnerability and adaptive capacity of the system (Allen and Prosperi, 2016).

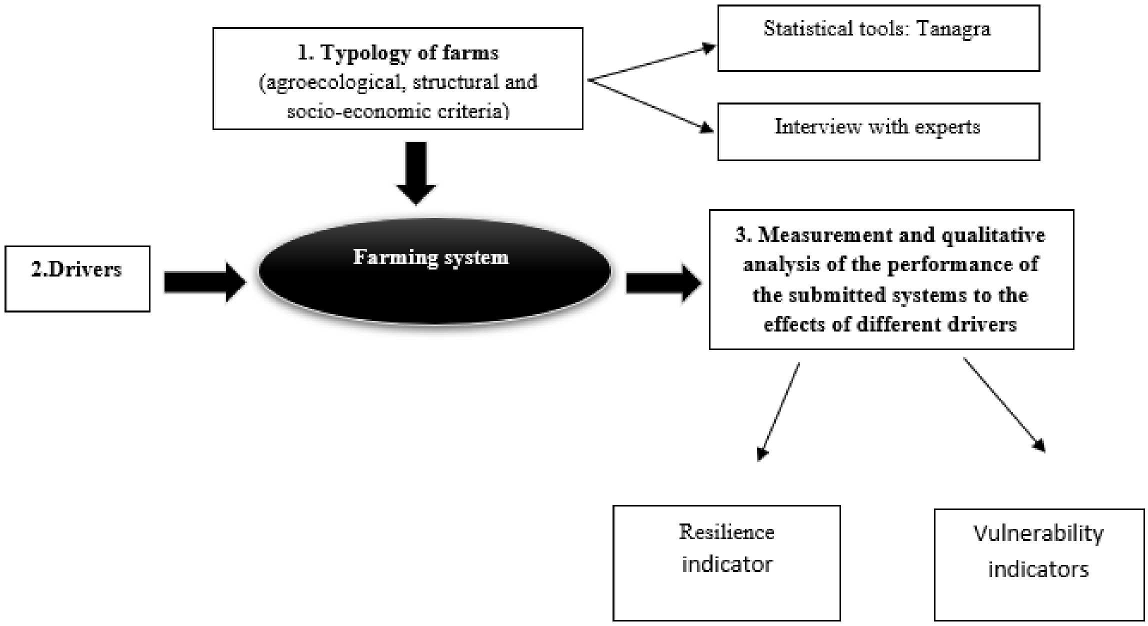


Figure 24 Summary of the methodological approach followed

The general objective of this study is to propose strategies for adapting farms in the Baalbek Al Hermel region to climate change as well as their dependence on water resources in order to increase their resilience. Therefore, the designed study will ease farmers' mission and may supply them with a plan that will help lessen farms' vulnerability to risks of climate change.

The operational objectives are as follows: - Determination of the development trajectories of farms in the Baalbek Al Hermel region.

- Determination of the factors for changing practices

- Implementation of adaptation strategies to climate change which are adapted to the situation of the Baalbek Al Hermel region.

To reflect on this issue, we assume that:

-Developing a typology of farms, in order to test scenarios on them, seems an important tool in order to assess and carry out a multi-criteria analysis of farms and to study their resilience and vulnerability.

- Farmers in the Baalbek Al Hermel region adopt agricultural practices that consume a lot of water. To do this, developing new incentive policies that not only increase the income of farmers, but also change their practices towards more environmentally friendly practices will make these farms more resilient and less vulnerable to shocks.

Material and method

Data collection and farms classification

This work is based on a sample of 101 surveys carried out at the level of crop production farms in Baalbeck El Hermel in 2019. These farms were chosen at random from different villages in the Baalbeck ELHermel region, taking into account two main criteria: the diversity of crops and the climatic variability of the study area. The data obtained from the questionnaire allowed us to calculate the production costs and the gross margin resulting from the agricultural activity for each farmer. The diversity of farms in the Baalbek Al Hermel region makes studying this area complicated; however, a typology makes it easier to understand. A typology of a farm represents the diversity of systems that are based on the distinction between a set of types of farms based on a certain number of criteria that are defined according to the objective of this typology. In other words, the development of a typology of farms aims to bring together in the same group, a set of farms who have almost the same characteristics, and thus reduce their diversity in order to represent them as easily as possible. In the case of our study, the development of the agricultural typology in the three Lebanese villages, Bouday, Hermel and Saarin will allow us to group the farms that have the same characteristics in the same system.

The statistical analysis of farms based on the two techniques Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HAC) on the Tanagra software allowed us to classify the farms surveyed into 5 types of agricultural systems having the same characteristics. The five types are as follows: Large farms dominated by plants (LP), Small intensive plant-dominated farms (SP), Small farms with arboriculture dominance (SA), Small farms with olive growing (SO), and Medium-sized diversified grain-dominated farms (MDC).

Change factors and cognitive maps

After farm classification, interviews were realized with the 101 farmers who were divided into 5 groups according to the type of their farms. Farmers in each group were asked to list the three factors of change that they considered to be the most important. During the interviews, participants were asked to write down on post-it notes, which were retrieved after an hour, and the results recorded on a table. The most cited change factor for each farm type was selected to be the shock to which the farms will be subjected when creating the cognitive maps, and the results were presented to the participants.

The cognitive maps are a participatory tool for obtaining semi-quantitative results (relative terms are used). First of all, in order to create a map, "concepts" are to be chosen. These concepts are the structural elements, the functions of the farms, as well as the constraints considered by the participants as important in the study area (income, cropping systems, and decline in water resources).

These concepts are represented in the form of boxes. Each of these boxes can have a direct or indirect impact on other boxes. It can even have a self-impact on its development. For this study, four types of impact (Table 9 below) were proposed to the participants to create the cognitive maps. For each type of farm, a map had to be produced for the present situation and for the future situation aftershock (the 15-year time span proposed to the participants was accepted without debate). The shock used for each type was the most previously mentioned change factor for each farm.

Table 9 The different impacts in cognitive maps

Symbol	Impact
- -	Very negative impact
-	Negative impact
+	Positive impact
++	Very positive impact

Resilience study

Indicators are specific, measurable and observable parameters used in charachterizing the stability of agricultural systems in the face of external disturbances and providing information on states that are not directly measurable (Parsonson Ensor nd Saunders, 2011). Several socioeconomic, agronomic and environmental indicators that reflect the evolution of the capital of agricultural systems are calculated to analyze the resilience of a system (Souissi et al., 2018). The resilience analysis is carried out in several stages: first of all, the indicators were selected and then an evaluation grid was made for these indicators.

Choice of indicators

A list of indicators was presented to the 101 participants. They were able to add additional indicators and rank them in order of importance for each type of farm. Each participant had to write down on post-it notes the three resilience indicators that seemed to be the most relevant for each farm. The post-it notes were then collected to create a summary table presented to the participants. The list of proposed indicators in Table 10 below was drawn up from the bibliography and the interviews made.

Table 10 Indicators of resilience. Source: El Ansari et al., 2018; Souissi et al., 2017; Castel et al., 2014; Gameroff and apple tree, 2012; Bar et al., 2011

Indicators	Relevance	Source
Land: land status, size of farms, heirs	Indicators of natural, social and financial capital.	Soussi et al., 2017
Labor: Number of employees, price		
Income: price variation, price, production sold, price of products sold		
Yields: Technical routes, efficiency of inputs	Most common agronomic indicators to assess the performance of a farm	El Ansari et al, 2018
Family assets: cash, livestock, insurance, animal sales	Essential for the balance of farms	Bar et al., 2011
Marketing: processing and labeling	Cited during workshop 1 as factors of significant change for several types of farms. Major constraints according to farmers.	Castel et al., 2014
Irrigation: Access to water, type of irrigation, guidance	Very important for certain types of operations. Allows the intensification of production.	El Ansari et al, 2018

Policies: Subsidies, SMAC, export regulations	Agriculture is heavily subsidized and supported by the state.	Gameroff and Pommier, 2012

The indicators (see Table 10) chosen are aggregate indicators (composed of several variables). Indeed, due to the time allotted and the required precision, it was not possible to work during the interviews on each of the variables independently. Societal indicators have not been selected, although they are very important. Bibliographic data (Baccar, 2017) make it possible to know the links that each type of farm has with its community. These are the data that will be used in the results section.

Evaluation grids

In order to study resilience, it is necessary to compare the indicators reflecting the performance of current farms and those reflecting the performance of future farms. A grid comprising all the selected indicators was distributed to the participants. The participants had to rate the performance (achievement of organizational objectives) of the farms. For this, they had to assign a relative score to each indicator. Five choices were offered: very good, good, average, poor and poor. Low income, for example, could be rated as "low" or "mediocre" depending on the magnitude decided by the participants, and the choice selected had to be justified by a comment. A grid for current situation in each farm type had to be completed. Then, participants had to fill in similar grids for future operations. The comparison of the scores assigned to each indicator, for the present and for the future, allows the study of farm resilience.

Resilience assessment

In order to study the resilience of the different farming systems, we will proceed to fill in evaluation grids of resilience indicators, from the data previously collected in the database (questionnaires and interviews with farmers). In addition, information collected from phone calls with key persons (stakeholders in the study area), and the expert Dr Salem Darwish, who is an Assistant Professor in the Faculty of Agriculture in the Lebanese University, were of great help in forming the grids.

The indicator scores will be translated into figures to allow analysis of the results. The "very good" indicator will correspond to 5, the "good" to 4, the "average good" to 3.5, the "average" to 3, the "poor" to 2 and the "mediocre" to 1. The intermediate level average / good was added because the actors ticked between the "average" and "good" boxes several times in the grids.

Results

Current situation and future situation for farms

Change factors

Several change factors can impact the evolution of different farming systems to different degrees depending on their characteristics. In the case of the Baalbek Al Hermel region in Lebanon, the different change factors that may affect farms in the 3 villages are: the climate, water resources, irrigation, crop systems, agricultural policies, inputs, soil degradation, labor force, and diseases. In addition, the proximity of farms to markets can be considered a change factor in a way such as the closest the farm is, the less transportation costs will need. Finally, marketing as well is a factor of terms of selling products through promoting and advertising.

Firstly, given that the Baalbek Al Hermel region is already a semi-arid region, the climate change leading to a decrease in precipitation or an increase in temperature could strongly impact the various production systems of farms (plants and / or animals) in terms of quality as well as performance. Moreover, the proximity of farms to markets would impact the marketing of their productions, as well as it could generate additional transportation costs. Additionally, water resources can also have an impact on farms, since a non-optimal use of a water source, such as wells for example could lead to an overexploitation of underground water resources, and therefore, this could lead to a drying up of water tables. Not to mention that the method of irrigation could impact the development of farms by intensifying production. Besides, crop systems could impact the development of farms according to their water consumption as well as to the size of the inputs they require.

In order to subject the farming systems to the different change factors, we will first start by choosing the most relevant ones. For all types of farming, the most relevant factors are climate, water resources, irrigation, cropping systems and inputs.

Cognitive maps

The use of cognitive maps as a tool for the study of resilience will allow us to characterize future exploitations, and thus provide us with a consensual representation of current and future situation for each farming system.

1st type of farms LP: Large farms dominated by plants (LP)

For this first type of farm, farmers have almost half of their farms irrigated. In addition, they are dominated by vegetable crops which consume a lot of water but there are also cereals, olive trees and tobacco too. However, there is no animal production system. They mainly use wells as a source of water and sprinklers as a method of irrigation, which constitutes pressure around water resources since the excessive use of wells would lead to a drop in the piezometric level and drying up of the groundwater table. Additionally, the climate change represented in decreased precipitation as well as irregularity and increased temperature, further accentuates the problem around water. Moreover, the dollar crisis and geopolitical instability which causes the increase in production and input costs as well as price instability, would obviously negatively impact the farmer's income and that could also impact the land. In addition, the farms are far from the market, which poses a problem of product marketing, in addition to the additional transport costs.

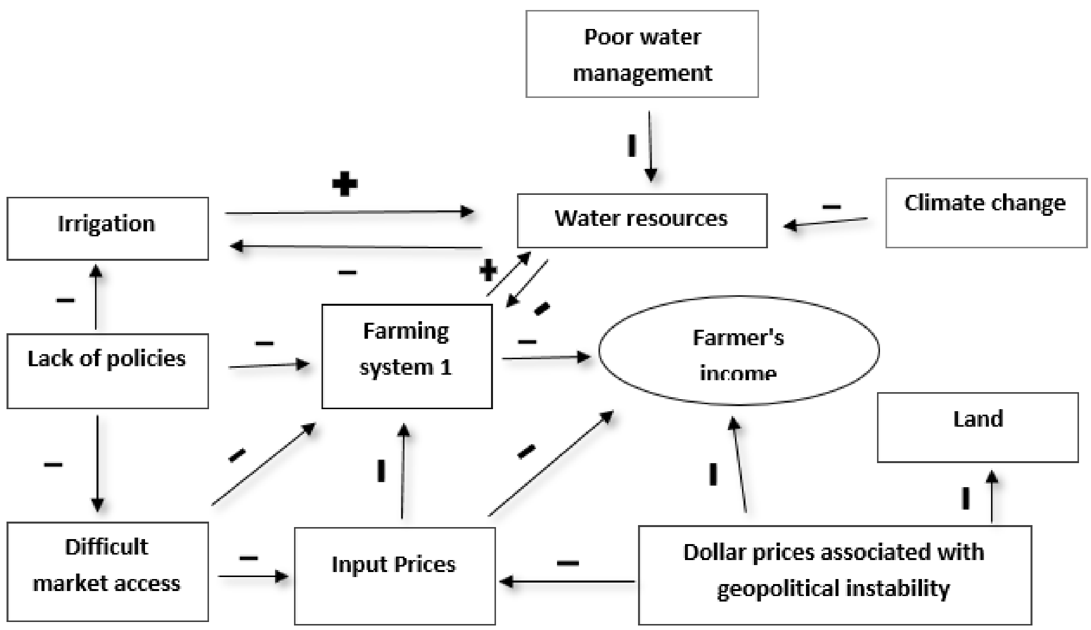


Figure 25 Cognitive map of LP system (current situation)

Future situation of LP:

For this farming system, the introduction of fruit trees would be the only change in the plant production system, also the introduction of the animal production system would constitute a new change, allowing diversification in the level of this type of farming. On one hand, adopting drip irrigation, which is more water efficient, could be a positive change for farms, since even this requires less labor than other irrigation techniques which lower input costs. On the other hand, this would impact the salaried workforce by reducing employment. Additionally, being a semi-arid zone, climate change characterized by a decrease in precipitation and an increase in temperature, would inevitably impact cropping systems by reducing their cycles, in addition to the displacement of their zones, as well as a drop in yield and the quality of production, which will lead to a decline in the farmer's income. Moreover, the adoption of new policies in the face of climate change and the availability of water in this system would have a positive impact on its operations, given that they could implement adaptation measures appropriate to their situation. For example: policies encouraging farmers to adopt agricultural practices that are more resistant to drought and that consume less water. In addition, the involvement of farmers in this system in decision-making at the level of their villages as well as ensuring their agricultural monitoring, will allow better management and use of water, as well as the profitability of their farms by impacting the prices of their productions on the market. Besides, the introduction of professional organizations would allow farmers to better adapt to climate change as well as ensure their access to new technologies (irrigation, mechanization).

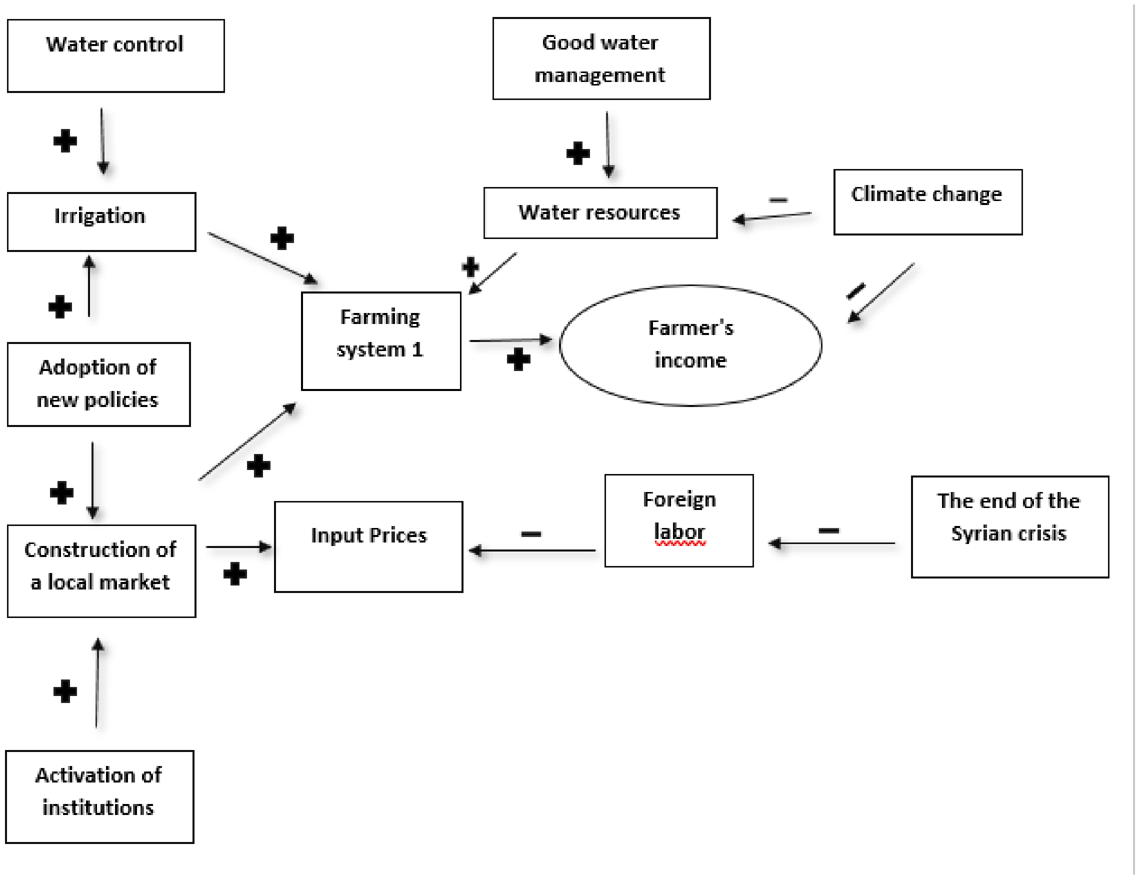


Figure 26 Cognitive map of the future situation of LP system

2nd type of farms SP: Small intensive plant-dominated farms (SP)

For this 2nd type of farm, farmers have almost half of their farms irrigated. In addition, they are dominated by surface vegetable crops (94%) which consume a lot of water, thus posing the problem of monoculture that causes soil degradation. However, there are also cereals, fruit trees and tobacco too. There is no cattle or sheep animal production system, but maybe there is another system as the farmers pay animal production costs. They mainly use as a source of water and as a method of irrigation: wells and drip irrigation. That puts pressure on water resources since the excessive use of wells would lead to a drop in the piezometric level and drying up of the underground water table.

The farmers in this system have a high gross margin / ha compared to the average margin of all the farms, and a low off-farm income, which shows that they are mainly dependent on their farms and do not carry out an activity outside their profitable farms.

Due to climate change presented by decreasing precipitation as well as irregularity and increasing temperature, further accentuates the problem around water.
In addition, the dollar crisis and the geopolitical instability which generates the increase in production and input costs as well as the instability of prices, would obviously impact negatively on the farmer's income as well as reduce land agricultural.
In addition, the market, which is very far from the farms, poses a problem in terms of marketing, as well as adding transport costs to input costs.

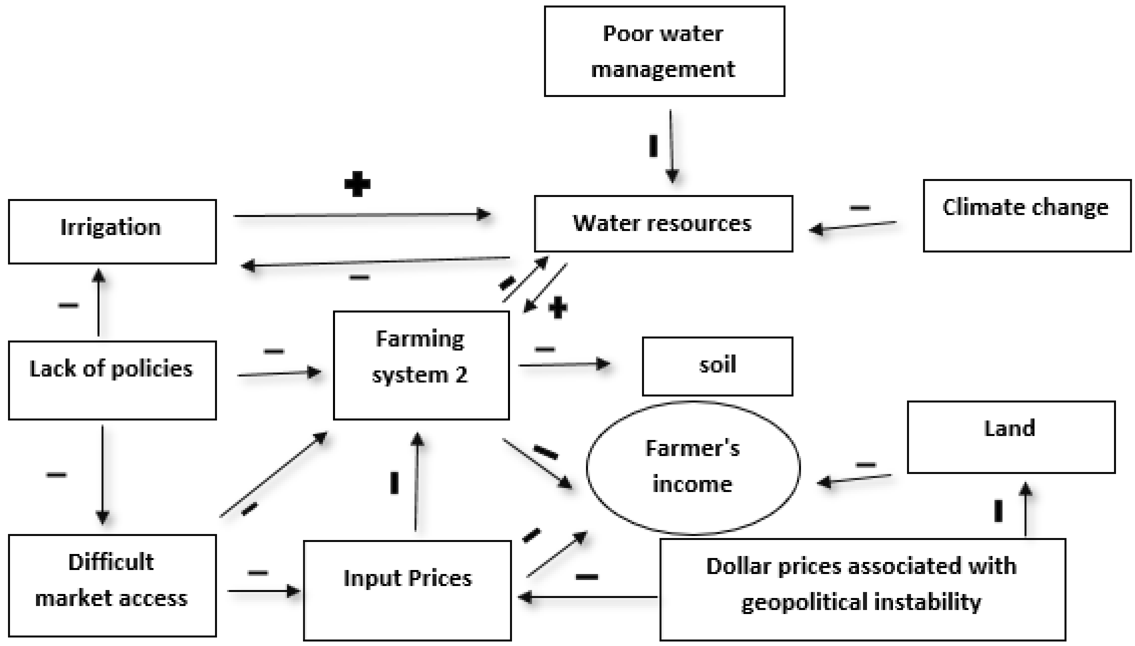


Figure 27 Cognitive map SP system (current situation)

Future situation of SP:

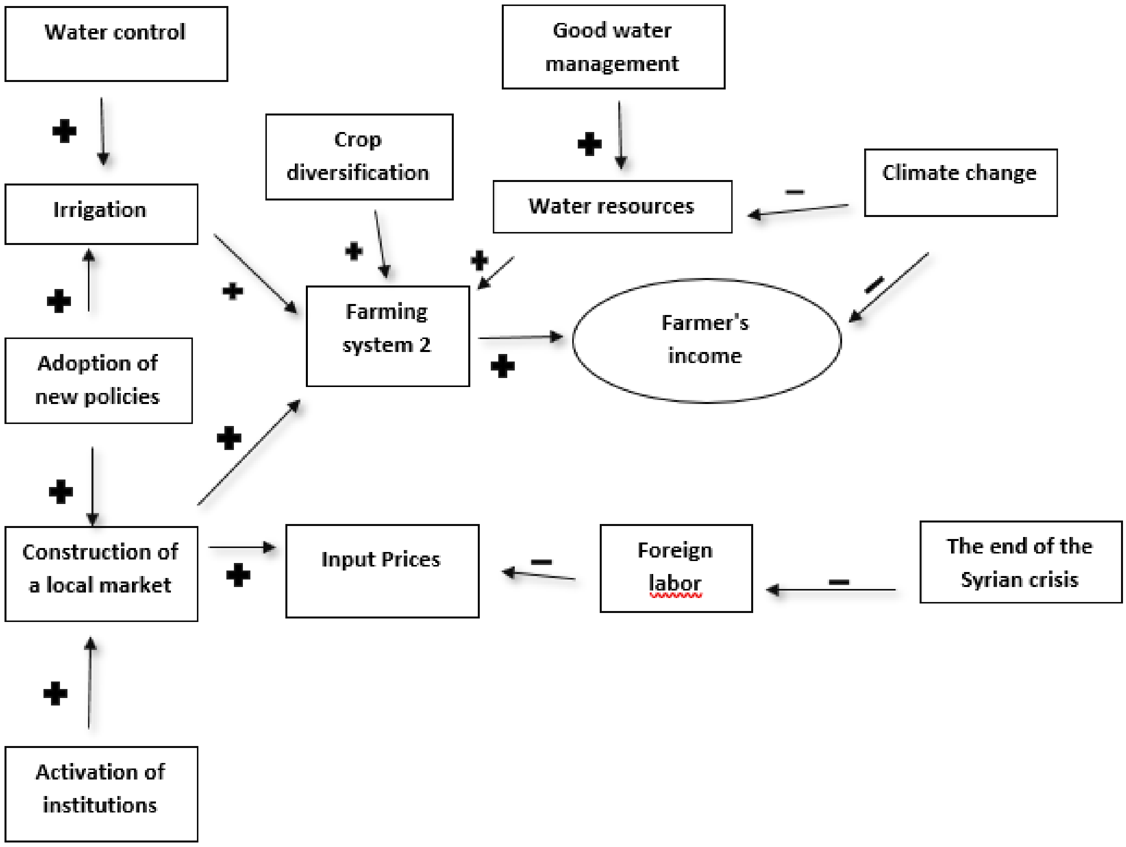


Figure 28 Cognitive map SP system (future situation)

The shock for this operating system would be the decline in underground water resources as well as climate change. The decrease in water resources would push farmers to reduce their irrigated areas, which would obviously lead to a change in the rotation of farms. The changes that could take place are: the introduction of olive trees as well as a reduction in market gardening so as not to degrade the soil, in addition to the orientation towards crop diversification. Besides, the adoption of new policies in the face of climate change and the availability of water in this system would have a positive impact on its operations, given that they could implement adaptation measures appropriate to their situation. For example: policies encouraging farmers to adopt agricultural practices that are more resistant to drought and that consume less water. In addition, the involvement of farmers in this system in decision-making at the level of their villages as well as ensuring their agricultural monitoring, will allow better management and use of water, as well as the profitability of their farms by impacting the prices of their productions on the market.

The introduction of professional organizations would allow farmers to better adapt to climate change as well as ensure their access to new technologies (irrigation, mechanization).

3rd type SA: Small farms with arboriculture dominance (SA)

For this 3rd type of farm, farmers have about 35% of their total useful agricultural areas irrigated. In addition, they are dominated by fruit trees on the surface (88%) which consume water thus posing the problem of monoculture which causes soil degradation. However, there are also very few olive trees and vegetable crops and no cereals, there is no animal production system. They mainly use as a source of water and as a method of irrigation: wells and drip irrigation, which puts pressure on water resources. The excessive use of wells would lead to a drop in the piezometric level and drying up of the underground water table, in addition to the costs of pumping water that are added. On the other hand, the method of irrigation adopted is water efficient. Moreover, the climate change represented by decreasing precipitation as well as irregularity and increasing temperature, further accentuates the problem around water.

In addition, the dollar crisis and geopolitical instability which causes the increase in production costs and inputs as well as price instability, would obviously negatively impact the farmer's income. Besides, these farms are very far in relation to the average distance of all the farms in relation to the market, which could obviously pose a problem of selling their production, and which would increase transport costs.

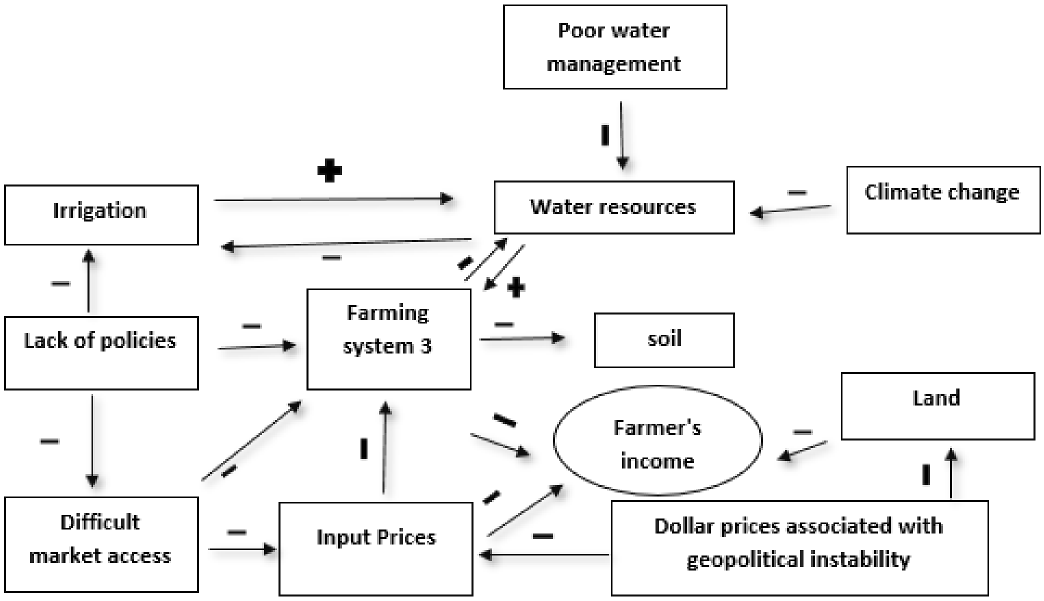


Figure 29 Cognitive map SA system (current situation)

Future situation of SA:

What constitutes a shock for this type of exploitation is access to the market, climate change and the decline in underground water resources. Firstly, the decrease in water resources would push farmers to reduce their irrigated areas, which would obviously lead to a change in the rotation of farms. Additionally, a decrease in the area intended for fruit growing with a balanced increase in the areas of olive trees and market garden crops associated with the introduction of cereals could be a change in the future, with even a diversification of production systems by introducing the animal system production. Moreover, this farming system could also see a better evolution of the quality and the traceability of its fruit productions despite a reduction in the area: there would be an increase in yield, by having a good control of the technical routes as well as of the water, therefore, ensuring an income for the farmers. Besides, the development of a market near these farms is important in order to promote their productions, as well as to facilitate the sale of their productions. In addition, the adoption of new policies in the face of climate change and the availability of water in this system would have a positive impact on its operations, given that they could implement adaptation measures appropriate to their situation.

For example: policies encouraging farmers to adopt agricultural practices that are more resistant to drought and that consume less water. Moreover, the involvement of farmers in this system in decision-making at the level of their villages as well as ensuring their agricultural monitoring, will allow better management and use of water, as well as the profitability of their farms by impacting the prices of their productions on the market. Finally, the introduction of professional organizations would allow farmers to better adapt to climate change as well as ensure their access to new technologies (irrigation, mechanization).

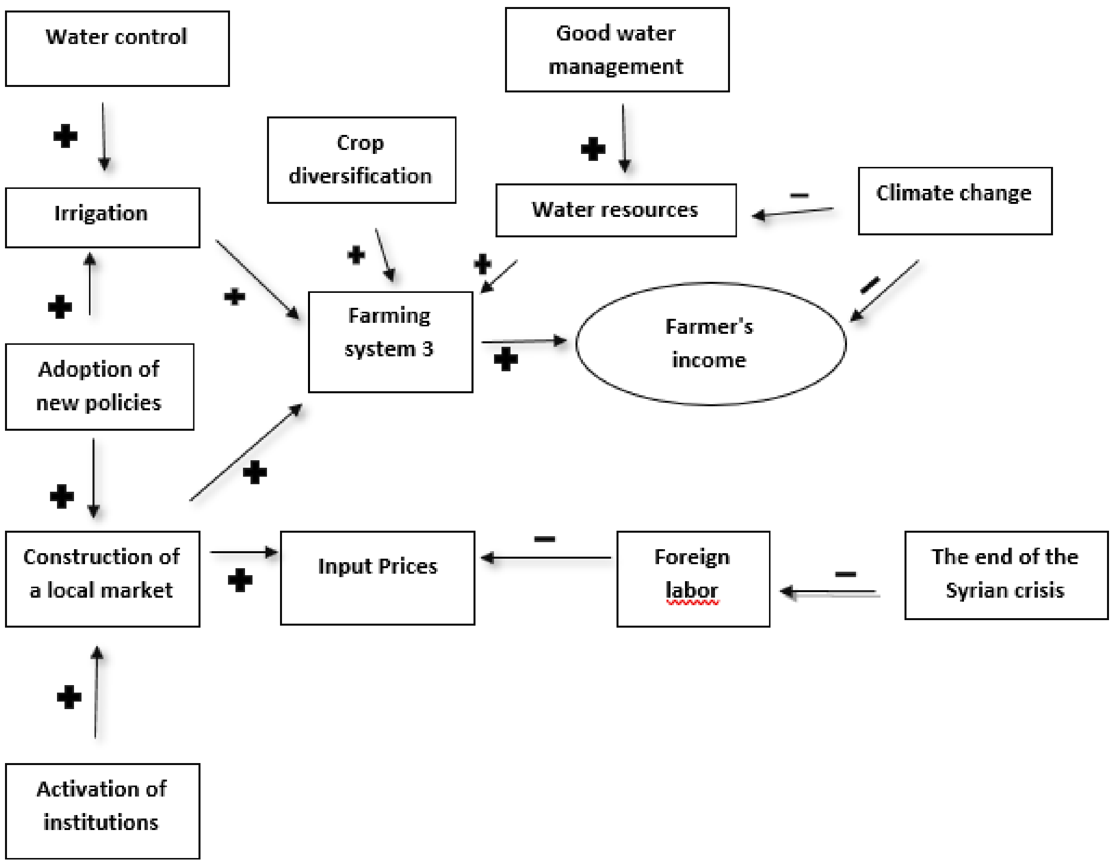


Figure 30 Cognitive map SA system (future situation)

4th type of farms SO: *Small farms with olive growing (SO)*

The most important shock that this type of exploitation can undergo is the decline in water resources and climate change, as well as access to the market which is difficult. Type 4 is specialized in the cultivation of olive trees (45% of the total UAA) and market gardening (42%) as well as other crops but their areas are very minimal. In addition, the irrigated area of farms represents 37% of the total area. This type of operation is also oriented towards the system of cattle and sheep animal production. However, they are very far compared to the average distance from the market, which poses a problem in terms of marketing the production as well as it will add more transport costs. In addition it causes the abandonment of land by the farmers. As for the irrigation dose, it is high compared to the average, which shows that farms of this type consume a lot of water.

Future situation of SO:

The development of a market near these farms will help promoting their productions, as well as facilitating the sale of their productions. In addition, the adoption of new policies in the face of climate change and the availability of water in this system would have a positive impact on its operations, given that they could implement adaptation measures appropriate to their situation. For example: policies encouraging farmers to adopt agricultural practices that are more resistant to drought and that consume less water. Moreover, the involvement of farmers in this system in decision-making at the level of their villages as well as ensuring their agricultural monitoring, will allow better management and use of water, as well as the profitability of their farms by impacting the prices of their productions on the market. Finally, the introduction of professional organizations would allow farmers to better adapt to climate change as well as ensure their access to new technologies (irrigation, mechanization).

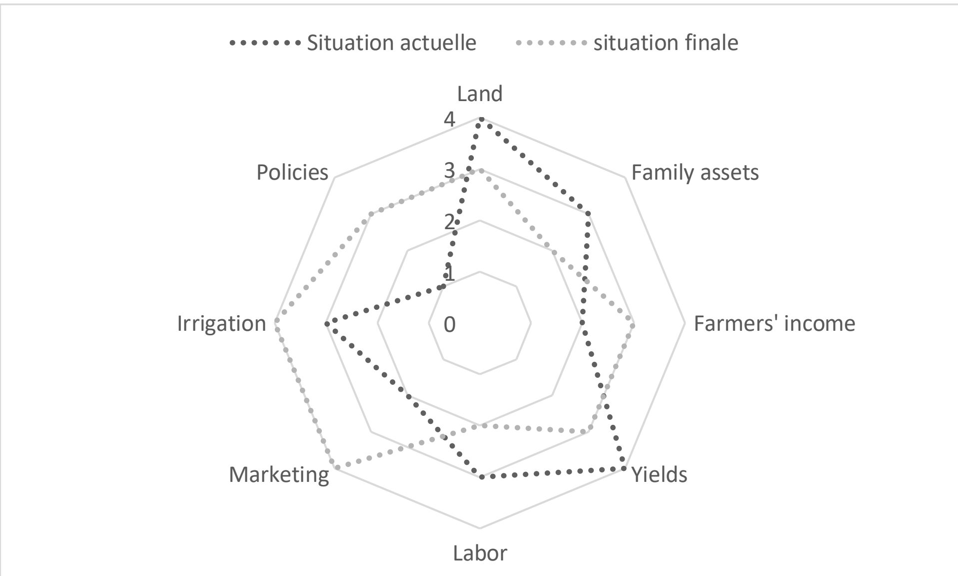


Figure 31 Current and future performance of type 1

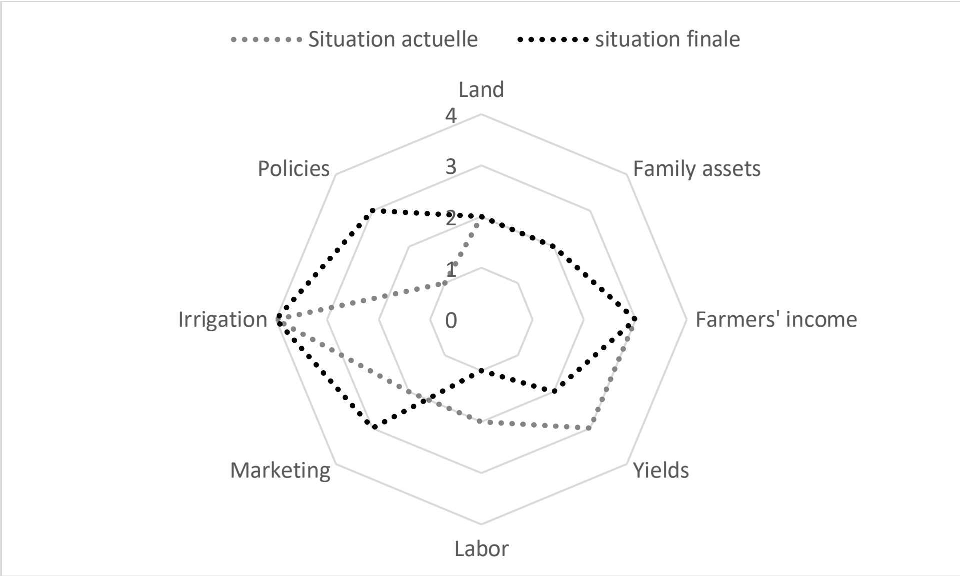


Figure 32 Current and future performance of type 2

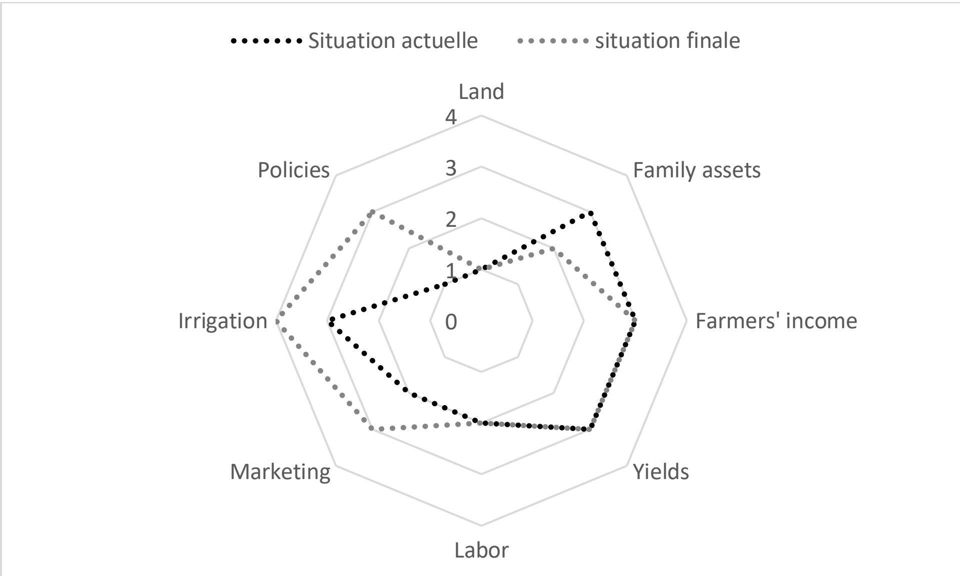


Figure 33 Current and future performance of type 3

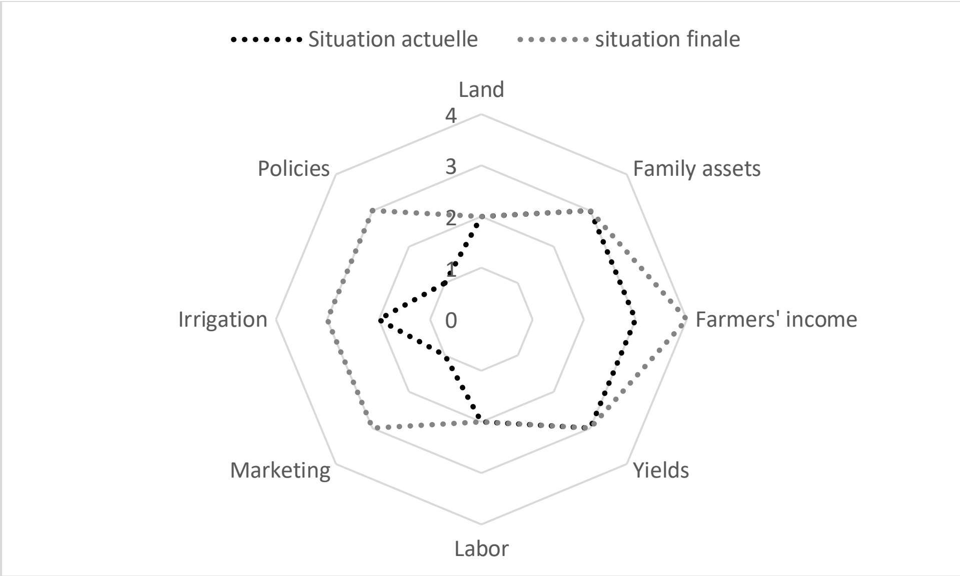


Figure 34 Current and future performance of type 4

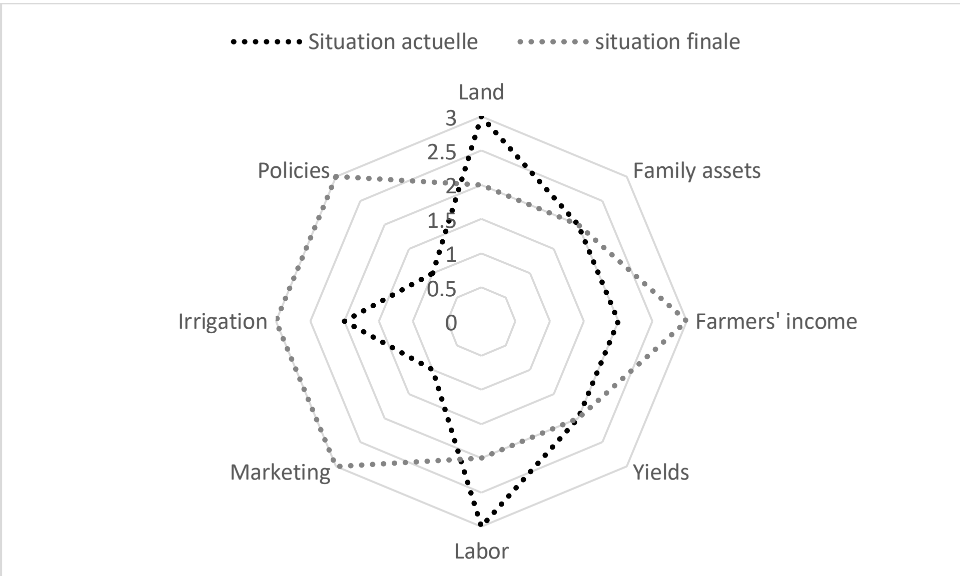


Figure 35 Current and future performance of type 5

The 5 farming systems are subject to the same shocks: climate change, the decline in water resources, as well as difficult access to the market, and the absence of policies.

We note that the yields for all operating systems identified in the current situation are high compared to the future situation which shows that they are resilient for now. However, due to climate change presented by increases in the temperature, low and irregular rainfall, a reduction in crop cycles, will experience a drop in the future situation or they can keep the same yield which constitutes a vulnerability for the farms of Baalbek-Hermel.

Additionally, we notice that in the future, the adoption of new policies can encourage more water management, as well as it will encourage farmers to adopt new more resistant practices. It will also encourage institutions and the ministry of agriculture to be more active, and therefore this will make the farming systems in the future situation more resilient than now.

For market access, we note that in the current situation, the farms of all systems are at a great distance from the market, which poses a problem in terms of marketing, thus in production. It also adds transport costs, which makes the different systems vulnerable. On the other hand, in the future situation, by creating local markets, marketing increases, the prices of inputs decrease, which increases the income of farmers, and thus the resilience of farms.

Moreover, the number of active family members will experience a decline, as young people abandon the agricultural sector more and more, which could make these farms less resilient.

Besides, we note that in the future situation, irrigation will become more efficient; this would surely be due to a more optimal management of water resources, using more water-saving irrigation methods, and above all an optimal distribution of this water between farms, which would constitute a source of farm resilience.

In the future situation, perhaps the Syrian crisis will end, and therefore the Syrian refugees will return to their countries. Hence, the need for local labor force, which is more expensive, will increase and consequently the production costs will increase, which constitutes a source of vulnerability for the farmers.

For land, due to climate change which is more accentuated, in addition to the dollar crisis that the country is currently experiencing, would impact farmers and push them to leave part of their land, which is a source of vulnerability for them.

Discussions

Farms in the Baalbek Al Hermel region are faced with many challenges that impact their development, and thus decrease their resilience and increase their vulnerability.

We cannot limit these issues to the repercussions of climate change on the production of agricultural farms in the studied area. Given that, according to the study carried out on the holdings of 5 types of farms in the region of Baalbek Al Hermel, we noticed that there are other factors that can strongly affect the performance of the latter, and thus, make them more vulnerable and less resilient. Therefore, adaptation strategies should not focus as on the impacts of climate change and the reduction of water resources, but also on other factors that make farms more and more vulnerable and less resilient.

Recently, Lebanon is facing an economic crisis presented by a dollar shortage. This crisis has a colossal impact on different sectors, among them the agricultural sector. Farmers rely heavily on the import of basic products (seeds, pesticides, fertilizers ...), importers find themselves in a very difficult situation faced with this problem, prices are experiencing inflation, sometimes even from 30 to 40 %, and on the other hand, agricultural production is in decline. In addition, suppliers, who previously gave farmers the option to pay on credit and waited until the end of the season, now have to force farmers to pay in cash and US dollars, because they owe the bank themselves. . According to studies carried out despite the lack of quantitative data, they estimate that this year will see a decline of 20 to 30% of agricultural production, while it is a year that needs more abundant agricultural production. They also believe if import restrictions remain unchanged in 2021, the situation will worsen. So far, farmers rely on stocks. Unfortunately, due to the real depreciation of the pound, Lebanon's agricultural production could have become more competitive, especially for exports. Farmers faced with this crisis are faced with two options: either they abandon this sector, or they reduce their agricultural land and they invest in what they already have, and resort to trafficking from Syria to raw materials they need.

To deal with this, FAO is preparing to launch a pilot project with the government to distribute aid to farmers so that they can buy the agricultural products they need. They will issue vouchers to the most vulnerable farmers and return the goods to suppliers. Their major concern is that farmers do not miss the planting season, despite the limited budget they have (Baaklini S, 2020).

On the other hand, in Lebanon, the Syrians represent 80% of the foreign workforce, followed by the Egyptians, Sri Lankans and Ethiopians. They mainly occupy low-skilled positions, and work mainly in the construction of buildings, and agriculture. According to a recent CREAL study, they estimate that 3 quarters of jobs in the agricultural sector are held mainly by immigrants, but the latter are still limited to the least qualified and the least well paid positions. The Lebanese labor, which is expensive in comparison with the Syrian labor, is therefore unemployed since it is less in demand. Thus, farmers are very concerned because, after the Syrian crisis, they will find themselves facing an increase in the cost of Lebanese labor, which will increase production costs for them.

In addition, there is the problem of the Ministry of Agriculture, which is virtually absent in the Baalbek- Hermel region, as well as the institutions. There is a need for them to become more active, to provide agricultural advice and monitoring to operators and also involve them in decision-making at the level of their regions instead of making individual decisions. In addition, water management at the level of the region is experiencing poor management and use, and the demand increases in the face of the decreasing supply. Therefore, it is important to develop agricultural policies encouraging farmers to adopt agricultural practices that consume less water, with a more water-saving method of irrigation such as drip irrigation. Also, as an adaptation strategy, there may be the development of a policy for the establishment of hydraulic infrastructures. Indeed, there is the Orontes river (Assi River), which has its source in Lebanon, then it crosses Syria to flow into the Mediterranean via Turkey. Given the importance of the river, it could have contributed more to the development of the poor area of Hermel. It is true that for a long time, many Lebanese farmers have drawn water from the watershed of this river, but the infrastructure is lacking, which reflects the lack of interest of the Lebanese State for the entire peripheral zone in general, and all the hydraulic structures in particular, especially to prevent them from obtaining more samples.

Moreover, we could add the proximity to the market which is far away for farmers to the factors impacting the resilience of farms in the Baalbek Al Hermel region. Hence, it generates a problem of marketing and the disposal of their production, thus the increase in input costs by adding transport costs. That makes farms more vulnerable, hence the need for the creation of a local market in each village to facilitate the marketing of local products by farmers.

Conclusion

This study has shown us that farms in Lebanon in general, and in the region of Baalbek- Hermel in particular It is highlighted in order to understand, first of all, the issues associated with climate change in the three villages studied in the region of Baalbak-AlHermel, to then study the resilience of their farms, and thus define adaptation strategies closer to the reality of the latter and therefore be integrated into the project.

After studying the characteristics of each village, we were able to extract the main issues that we can summarize as follows: the dollar shortage, which can have negative consequences on production costs which will increase, in the face of farmers with low income, there is also the geopolitical instability that the country is experiencing and which further accentuates the crisis, in addition to their great dependence on water resources, which are becoming increasingly limited due to global warming, in the face of increasing demand .. etc. All of this calls into question the adaptation of farmers in the Baalbak Al-Hermel region to this situation.

These issues allowed us to have a clearer vision of the criteria selected in order to produce the exploitation typology and thus, better understand the context of the study area.

To develop this typology then, we used 3 categories of classification criteria: criteria taking into account the endowment of resources divided into production potential (UAA, access to the market, etc.) and the availability of financial resources. (Gross margin per farm, non-farm income), criteria taking into account the production objectives (family farm labor, time spent on the farm, etc.), and criteria taking into account the levels of intensification of production (input costs, etc.).

Using the Tanagra tool, we were able to have 5 farming systems from 101 farms in 3 villages (Bouday, Sariin and Hermel) in the region:

- 1st type of farm: Large farms specializing mainly in cereals, also with vegetable crops and tobacco, irrigated (43%).

- 2nd type of farm: Small farms specializing in market gardening, irrigated (40%)

- 3rd type of farm: small farms specializing in fruit growing with little irrigation.

- 4th type of farm: small farms specializing in olive growing, as well as in the animal production system (cattle and sheep), irrigated.

- 5th type of farm: medium-sized farms, specialized mainly in cereals and olive growing, and in the system of sheep and bovine animal production, irrigated.

The evolution of these different farming systems can be impacted by several factors of change the most relevant of which are climate, water resources, irrigation, cropping systems and inputs.

After submitting the operating classes to these different drivers, we were then able to study their resilience using cognitive maps as well as evaluation grids.

We cannot limit the challenges of the region to the repercussions of climate change on the production of agricultural holdings in the area studied, given that, according to the study carried out on the holdings of the 3 villages of Bouday, Sariin and Hermel In the Baalbek Al Hermel region, we have noticed that other factors can strongly affect the performance of the latter, and thus, make them more vulnerable and less resilient, therefore, adaptation strategies should not only focus on the impacts of climate change and the reduction of water resources, but also other factors that make farms more and more vulnerable and less resilient.

All this leads us to recommend the activation of the functions of the Ministry of Agriculture which is almost absent in the region, as well as the institutions, in order to provide agricultural advice and monitoring to farmers. It is also recommended to involve these institutions in the decision-making at the level of their regions instead of making individual decisions. In addition, to the management of water at the level of the region which is experiencing poor management and use, and demand which increases in the face of supply which decreases, and this, by developing agricultural policies encouraging farmers to adopt agricultural practices that consume less water, with a more water-saving method of irrigation such as drip irrigation and at the same time, ensuring a good income. Also, as an adaptation strategy, there may be the development of a policy for the establishment of hydraulic infrastructures. In addition to this, the need for the creation of a local market in each village to facilitate the marketing of local products by farmers and thus, ensure them a greater margin, given that the proximity of the market is far from the farms. farming in the village, thus posing the problem of marketing, and marketing their production as well as increasing input costs by adding transport costs.

Chapter IV

Assessment by bioeconomic modeling of the resilience of agricultural production systems in a semi-arid region: Case of Baalbeck El Hermel – Lebanon

Part I

Title: Assessment by bioeconomic modeling of the resilience of agricultural production systems in a semi-arid region: Case of Baalbeck El Hermel – Lebanon (Water availability)

Abstract

The semi-arid region of Baalbeck El Hermel is increasingly threatened by climate change. The agricultural systems constituting the main source of household subsistence in this zone show a significant vulnerability to these disturbances, especially concerning the limit in water resources. This study was established to evaluate, through a bioeconomic modeling approach, the resilience of agricultural systems in Baalbeck El Hermel and identify their adaptation strategies under conditions of water scarcity. In this context, we have chosen three typical farms representative of the driest northern zone receiving the least precipitation.

Analysis of the results showed several behaviors and levels of resilience of these farms: 1) farms specializing in market gardening or perennial crops are very sensitive to drought conditions and are not resilient in the face of water limit conditions; 2) the diversified farm with olive tree dominance is less sensitive and more resilient. The analysis of the water pricing scenario showed an improvement in water management but a limit in the adaptive capacity of farmers, hence the necessity to adapt resilience-building strategies for the targeted area.

Author keywords

Farming system, resilience, semi-arid zone, bioeconomic model, climate change, water availability.

Introduction

Climate and environmental crises have lengthy threatened agricultural production around the world (Menike and Arachchi, 2016). Research has shown that more than 25% of disaster costs are absorbed by means of agriculture in the case of weather crises, and nearly 80% of those expenses are in drought conditions (Crises and resilience in the Mediterranean, 2016). The Mediterranean basin is one of the regions the most susceptible to climate change, especially its water resources. A predicted increase in temperatures of greater than 2 ° C by 2040 (Hoegh-Guldberg et al., 2019; Nasser et al., 2020) and a decrease in rainfall will reduce water availability and cause drought conditions and degradation of soil (Darwish et al., 2005).

Located to the east of the Mediterranean, Lebanon could be one of these most inclined countries. Its agricultural sector is characterized by rain-fed but primarily irrigated crops, and generally, the majority of crops require additional water resources, especially during the hot season (Verner et al., 2018). However, due to climatic risks, water availability has decreased and the farmer in rural regions faces the challenge of water scarcity. Lack of making plans (Nasser et al., 2020) and mismanagement of resources will exacerbate this problem. The farmer will consequently have to find the most effective manner of adaptation to stand those challenges.

To better understand the adaptive capacities of rural populations, it is necessary to understand the livelihoods of farmers (Menike and Arachchi, 2016) and the role of agriculture as a resilient livelihood for these populations.

Resilience is "the capacity of an individual or a system to absorb disturbances, to reorganize itself and to adapt its operating techniques" (Crises and resilience in the Mediterranean, 2016). In other words, it is the means adapted by a system so that it remains in a situation of equilibrium in the face of various challenges. In agriculture, the resilience of production systems is "the ability to reorganize and maintain the function and structure of systems, which are interconnected and span different spatial and temporal scales" (Souissi et al., 2018). Thus, the analysis of resilience is equivalent to the analysis of 3 approaches at the level of agricultural systems: the structure of these systems at different scales (farm scale, regional and national), the disruptions that can occur and influence these systems and the resilient livelihoods that allow them to cope with disruptions and threats to maintain stability.

In a semi-arid zone, farming systems are among the most vulnerable to climate change, so farmers face risks of drought and water scarcity. The decision-making of these farmers must follow an effective adaptation strategy to be able to overcome these challenges. However, the lack of appropriate resource management and adaptation policies in our area, on the part of the government, in addition to environmental and climatic disturbances, forces farmers to accept all risks and create their own strategy individually. The aim of this study is to understand how farmers in these areas currently perform in the face of limited water resources and agriculture with little or no government support, in order to predict what could be the behavior of this farmer in case of decrease in water availability in the future.

Based on this concept, and based on decision-support tools, our main objective will be to assess (using bioeconomic modelling) the resilience of farmers in the semi-arid Baalbeck El Hermel zone to climate change in a context of limited water resources.

This work will be divided into two parts:

First, we will build a bioeconomic model adapted to this typology and perform simulations on the basis of adaptation scenario per type group based on certain numbers of socio-economic and environmental indicators.

Secondly, the analysis of the results will allow us to assess the resilience of typical farms according to a simplified resilience analysis framework.

Methodology

Resilience analysis

Choice of typical farms for modeling

Modeling is a complex tool and the choice of the typical farm depends in the first place on the objective of the research and the availability of the necessary information. In fact, the Baalbeck ELHermel region is divided into 3 agro-climatic levels and the typology that we have produced has enabled us to distinguish the agricultural systems characterizing each zone. Building bioeconomic models for all farm groups is difficult due to their complexity, the limit of available information (Souissi et al., 2018) and the time required for the work. Therefore, we have chosen a single agro-climatic zone for the modeling, the North zone, which is considered the most vulnerable to climate change (low rainfall). This zone is characterized by the presence of three types of farms, for this we have chosen, based on the surveys, three typical farms each representative of a sub-group of the North zone. Moreover, the three agricultural systems targeted are generally characterized by small to medium-sized farms (the most common size in the North region), by a single dominant type of crop (either market gardening, arboriculture or olive trees) and are 100% irrigated farms (Results-3, table 4). The analysis of the performance of these farms will allow us to characterize the diversity present in the northern zone and identify the farms with the greatest capacity to adapt in a semi-arid climate in the face of limited water conditions.

In this regard, and in the presence of an expert agricultural advisor in the North region we carried out surveys of one hour of time by telephone with 3 typical farmers each representing a farm type, to collect the information needed for modeling. These questionnaires contain a part concerning the characteristics of the targeted farms and another part concerning their perspectives on climate change and the scenarios expected in the future concerning the limit of water resources and the impacts on their agricultural systems.

From the rotations of these typical farms, their socioeconomic characteristics and the irrigation alternatives that can be adapted (dry instead of irrigated), we were able to build our bioeconomic model. The scenarios are then adapted according to the perspectives of the farmers and the suggestions proposed by the experts to improve the water limit situation.

Choice of indicators

Indicators are specific, measurable and observable parameters used in characterizing the stability of agricultural systems in the face of external disturbances and providing information on states that are not directly measurable (Parsonson Ensor and Saunders, 2011). Several socio-economic, agronomic and environmental indicators that reflect the evolution of the capital of agricultural systems are calculated to analyze the resilience of a system (Souissi et al., 2018). The choice of indicators varies according to their level of relevance to the situation being dealt with and the availability of information on the ground. On the other hand, the choice of these resilience indicators according to Parsonson Ensor and Saunders (2011) is based on the analysis of the evolution of the three capitals:

- Human (linked to the permanent and seasonal family workforce contributing to agricultural work, to the level of skills of the workforce, the training of the workforce, etc.);
- Natural (linked to the three categories: natural resource , land and ecosystem);
- Economic (linked to profitability, liquidity and agricultural yield).

This step is essential since it makes it possible to study the stability of each of these capitals in the face of natural or human disturbances. In our study, we have chosen to analyze social, economic and environmental indicators in relation to these 3 capitals with regard to the data collected for typical farms and their possibility of modelling.

Bioeconomic modeling

After the development of a functional typology and the choice of typical farms, we are in the construction phase of a bioeconomic model.

Modeling is the development of an analysis and decision-making tool based on mathematical programming (technique for solving optimization problems under constraint) and on the concept of the possibility of production in a constraining environment. This tool helps us to understand the behavior of the studied system, the possibilities and the perspectives of evolution in the face of changes in its environment.

It is a static linear model produced with GAMS software (General Algebraic Modeling System). GAMS is a mathematical programming software widely used in economic modeling and aiming to facilitate the resolution of systems of equations in linear or nonlinear models.

In this work, the model built optimizes an objective function by choosing the most profitable crops (rotation) according to the constraints at the levels of land, water, labor and the previous crop. This model was adapted in the study by Khansa (2017).

The inputs to this model come from the results of surveys with farmers, expert opinions and the bibliography.

B. ***The objective function***

The objective function maximizes farm income. Its mathematical structure is formulated as follows:

$$Max\ Z = \sum (GM\ (C,T) \times X\ (C,T))$$

With:

Z = expected agricultural income

X (C, T) = agricultural area by crop and by technique (dry, irrigated)

GM (C, T) = gross margin per crop and per technique (dry, irrigated), calculated by subtracting the production costs from the yield per crop and per technique according to the following formula:

$$GM\ (C,T)\ = Price(C)\ *\ CY(C,T)\ -\ Pcost(C,T)\ -\ Cw(C,T)\ -\ Lr(C,T) * Lcost - Dw(C,T) * Wprice$$

With:

Price (C) = price of agricultural products in LL per kg

CY (C, T) = crop yield per kg per dnm

Pcost (C, T) = operational production costs excluding irrigation by crop and by technique in LL per dnm

Cw (C, T) = technical loads of irrigation systems per crop and per technique in LL per dnm

Lr (C, T) = labor requirement per crop and per technique in hours per dnm

Lcost = labor cost in LL per hour

Dw (C, T) = dose of water supplied per crop per technique in m3 per dnm

W price = pricing of a cubic meter of water in LL

(Water price is zero for the base scenario).

C. *Constraints :*

1- Earth constraint:

The sum of the areas used by the farmer is less than or equal to the agricultural area owned by the farmer.

$$\sum_{C,T} X(C,T) \leq UAA$$

With:

X (C, T) = agricultural area by crop and by technique (dry, irrigated)

UAA = agricultural area owned by the farmer

2- Water stress:

The total amounts of water consumed by crops must be less than or equal to the amount of water available per type of farm.

$$\sum_{C,T} Dw(C,T) \times X(C,T) \leq WA$$

With:

Dw (C, T): dose of water supplied per annual crop per technique in m3 per dnm

WA: water availability by type of operation. The quantity of water available per farm was estimated by farmers and verified by two experts in the region (agricultural advisor and agricultural engineer specializing in the installation of pumping systems for wells).

The quantities of water available per farm type are shown in the table 11 below.

Table 11 Quantity of water available per typical farm

Farm Type	**Quantity of water available in m^3**
PV_North	40,000
PA_North	10,000
PO_North	26,000

3- Labor constraint:

The sum of labor requirements per crop is less than or equal to the available family labor added to the seasonal labor required.

$$\sum_{C,T} Lr(C,T) * X(C,T) \leq LF + LD$$

With:

Lr (C, T) = labor requirement per crop in hours per dnm

LF = family labor available in hours per season

LD = seasonal labor recruited in hours per season (calculated by the model)

4- Constraint of perennial crops

The area of perennial crops is considered fixed in this model and cannot vary. The sum of area of perennial crops must be equal to the total area allocated for perennial crops.

$$\sum_{Cp} X(C,T) = Ac\ (Cp)$$

With:

X (Cp, T) = area per perennial crop in dnm

Ac (Cp) = total area of perennial crops in dnm

5- Crop rotation

Although this model is static, we took into account the crop rotation constraint. The rotation constraint takes into account the succession of two annual crops on the same plot. This constraint expresses that the area of a crop must not exceed the sum of the areas of these possible previous crops.

$$\sum_{pc} X(ca,T) \leq \sum_{pc} Apc(pc)$$

Apc (pc) = area of previous crop in dnm

Model validation

In order to validate the relevance of the model, we made a comparison between the results obtained by the model and the data collected from the surveys for each typical farm. The comparison of the performance of these typical farms was made by calculating the percentage of the absolute deviation (PAD) (Souissi et al., 2018) according to this formula:

$$PAD\% = \frac{|Xs - Xi|}{Xs} * 100$$

With Xs represents the simulated surface (prediction by the model) and Xi the surface observed in the surveys.

Scenario building

In this step, we will establish scenarios that will be simulated by the model. Modeling scenarios are interesting tools for scientific research since they allow the analysis of complex information that brings together several disciplines and can transparently represent the effects of change in the future understood by all kinds of stakeholders (Börjeson et al., 2006).

In this study, we were able to develop and test scenarios about climate problems based on the perspectives of the actors contacted in the North zone (part IV-II-1). All these actors are more and more aware of climate change and its possible impacts on agricultural systems. They perceive an increase in drought in the future due to 3 climatic factors: the rise in temperature, the shortening of the wet seasons (delay in the first autumn rains) and the variability of precipitation from year to year. Likewise, farmers and experts have noted a gradual decrease in the level of groundwater which is the main source of irrigation in this area (the extraction of groundwater is becoming more and more difficult as the boreholes are deeper). The overexploitation of the wells to meet the growing demand caused this drop in the piezometric level and the deepening of the boreholes.

Therefore, we have chosen to test one scenario in relation to the effect of climate change on water resources resulting in the gradual decrease in water availability. The scenario is described below:

1- Base Scenario: The base scenario represents the initial situation of the system before the integration of the effects of climate change.

2- “Water availability” scenario: this scenario provides for a gradual drop in water availability per farm; i.e. 20%, 50% and 80%. This decrease is explained by the effect of climate change and by an excessive use of water resources.

Identification of the resilience of typical farms

From the results obtained by the scenarios and the comparison of the different resilience indicators calculated by the model, we will identify the level of resilience of each typical farm. A summary framework for the analysis of simplified resilience is described below (Figure 36) with these different components and the levels of resilience based on the study by Souissi et al. (2018).

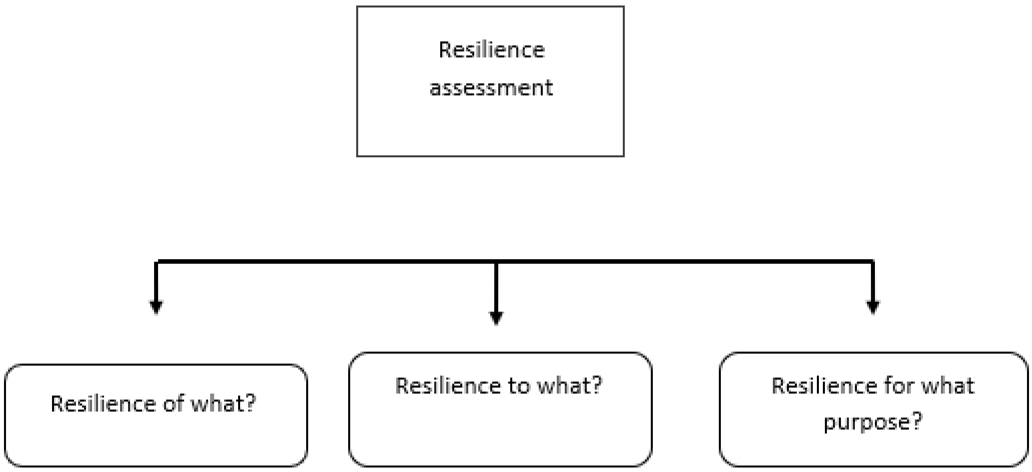


Figure 36 Summary framework of the resilience analysis in the northern Baalbeck El Hermel area

Results

Characteristics of the types of farms chosen for modeling

To carry out the modeling, a single agro-climatic zone was chosen, the North zone. This area is considered the most vulnerable to climate change because of its harshest semi-arid climate compared to the other two areas (high temperatures and very low precipitation).

From the three surveys carried out with typical farmers each representing a typical holding in the North region, we were able to collect the indicators necessary for modeling. Thus, we were able to verify the size of the farm, the rotation of crops, the area per crop, the previous crop, the need for labor, the availability of family labor and the quantity of water consumed by crop as well as water availability. The results showed that all of these farms irrigate the entire cultivated area and that each of these farmers has one or more underground boreholes from which they irrigate. Furthermore, we were able to identify how the characteristics of these agricultural systems vary if they follow an alternative dry irrigation technique (Table 12).

According to the farmers surveyed and the experts, annual crops, in particular summer vegetable crops (Molokhia, tomatoes, etc.), cannot be grown dry in this area because of the high temperatures and the lack of precipitation during this season. Winter annual crops (chickpeas and beans, cabbage, etc.) and perennial crops can be grown dry in this zone but their yield per crop will drop to about half.

Table 12 Characteristics of the SO type farm in dry and irrigation

	Irrigated			Non-irrigated (dry)		
Culture	Vine	Olive	Molokhia	Vine	Olive	Molokhia
Area (dnm)	10	50	10	10	50	0
Previous crop area (dnm)	0			0		
Price (LL)	1,500	135,000	23,000	1,500	135,000	0
Yield (kg)	6000	11 *	68	3000	7	0
Production cost excluding irrigation (LL / dnm)	605,000	515,000	370,000	605,000	515,000	0
Irrigation cost (LL / dnm)	50,000	50,000	90,000	0	0	0
Quantity of water consumed (m3 / dnm)	400	300	400	0	0	0
Work requirement in hours / dnm	68	44	44	68	44	0
Total family labor availability (hour)	1140			1140		

* Olive yield is the number of gallons of oil per denom

Assessment of the bioeconomic model

Model validation results

The validation of the bioeconomic model was carried out by comparing the actual rotation with the data simulated by the model (carried out on GAMS) using the base model as a reference (without effect of climate change). Figure 37 illustrates the comparison of these two results for each farm type. This comparison showed that for each type of farm, the majority of crop areas do not exceed a relative error of more than 30% (Table 13).

The model reproduced the real (observed) situation for the different farming systems and for each crop reason, with the exception of the SP farm which has a relative error equal to 35.48% (Table 13 and Figure 37). For this type of farm, the suitable crops are market gardens which are very risky: their yields and prices vary a lot. The model does not take into account the decision of the farmer to spread the risk for these crops, by not taking into account the variation in yield due to climatic variations and pests as well as the variation of the market price. For the two other types, rotation is well simulated and the error is 0% (since these are dominant perennial crops with a constant surface area).

Table 13 Result of the validation of the bioeconomic model for the 3 types of farms in the North zone

Farm Type	Crop	Observed area	Simulated surface	PAD%
SA farm	Apricot	20	20	0
	Peach	10	10	0
SO farm	Vine	10	10	0
	Olive	50	50	0
	Molokhia	10	10	0
SP farm	Peas	15	0	-
	Cabbage	20	27	25.93
	Bean	60	93	35.48

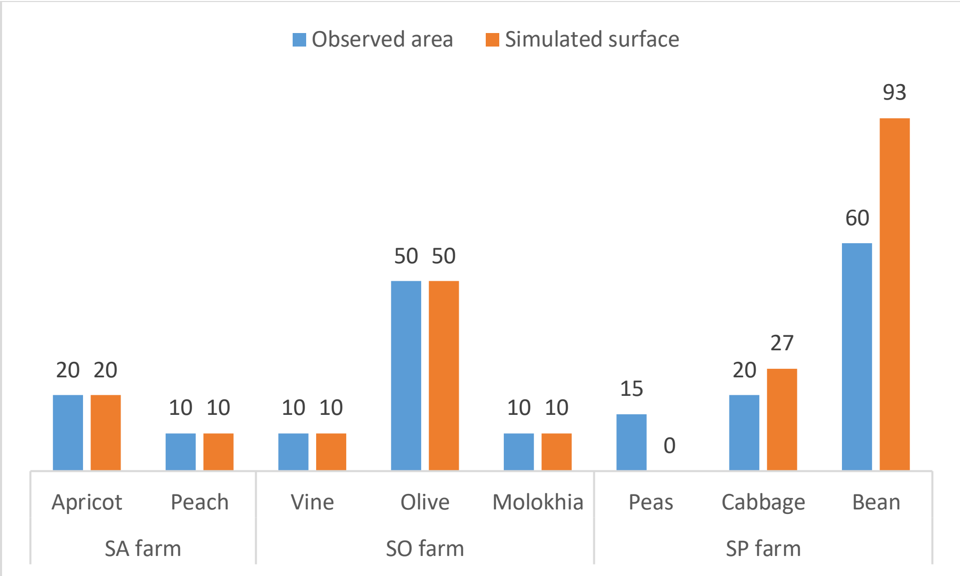


Figure 37 Comparison of the actual rotation and the simulated rotation for the three types of agricultural farms

Choice of indicators

The indicators chosen to be calculated by the model and to help in the assessment of the resilience of the agricultural systems studied in the face of climate change are socio-economic and environmental indicators representing the three types of capital (human, natural and economic).

For Economic capital:

- Annual gross margin which is among the most important indicators for farmers in semi-arid zones (ensuring sufficient family income) and its stability depends on the adaptive capacity of farms
- Vegetable rotation to assess the cropping systems most suited to climate change.

For Natural Capital:

- The total cultivated area which varies according to the disturbances and its capacity to return to its initial state indicates its degree of resilience.

- The amount of water used for irrigation which is a limiting factor in semi-arid areas and its availability is necessary for irrigation.
- Total irrigated area and dry and irrigated crop area in relation to water availability.

For Human capital:

- The amount of work which may be affected by natural disturbances due to its direct relationship to suitable crop types and farming systems.

Scenario analysis

The targeted scenarios were simulated by the bioeconomic model at the farm scale in order to assess the performance and adaptability of agricultural systems in the North of Baalbeck El Hermel by calculating a set of indicators (previous part).

A. Reference scenario S0

This scenario represents the simulation of typical farms without the introduction of the variability of water availability. This is the (basic) control scenario to which we will compare the variation in behavior for each farm type according to the different indicators calculated by the model.

B. "Water availability" scenario

The objective of this scenario is to simulate the performance of farms by testing the variation of agricultural rotations under conditions of progressive decrease in water stocks per farm (decrease of 20%, 50% and 80%). The behavior of farming systems in response to this scenario depends on the characteristics of the holding and the types of crops initially existing on the holding. Analysis of the results of the "water availability" scenario showed several behaviors:

- The areas of the 3 farms types, SP, SA and SO, were fully irrigated in the base scenario with total water availability (40,000 m², 10,000 m3 and 26,000 m3 respectively).
- After the introduction of the climate change scenario with a gradual decrease in water availability by 20%, 50% and 80%, the irrigated area of the three farms decreased to less than 22% of the total cultivated agricultural area for a water availability of 20%. The two SP and SO type farms showed almost the same behavior in terms of reduction

of the irrigated area with a gradual decrease of just 10% of the irrigated area (respectively from 120 to 107 dnm and from 70 to 67 dnm) when the availability in water decreases by 20% whereas for the PA type farm, the irrigated surface decreases by more than 30% (from 30 to 20 dnm) for the same degree of water availability. The lower the availability of water, the more the irrigated area decreases to 22% and 21% of the total cultivated area respectively for SP and SO farms, while it decreases to 11% for the SA type farm (Figure 38 and Table 14).

Table 14 Variation in agricultural area between the base scenario and the water availability scenario for farms types

Farm Type	Technical	100%	80%	50%	20%
SP	Irrigated area	120	107	67	27
	Dry surface		13	53	93
SA	Irrigated area	30	20	8	3
	Dry surface		10	22	27
SO	Irrigated area	70	63	37	13
	Dry surface		7	33	50

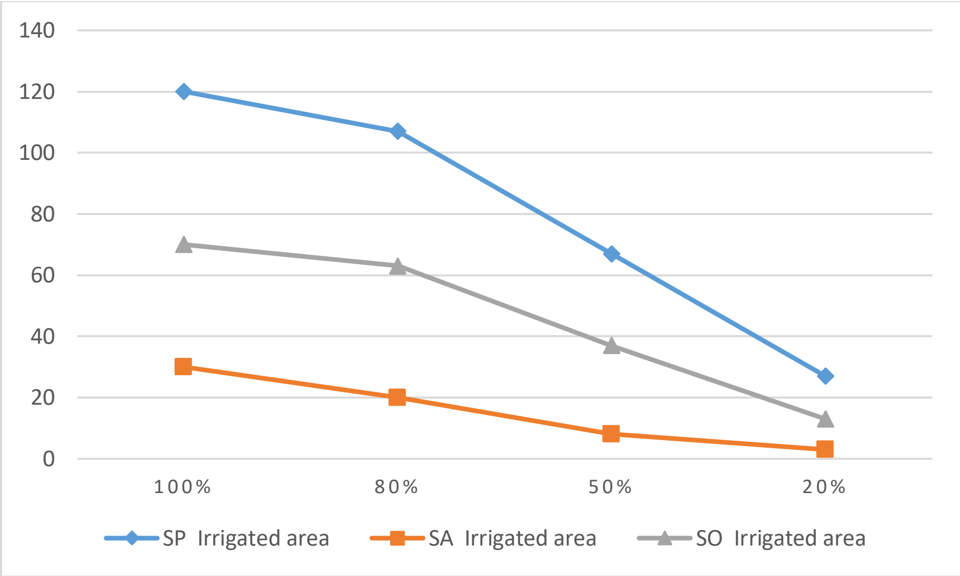


Figure 38 Variation of the irrigated agricultural area according to the availability of water between the base scenario and the scenario of water availability

- The comparison of the variation in gross margin for these typical farms with the base scenario showed a decrease in the latter by a variable trend for the three farms (Figure 39). The results will then be detailed for each typical farm.

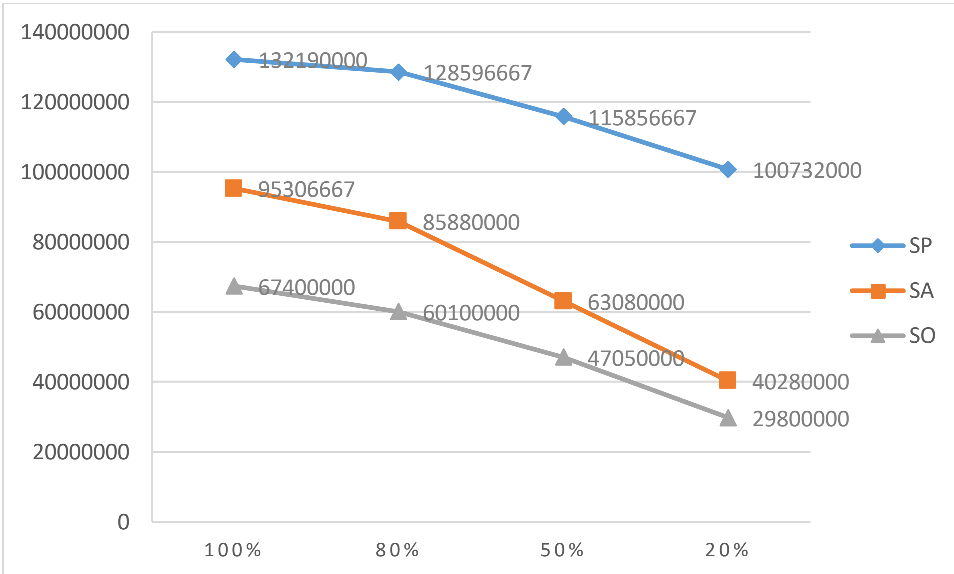


Figure 39 Variation in gross margin between base scenario and water availability scenario

The behavior of these farming systems in terms of crop selection and management is analyzed as follows:

<u>For the farm dominated by market gardening (SP):</u>

This farm is characterized by a single type of crop, market gardens. In fact, for the base scenario, these farmers cultivated two vegetable crops (beans and cabbage) which are totally irrigated. With the decrease in the quantity of water available and the introduction of dry crops, we notice that the farmer has kept the same cultivated area (120 dnm). However, in rotation, the farmer chose to keep a single crop on his farm (beans) by introducing two irrigation techniques (dry and irrigated). Analysis of the results showed that for a 20% reduction in the amount of water available, 89% of beans grown are irrigated while just 11% are grown dry. With the gradual decrease in the quantity of water available, we notice that the farmer begins to gradually reduce the area of beans irrigated to reach 22% of the total area when the availability of water decreases to 20%, and replace it with dry beans. (Figure 40).

This behavior proves that this crop is the most profitable for this exploitation under conditions of limited water in comparison with the other cultivations even if it is cultivated dry.

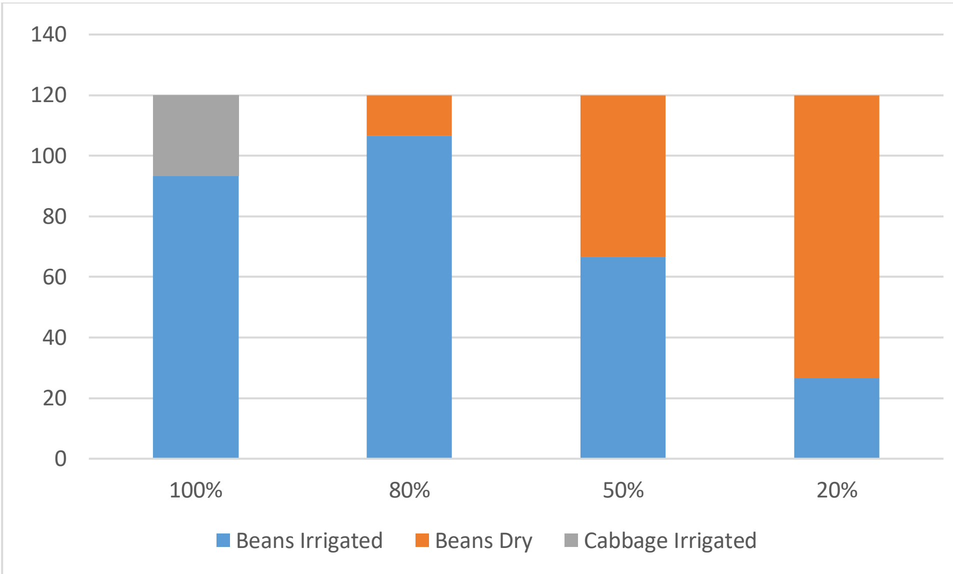


Figure 40 Distribution of crops by irrigation technique according to the base scenario and the water availability scenario for the SP farm

Regarding the need for labor, the analysis of the results showed a higher total consumption of labor compared to the base scenario which increases from 3920 hours per year to 4320 hours per year when water availability decreases by 20% of its total quantity. This demand for labor is constant with the decrease in water availability. This variation proves that growing bean grown on its own is more labor-intensive than if grown with other crops.

Nevertheless, we noticed that, for this farm having the lowest gross margin in comparison with the other typical farms, the gross margin decreased from 67.4 million Lebanese pounds to 60.1 million Lebanese pounds when the water availability decreases 20% of its initial quantity. The lower the availability of water, the more remarkable the decrease in gross margin: less than 45% of its initial value (29.8 million Lebanese pounds) with a water availability of 20% (figure 39). This variation shows the importance of irrigation as well as the diversification of crops in increasing agricultural yield and consequently the gross margin for this type of operation.

<u>For the farm with fruit tree dominance (SA):</u>

This type of farm cultivates fruit trees as the main crops. The base scenario showed an adaptation of two crops, peach and apricot, fully irrigated and covering the entire agricultural area used. The results for this scenario showed conservation of the rotation and of the cultivated agricultural area for all the water availability conditions.

With a decrease in water availability of 20% of its initial quantity, we notice that the farmer has reduced the irrigated apricot surface to half (10 dnm irrigated and 10 dnm dry) while keeping the entire surface of apricot irrigated. With more decrease in water availability for this farm (50% and 20%), the farmer stops irrigating the entire apricot area (dry processing) and gradually reduces the irrigated apricot area until to 66% of its total surface (figure 41). This behavior proves that the farmer has chosen to keep the most profitable crop, as much as possible, in irrigated (apricot) by gradually transforming the other dry crop.

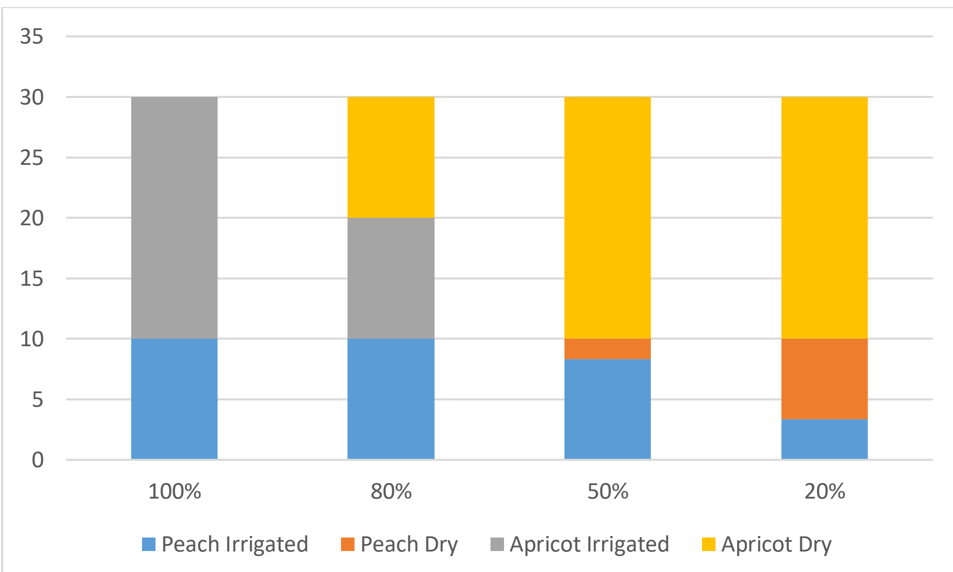


Figure 41 Distribution of crops by irrigation technique according to the base scenario and the water availability scenario for the SA type farm

For this scenario, unlike type SP farm, the labor consumption remains constant by comparing with the base scenario of 4880 hours of work per year (Figure 43). This stability is expected since the farmer kept the same crop rotation by just changing the irrigation technique which does not affect the workforce in our study.

With regard to the gross margin, the analysis of the results showed a gradual but significant decrease in the gross margin for this farm type. With a decrease in water availability of 20%, the gross margin decreases from 95.31 million Lebanese pounds to 85.88 million Lebanese pounds (10% of its initial value). The lower the water availability, the more remarkable the decrease in gross margin and the farmer loses more than half of his gross margin when water availability becomes 20% (40.28 million Lebanese pounds) (Figure 39). This variability proves that these perennial crops are much more profitable in irrigated than in dry land.

<u>For the SO type of farm:</u>

This type is characterized by the presence of several types of crops but mainly olive trees. The analysis of the results showed that for the basic scenario, the farmer cultivates and irrigates the entire available agricultural surface (70 dnm) with a diversity of 3 crops: olive trees, vines and Molokhia (Figure 42). With the decrease in water availability for this farm by 20%, we notice that the farmer kept the same cultivated agricultural area, the same rotations and just transformed part of the area of the olive trees from irrigated to dry (14%). When water availability decreases to the half, the farmer reduces the irrigated area of olive trees by up to 33%, but keeping the area of other crops fully irrigated (Figure 42). When the amount of water available becomes very low by 20%, we notice a decrease in the total cultivated agricultural area up to 63 dnm. The farmer transformed the total area of dry olive trees, kept the entire vineyard area irrigated and reduced the area of Molokhia (from 10 dnm to 3 dnm) but keeping this crop irrigated (Figure 42).

This behavior proves that the farmer has kept the most profitable crop completely irrigated (the vine) by reducing either the total area of his farm or by switching to the dry technique.

Regarding the total labor consumption, it remains constant for a total water availability of 80% and 50% of 3320 working hours per year but it decreases to 3012 working hours when the water availability becomes 20 % (Figure 4).3 This reduction is expected since the farmer has reduced the cultivated agricultural area which is directly related to the consumption of labor.

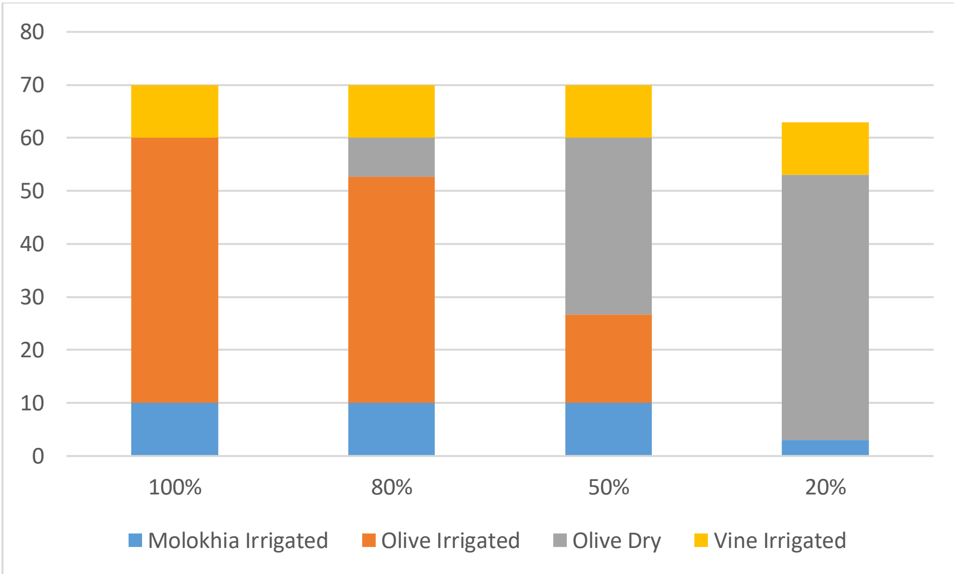


Figure 42 Distribution of crops by irrigation techniques according to the base scenario and the water availability scenario for the SO type farm

The analysis of the variation of the gross margin for this operation showed a gradual but small decrease in the gross margin compared to the base scenario. It decreases from 132.19 million Lebanese pounds to 128.6 million, 115.86 million and 100.732 million Lebanese pounds when

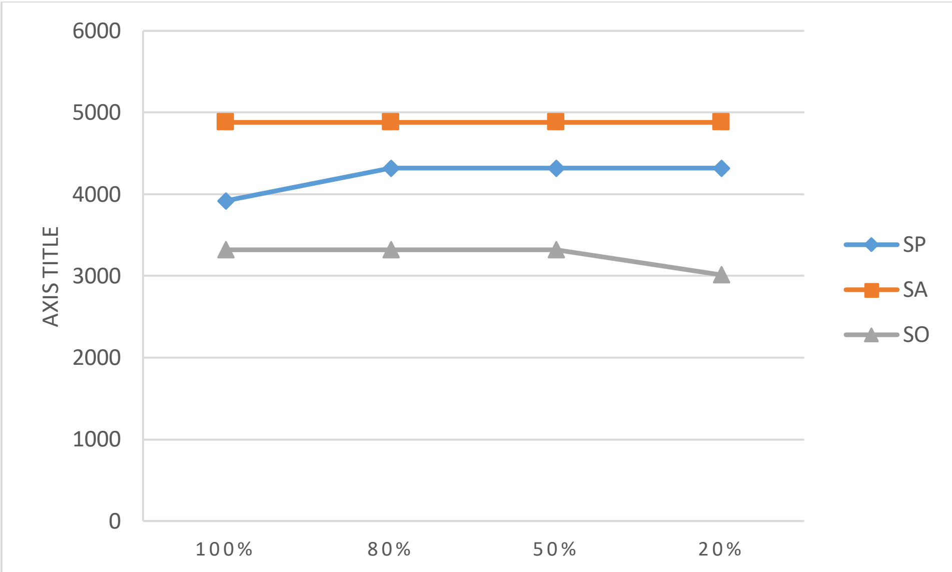


Figure 43 Distribution of the amount of work according to the base scenario and the water availability scenario for the three typical farms

water availability decreases respectively to 80%, 50% and 20% .This decrease proves that the cultivation of olive trees, even when grown dry, remains profitable and that the diversification of crops plays an important role in the maintenance of the farmer's income.

Resilience assessment of typical farms

To understand the behavior of each type of farms and these adaptation strategies when faced with the risk of water resource limits, we compared the three resilience indicators for each farm between two situations: base scenario and water availability scenario. This allowed us to identify the level of resilience of these farms if conditions of water scarcity will occur.

The analysis of the results obtained in the previous section allowed us to identify two levels of resilience in this study area:

<u>Non-resilient farms:</u> these are the two SP and SA type farms. These farms have shown a high sensitivity to climate change explained by a very significant reduction in the gross margin to 45% and 58% respectively of its initial value. These are farms that adapt mainly irrigated crops and the water factor is a crucial factor in their agricultural work. Therefore, the limit in water resources has shown a very large impact on crop yield even if the amount of labor increases or the agricultural

area increases. To adapt, these farmers have tried to just keep profitable crops on their farms and modify irrigation techniques according to the quantities of water available. The problem for these farms is the limit of cultivation on the farm and almost the absence of crop rotation and diversification. The choice of the farmer then focuses on a single type of crop. For example, it is expensive for arborists to replace perennial crops with other crops, hence their low flexibility to climate change. It is relevant for these farmers to introduce more diversified crops that consume less water (varieties resistant to drought conditions such as olive trees, pomegranates, etc.).

Little resilient farms: this is the SO type farm adapting diversified crops dominated by olive trees. This operation is less sensitive to the variation in the quantity of water available in terms of gross margin since it shows a slight decrease in the latter (decrease of up to 25% of its initial value). It is considered "not very resilient" in terms of gross margin but "not resilient" in terms of cultivated agricultural area. In fact, the farmer has reduced his UAA to limit these losses by eliminating the crop consuming water. This is expected since he tries to keep the most profitable crops and in a case of no alternatives, he preferred to keep a fallow area. The presence of a drought-resistant crop, the olive tree, has made it possible to maintain its gross margin and limit these losses.

Table 15 Adaptation strategies of agricultural systems according to production activities, the level of resilience and irrigation intensification

Farm Type	Level of diversification	Production system	Resilience indicators	Resilience level	Adaptation
SP	Specialized	Market gardening	↘↘ gross margin ≃ UAA ↗ amount of work	Not resilient	× crop irrigation ↘ diversification

SA	Specialized	Arboriculture	↘↘↘ gross margin ≃ UAA ≃ amount of work	Not resilient	↘ irrigation of less profitable crops No flexibility: cost of replacing perennial crops is high
SO	Diversified	Olive trees + market gardening + arboriculture	↘ gross margin ↘BASK ↘ amount of work	Little resilient	× irrigation of olive crops (profitable in the dry) ↘ surface area of crops consuming water ↘ diversification ≃ fully irrigated profitable cultivation

Discussions

The future of agricultural systems in the Mediterranean area is threatened by several external factors. The scarcity of water resources and the climate changes affecting this area are according to several authors the most threatening factors, especially in semi-arid regions. These authors predict a significant decrease in water availability caused by rising average temperatures and variability in precipitation in the future. These conditions will influence the productivity of agricultural systems in these areas and lead to uncertainty about the performance and future of existing farms. However, it is an area characterized by its diversification in terms of production systems distributed in a different way depending on the climatic context of the area.

In this context, the objective of our study is to develop a framework for assessing the resilience and the capacity to adapt to climate change of agricultural systems in the semi-arid region of Baalbeck El Hermel, taking into account the diversification of agricultural systems in this area.

To meet this objective, we have developed a methodology based on several main stages: the characterization of the diversity of agricultural systems in this territory by carrying out a quantitative typology according to precise variables, the design of a bioeconomic model and the simulation of a scenario identified for a single agro-climatic zone of Baalbeck El Hermel and the analysis of the resilience and adaptive capacity of these agricultural systems by comparing the indicators calculated by the bioeconomic model.

This work has brought out several results concerning the heterogeneity of the agricultural systems studied at the level of the governorate of Baalbeck El Hermel:

- According to the typology produced, the farms in the studied area present a diversity of agricultural production systems. The analysis of the diversity at the level of agro-climatic zones showed a low diversity of agricultural practices at the level of the North zone. Such a result is expected for an area receiving the least amount of precipitation and characterized by the highest average temperatures. We also found that despite the dominance of small agricultural areas, agricultural practices are diverse and several types of crops are present in Baalbeck El Hermel.
- According to the modeling carried out, the three types of farms have different adaptation strategies in the face of climate change which reflect different levels of resilience. These three farms do not have a strong capacity to adapt to climate change and they are either non-resilient or not very resilient. These results are in line with the perceptions of stakeholders on the low adaptive capacity and the vulnerability of farmers in the northern zone.

The "not very resilient" farm has the capacity to maintain a slight decrease in its gross margin even if the quantities of water available are very low. That is, even for years of drought, this farm has the capacity to keep a good income. Nevertheless, this type is forced to modify its structure (labor and UAA) to maintain the gross margin and consequently does not keep its initial situation stable. It is the most diversified type of farm in the northern area on the one hand and in the Baalbeck El Hermel area on the other. For this type of farm, the diversification of agricultural practices and the adaptation of crops resistant to drought (olive trees) obviously guaranteed for farmers a more remarkable income than for other farms. These results are similar to those of studies conducted with agricultural systems to prove the importance of diversification in the resilience of agriculture (Aspar, 2019; Lefeuvre, 2018; Souissi et al., 2017).

"Non-resilient" farms are farms unable to maintain their net gross margin under conditions of limited water resources. These are specialized farms producing either arboriculture or vegetable crops. In this group, the significant drop in gross margin is mainly due to the decrease in yields of arboriculture and market gardens unable to maintain their productivity in the absence of irrigation (water stress). These crops, despite their high profitability, are very risky crops and require high amounts of water. The farmer is forced to change his rotation (limit crops by choosing the most profitable in conditions of water stress) and limit his production because of dry techniques since for perennial crops it will be very expensive to replace them.

It is a question of proposing and developing support strategies for the farmer of the zone. Support can be in the form of policies offering premiums and subsidies on behalf of the government for the most vulnerable farmers especially that the crops present in the North are not subsidized crops (like tobacco and grains in Lebanon). So, this agricultural aid can help them invest in crops that are more resistant to drought.

At the same time, it is necessary to follow strategies to improve institutional procedures for water management and distribution (Khansa, 2017) and to limit water waste and illegal activities (BWE, 2014).

Conclusion

The objective of this study is to analyze the resilience and adaptive capacity of agricultural systems in the governorate of Baalbeck El Hermel, taking into account the diversity of production for this area. To meet this objective, a diversification of agricultural systems according to a quantitative typology followed by the construction of a bioeconomic simulation model has been adapted. This approach allowed us to create a decision support tool simulating crop choices.

First, we were able to identify five agricultural production systems distributed in the Baalbeck El Hermel area. We then characterized the diversification of agricultural practices according to the agro-climatic zone in which they are located. Finally, the simulation is carried out on three typical farms representative of a single agro-climatic zone that we have chosen and verified by the actors of the zone.

From this simulation we observed a low resilience of agricultural production systems in the North zone. The three typical farms have shown sensitivity to climate change, more particularly to the limit of water resources. The adaptation of a water pricing strategy has shown an improvement in water management in these farms but a decrease in their efficiency. In this regard, it seems essential to strengthen the resilience of agricultural systems in this area by adapting agricultural innovation strategies. These strategies may be accompanied over time by water and soil management policies. All these levers must be put in place by consulting the players in the area so that the work is closer to reality.

This study deserves to be deepened and the limitations concerning the crops cultivated in the area as well as the limitations of the data can be compensated by more detailed analyzes in the field. This modeling approach could be adapted in several Lebanese regions having the same context by insisting on the importance of the role of actors and policies in the supervision of agricultural work.

Part II

Title: Assessment by bioeconomic modeling of the resilience of agricultural production systems in a semi-arid region: Case of Baalbeck El Hermel – Lebanon (Water Price)

Abstract

Baalbeck El Hermel Governorate, particularly the semi-arid region is increasingly threatened by climate change. These disturbances, more specifically, concerning the limit in water resources generate problems for the agricultural systems constituting the principle source of families' subsistence in this zone. This study was established to evaluate, via a bioeconomic modeling approach, the resilience of agricultural systems in Baalbeck El Hermel and perceive their adaptation techniques under conditions of water scarcity. In this context, we have selected three typical farms representative of the driest northern zone receiving the least precipitation.

Several behaviors and levels of resilience of these farms were showed after analysis of the results: 1) farms specializing in market gardening or perennial crops are very sensitive to drought conditions and are not resilient in the face of water limit conditions; 2) the diversified farm with olive tree dominance is less sensitive and more resilient. The analysis of the water pricing scenario showed an improvement in water management but a limit in the adaptive capacity of farmers, hence the necessity to adapt resilience-building strategies for the targeted zone.

Keywords

Climate change, farming system, resilience, semi-arid zone, bioeconomic model, water availability, water pricing.

Introduction

Changes in climate have long challenged agricultural production and structure around the world (Menike and Arachchi, 2016). Many studies project that more than 25% of disaster costs are absorbed by agriculture in the case of climate crises, and nearly 80% of these costs in drought conditions (Crises and resilience in the Mediterranean, 2016). The Mediterranean basin is considered one of the areas that present major risks of climate and environmental change, especially its water resources. An estimated increase in temperatures of more than 2 °C by 2040 (Hoegh-Guldberg et al., 2019; Nasser et al., 2020) and a decrease in rainfall will reduce water availability and cause drought conditions and degradation of soil (Darwish et al., 2005).

Lebanon, located on the eastern coast of the Mediterranean, is no exception to the countries impacted by the disruption of the climate system. Its agricultural sector is characterized by rain-fed but above all irrigated crops, and generally the majority of crops require additional water supplies especially during the hot season (Verner et al., 2018). On the other hand, due to climatic hazards, water availability has decreased and the farmer in rural areas faces the challenge of water scarcity. Lack of planning (Nasser et al., 2020) and mismanagement of resources will exacerbate this problem. The farmer will therefore have to find the most effective means of adaptation to face these challenges.

To better understand the adaptive capacities of rural populations, it is necessary to understand the livelihoods of farmers (Menike and Arachchi, 2016) and the role of agriculture as a resilient livelihood for these populations.

Typically, resilience is “the ability of an individual or a system to absorb disturbances, reorganize while undergoing change and to adapt its operating methods” (Crises and resilience in the Mediterranean, 2016). In other words, it is the means adapted by a system so that it remains in a situation of equilibrium in the face of various challenges. In agriculture, “the ability of a production system to reorganize and maintain its function and structure, which are interconnected and span different spatial and temporal scales” can be conceptualized as resilience (Souissi et al., 2018). Thus, the analysis of resilience is equivalent to the analysis of 3 approaches at the level of agricultural systems: the structure of these systems at different scales (farm scale, regional and national), the disruptions that can occur and influence these systems and the resilient livelihoods that allow them to cope with disruptions and threats to maintain stability.

Agricultural production systems in a semi-arid zone are among the most vulnerable to climate change facing risks of drought and water scarcity. Farmers then must follow most effective means of adaptation to be able to overcome these risks. However, Lebanon suffers from a lack of appropriate resource management and adaptation policies, on the part of the government especially for fairly vulnerable areas. In addition, environmental and climatic disturbances force farmers to accept all risks and create their own strategy individually for the development of resilient agriculture. The aim of this study is to understand the performance of farmers currently in these areas in the face of limited water resources and agriculture with little or no government support, in order to predict what could be the behavior of this farmer in the event of decrease in water availability in the future.

Based on this concept, and based on decision-support tools, our main objective will be to assess through bioeconomic modelling the resilience to climate change of farmers in the semi-arid zone of Baalbeck El Hermel, in a context of limited water resources.

To meet our objectives, this work will be divided into two parts:

First, we will build a bioeconomic model adapted to this typology and perform simulations on the basis of several adaptation scenarios per type group based on certain numbers of socio-economic and environmental indicators.

Secondly, the analysis of the results will allow us to assess the resilience of typical farms according to a simplified resilience analysis framework.

Methodology

Resilience analysis

Choice of typical farms for modeling

Modeling is a complex tool and the choice of the typical farm depends in the first place on the objective of the research and the availability of the necessary information. In fact, the Baalbeck ELHermel region is divided into 3 agro-climatic levels and the typology that we have produced has enabled us to distinguish the agricultural systems characterizing each zone. Building bioeconomic models for all farm groups is difficult due to their complexity, the limit of available information (Souissi et al., 2018) and the time required for the work. Therefore, we have chosen a single agro-climatic zone for the modeling, the North zone, which is considered the most vulnerable to climate change (low rainfall). This zone is characterized by the presence of three types of farms, for this we have chosen, based on the surveys carried out , three typical farms each representative of a sub-group of the North zone. Moreover, the three agricultural systems targeted are generally characterized by small to medium-sized farms (the most common size in the North region), by a single dominant type of crop (either market gardening, arboriculture or olive trees) and are 100% irrigated farms .The analysis of the performance of these farms will allow us to characterize the diversity present in the northern zone and identify the farms with the greatest capacity to adapt in a semi-arid climate in the face of limited water conditions.

We carried out surveys of one hour of time by telephone with 3 typical farmers each representing a farm type, to collect the information needed for modeling. These questionnaires contain a part concerning the characteristics of the targeted farms and another part concerning their perspectives on climate change and the scenarios expected in the future concerning the limit of water resources and the impacts on their agricultural systems.

From the rotations of these typical farms, their socioeconomic characteristics and the irrigation alternatives that can be adapted (dry instead of irrigated), we were able to build our bioeconomic model. The scenarios are then adapted according to the perspectives of the farmers and the suggestions proposed by the experts to improve the water limit situation.

Choice of indicators

Indicators are specific, measurable and observable parameters used in characterizing the stability of agricultural systems in the face of external disturbances and providing information on states that are not directly measurable (Parsonson Ensor and Saunders, 2011). Several socio-economic, agronomic and environmental indicators that reflect the evolution of the capital of agricultural systems are calculated to analyze the resilience of a system (Souissi et al., 2018). The choice of indicators varies according to their level of relevance to the situation being dealt with and the availability of information on the ground. On the other hand, the choice of these resilience indicators according to Parsonson Ensor and Saunders (2011) is based on the analysis of the evolution of the three capitals:

- Human (linked to the permanent and seasonal family workforce contributing to agricultural work, to the level of skills of the workforce, the training of the workforce, etc.);
- Natural (linked to the three categories: natural resource , land and ecosystem);

- Economic (linked to profitability, liquidity and agricultural yield).

This step is essential since it makes it possible to study the stability of each of these capitals in the face of natural or human disturbances. In our study, we have chosen to analyze social, economic and environmental indicators in relation to these 3 capitals with regard to the data collected for typical farms and their possibility of modelling.

Bioeconomic modeling

After the development of a functional typology and the choice of typical farms, we are in the construction phase of a bioeconomic model.

Modeling is the development of an analysis and decision-making tool based on mathematical programming (technique for solving optimization problems under constraint) and on the concept of the possibility of production in a constraining environment. This tool helps us to understand the behavior of the studied system, the possibilities and the perspectives of evolution in the face of changes in its environment.

It is a static linear model produced with GAMS software (General Algebraic Modeling System). GAMS is a mathematical programming software widely used in economic modeling and aiming to facilitate the resolution of systems of equations in linear or nonlinear models.

In this work, the model built optimizes an objective function by choosing the most profitable crops (rotation) according to the constraints at the levels of land, water, labor and the previous crop. This model was adapted in the study by Khansa (2017).

The inputs to this model come from the results of surveys with farmers, expert opinions and the bibliography.

D. ***The objective function***

The objective function maximizes farm income. Its mathematical structure is formulated as follows:

$$Max\, Z = \sum (GM\,(C,T) \times X\,(C,T))$$

With:

Z = expected agricultural income

X (C, T) = agricultural area by crop and by technique (dry, irrigated)

GM (C, T) = gross margin per crop and per technique (dry, irrigated), calculated by subtracting the production costs from the yield per crop and per technique according to the following formula:

$$GM\ (C,T)\ = Price(C)\ *\ CY(C,T)\ -\ Pcost(C,T)\ -\ Cw(C,T)\ -\ Lr(C,T) * Lcost \\ -\ Dw(C,T) * Wprice$$

With:

Price (C) = price of agricultural products in LL per kg

CY (C, T) = crop yield per kg per dnm

Pcost (C, T) = operational production costs excluding irrigation by crop and by technique in LL per dnm

Cw (C, T) = technical loads of irrigation systems per crop and per technique in LL per dnm

Lr (C, T) = labor requirement per crop and per technique in hours per dnm

Lcost = labor cost in LL per hour

Dw (C, T) = dose of water supplied per crop per technique in m3 per dnm

W price = pricing of a cubic meter of water in LL

(Water price is zero for the base scenario).

E. ***Constraints :***

6- Earth constraint:

The sum of the areas used by the farmer is less than or equal to the agricultural area owned by the farmer.

$$\sum_{C,T} X(C,T) \leq UAA$$

With:

X (C, T) = agricultural area by crop and by technique (dry, irrigated)

UAA = agricultural area owned by the farmer

7- Water stress:

The total amounts of water consumed by crops must be less than or equal to the amount of water available per type of farm.

$$\sum_{C,T} Dw(C,T) \times X(C,T) \leq WA$$

With:

Dw (C, T): dose of water supplied per annual crop per technique in m3 per dnm

WA: water availability by type of operation. The quantity of water available per farm was estimated by farmers and verified by two experts in the region (agricultural advisor and agricultural engineer specializing in the installation of pumping systems for wells).

The quantities of water available per farm type are shown in the table 16 below.

Table 16 Quantity of water available per typical farm

Farm Type	Quantity of water available in m^3
PV_North	40,000
PA_North	10,000
PO_North	26,000

8- Labor constraint:

The sum of labor requirements per crop is less than or equal to the available family labor added to the seasonal labor required.

$$\sum_{C,T} Lr(C,T) * X(C,T) \leq LF + LD$$

With:

Lr (C, T) = labor requirement per crop in hours per dnm

LF = family labor available in hours per season

LD = seasonal labor recruited in hours per season (calculated by the model)

9- Constraint of perennial crops

The area of perennial crops is considered fixed in this model and cannot vary. The sum of area of perennial crops must be equal to the total area allocated for perennial crops.

$$\sum_{Cp} X(C,T) = Ac\ (Cp)$$

With:

X (Cp, T) = area per perennial crop in dnm

Ac (Cp) = total area of perennial crops in dnm

10- Crop rotation

Although this model is static, we took into account the crop rotation constraint. The rotation constraint takes into account the succession of two annual crops on the same plot. This constraint expresses that the area of a crop must not exceed the sum of the areas of these possible previous crops.

$$\sum_{pc} X(ca,T) \leq \sum_{pc} Apc(pc)$$

Apc (pc) = area of previous crop in dnm

Model validation

In order to validate the relevance of the model, we made a comparison between the results obtained by the model and the data collected from the surveys for each typical farm. The comparison of the performance of these typical farms was made by calculating the percentage of the absolute deviation (PAD) (Souissi et al., 2018) according to this formula:

$$PAD\% = \frac{|Xs - Xi|}{Xs} * 100$$

With Xs represents the simulated surface (prediction by the model) and Xi the surface observed in the surveys.

Scenario building

In this step we will establish scenarios that will be simulated by the model. Modeling scenarios are interesting tools for scientific research since they allow the analysis of complex information that brings together several disciplines and can transparently represent the effects of change in the future understood by all kinds of stakeholders (Börjeson et al., 2006).

In this study, we were able to develop and test scenarios in relation to climate problems based on the perspectives of the actors contacted in the North zone. All these actors are more and more aware of climate change and its possible impacts on agricultural systems. They perceive an increase in drought in the future due to 3 climatic factors: the rise in temperature, the shortening of the wet seasons (delay in the first autumn rains) and the variability of precipitation from year to year. Likewise, farmers and experts have noted a gradual decrease in the level of groundwater which is the main source of irrigation in this area (the extraction of groundwater is becoming more and more difficult as the boreholes are deeper). The overexploitation of the wells to meet the growing demand caused this drop in the piezometric level and the deepening of the boreholes.

Therefore, we have chosen to test one scenario in relation to a proposed adaptation strategy by experts regarding pricing on water consumed. The scenario is described below:

3- Base Scenario: The base scenario represents the initial situation of the system before the integration of the effects of climate change.

4- "Water price" scenario: for this scenario, the price of water per m^3 is not defined by the communities in the study area. Moreover, the irrigation costs are generally the pumping costs that we have taken into account in the model. According to experts in the area, it is better to establish a cost per cubic meter for water because of the uncontrolled consumption and overuse of groundwater. The aim of this scenario is to improve water management by farmers without losing much. So we did a sensitivity analysis by testing a price range between 200 and 3000 LL / m^3. The change in crop rotations for each typical farm was tested.

Identification of the resilience of typical farms

In order to analyze the impact of climate change on agricultural systems, it is necessary to identify the limits of the resilience of an agricultural system based on the different characteristics, its capacity to improve this resilience and the consequences of this change (Rivington et al., 2007). A resilience assessment framework will then answer three main questions (Meuwissen et al., 2019):

Resilience of what?

Farms are characterized by factors such as farm type, cropping system, water availability and quality of resources. The difference in these factors between farms implies a change in their performance and therefore in their resilience.

Resilience to what?

The vulnerability of a system increases according to the accumulation of these stresses and shocks causing in extreme cases, a passage beyond the critical threshold of operation and a decrease in the durability of the systems. So to assess the resilience of a system, it is necessary to identify whether it can return to its initial state following these disturbances and after how long.

Resilience for what purpose?

The main function of the agricultural system is the production of agricultural and environmental goods to meet these needs and market demand. It is characterized by a stock of 3 main capitals: human capital, natural capital, and financial capital. Indicators related to the 3 types of capital are necessary to identify the organizational structure of these systems and understand their capacity to overcome challenges.

From the results obtained by the scenarios and the comparison of the different resilience indicators calculated by the model, we will identify the level of resilience of each typical farm. A summary framework for the analysis of simplified resilience is described below (Figure 1) with the different components and levels of resilience based on the study by Souissi et al. (2018).

Results

Characteristics of the types of farms chosen for modeling

To carry out the modeling, a single agro-climatic zone was chosen, the North zone. This area is considered the most vulnerable to climate change because of its harshest semi-arid climate compared to the other two areas (high temperatures and very low precipitation).

From the three surveys carried out with typical farmers each representing a typical holding in the North region, we were able to collect the indicators necessary for modeling. Thus, we were able to verify the size of the farm, the rotation of crops, the area per crop, the previous crop, the need for labor, the availability of family labor and the quantity of water consumed by crop as well as water availability. The results showed that all of these farms irrigate the entire cultivated area and that each of these farmers has one or more underground boreholes from which they irrigate. Furthermore, we were able to identify how the characteristics of these agricultural systems vary if they follow an alternative dry irrigation technique (Table 17). According to the farmers surveyed and the experts, annual crops, in particular summer vegetable crops (Molokhia, tomatoes, etc.), cannot be grown dry in this area because of the high temperatures and the lack of precipitation during this season. Winter annual crops (chickpeas and beans, cabbage, etc.) and perennial crops can be grown dry in this zone but their yield per crop will drop to about half.

Table 17 Characteristics of the SO type farm in dry and irrigation

	Irrigated			Non-irrigated (dry)		
Culture	Vine	Olive	Molokhia	Vine	Olive	Molokhia
Area (dnm)	10	50	10	10	50	0
Previous crop area (dnm)	0			0		
Price (LL)	1,500	135,000	23,000	1,500	135,000	0
Yield (kg)	6,000	11 *	68	3,000	7	0
Production cost excluding irrigation (LL / dnm)	605,000	515,000	370,000	605,000	515,000	0

Irrigation cost (LL / dnm)	50,000	50,000	90,000	0	0	0
Quantity of water consumed (m3 / dnm)	400	300	400	0	0	0
Work requirement in hours / dnm	68	44	44	68	44	0
Total family labor availability (hour)	1140			1140		

* Olive yield is the number of gallons of oil per denom

Assessment of the bioeconomic model

Model validation results

The validation of the bioeconomic model was carried out by comparing the actual rotation with the data simulated by the model (carried out on GAMS) using the base model as a reference (without effect of climate change). Figure 44 illustrates the comparison of these two results for each farm type. This comparison showed that for each type of farm, the majority of crop areas do not exceed a relative error of more than 30% (Table 18).

The model reproduced the real (observed) situation for the different farming systems and for each crop reason, with the exception of the SP farm which has a relative error equal to 35.48% .For this type of farm, the suitable crops are market gardens which are very risky: their yields and prices vary a lot. The model does not take into account the decision of the farmer to spread the risk for these crops, by not taking into account the variation in yield due to climatic variations and pests as well as the variation of the market price. For the two other types, rotation is well simulated and the error is 0% (since these are dominant perennial crops with a constant surface area).

Table 18 Result of the validation of the bioeconomic model for the 3 types of farms in the North zone

Farm Type	Crop	Observed area	Simulated surface	PAD%
SA farm	Apricot	20	20	0

	Peach	10	10	0
SO farm	Vine	10	10	0
	Olive	50	50	0
	Molokhia	10	10	0
SP farm	Peas	15	0	-
	Cabbage	20	27	25.93
	Bean	60	93	35.48

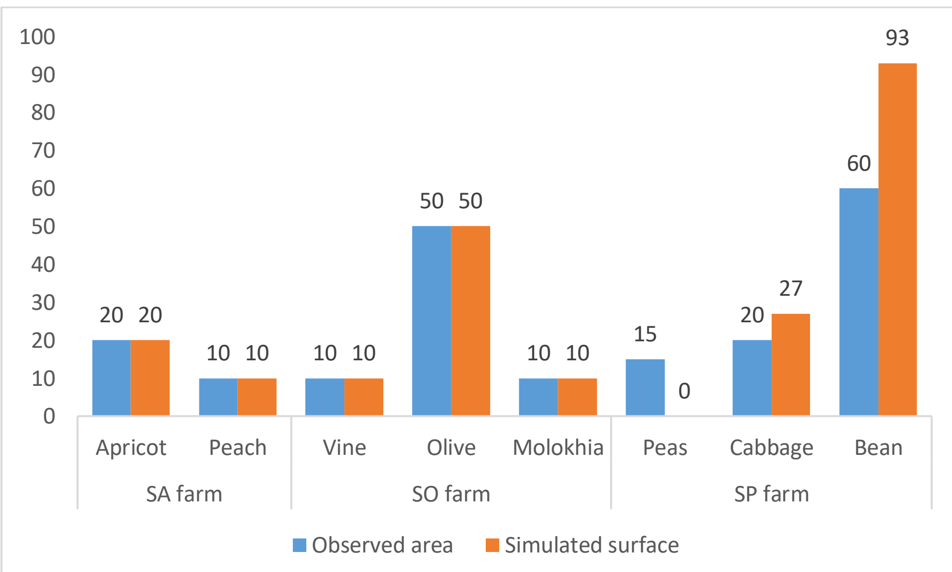


Figure 44 Comparison of the actual rotation and the simulated rotation for the three types of agricultural farms

Choice of indicators

The indicators chosen to be calculated by the model and to help in the assessment of the resilience of the agricultural systems studied in the face of climate change are socio-economic and environmental indicators representing the three types of capital (human, natural and economic).

For Economic capital:

- Annual gross margin which is among the most important indicators for farmers in semi-arid zones (ensuring sufficient family income) and its stability depends on the adaptive capacity of farms
- Vegetable rotation to assess the cropping systems most suited to climate change.

For Natural Capital:

- The total cultivated area which varies according to the disturbances and its capacity to return to its initial state indicates its degree of resilience.
- The amount of water used for irrigation which is a limiting factor in semi-arid areas and its availability is necessary for irrigation.
- Total irrigated area and dry and irrigated crop area in relation to water availability.

For Human capital:

- The amount of work which may be affected by natural disturbances due to its direct relationship to suitable crop types and farming systems.
-

Scenario analysis

The targeted scenarios were simulated by the bioeconomic model at the farm scale in order to assess the performance and adaptability of agricultural systems in the North of Baalbeck El Hermel by calculating a set of indicators (previous part).

C. Reference scenario S0

This scenario represents the simulation of typical farms without the introduction of the variability of water availability. This is the (basic) control scenario to which we will compare the variation in behavior for each farm type according to the different indicators calculated by the model.

D. "Water price" scenario

A second scenario is tested with several pricing prices of water for irrigation: 200, 300, 400, 600, 800, 1000, 1500, 2000, 2700 and 3000 Lebanese pounds per m3.

The objective of this scenario is to analyze for each farm type the behavior and the sensitivity of the farmers in the event of the introduction of a tariff on water consumption. This will allow us to understand how farmers will be able to improve their water management if this resource will be priced and what will be the most suitable price that decision-makers can adopt for water without the farmers losing much.

<u>For SP farm type:</u>

The introduction of a water tariff has shown a variation in behavior for this type of farm. Three behaviors are observed for this type .

1. For a tariff of between 200 and 400 LL / m3, the average water consumption is total and the entire cultivated agricultural surface is irrigated. The farmer keeps the same rotation and the same irrigation techniques.

2. With the increase in the price of water, up to 1500 LL / m3, we notice a decrease in water consumption but keeping the entire area irrigated. The farmer in this case chose to keep a single crop on his farm (the bean) at 100% irrigated.

3. For prices above 1,500 LL / m3, the farmer transforms the entire cultivated agricultural area into dry land and water consumption is canceled out. He then just grows dry beans, the most profitable crop for this farm, on the entire farm area.

Therefore, the gross margin of this operation decreases with the increase in the price of water. We note that with prices between 200 and 400 LL / m3, the gross margin decreases slightly from 95.3million Lebanese pounds to 79.5million (16%). With the increase in the price of water, the gross margin falls especially when the price exceeds 1000 LL / m3 to reach 25.1 million Lebanese pounds for a water price of 3000 LL / m3 and the farmer loses more than 70% of the initial gross margin (Figure 45).

This drop can be explained by the transition to a monoculture on the one hand, then the adaptation of a less profitable non-irrigated crop on the other hand.

For labor consumption, we notice its increase from a total of 3920 working hours to 4320 working hours when the cost of water increases by more than 400 LL / m3, that is to say when the farmer shifts from two crops to one crop. This means that growing beans consumes more labor than other crops.

Consequently, a water tariff of between 600 and 1000 LL / m3 forces the farmer to reduce his water consumption without his income decreasing remarkably but affects the efficiency of his rotation (switch to monoculture).

Table 19 Variation of the quantity of water consumed, of the irrigated area and of the quantity of work according to the different water prices for SP type operation

Water price	0	200	300	400	600	800	1000	1500	2000	2700	3000
Water consumed	40,000	40,000	40,000	40,000	36000	36000	36000	36000	0	0	0
% irrigated area	100	100	100	100	100	100	100	100	0	0	0
Job	3920	3920	3920	3920	4320	4320	4320	4320	4320	4320	4320

Table 20 Variation of crop rotations for different water prices

Culture	Technical	0	200	300	400	600	800	1000	1500	2000	2700	3000
Cabbage	Irrigated	26.7	26.7	26.7	26.7							
Bean	Dry									120	120	120
Bean	Irrigated	93.3	93.3	93.3	93.3	120	120	120	120			

For type SA operation:

The analysis of the results for this type showed that it is less sensitive to the variability of the price of water than the previous farm. The farmer on this farm keeps all the crops irrigated for all water prices. The water is completely consumed and the workforce remains constant. What is affected is the gross margin which shows a gradual and significant decrease in its value because of the high revenue for water especially for the highest water prices. This margin decreases from 67.4 million Lebanese pounds to 37.4 million Lebanese pounds for respective water prices of 0 LL / m3 and 3000 LL / m3 (decrease of 55% of its initial value).

This behavior proves that perennial crops are much more profitable if they are irrigated and the farmer prefers to cultivate them in irrigated even if the water receipt is high. The pricing of water for this type of operation is not effective in improving the management of this resource.

Table 21 Variation in the quantity of water consumed, the irrigated surface and the quantity of work according to the different water prices for the SA type farm

Water price	0	200	300	400	600	800	1000	1500	2000	2700	3000
Water consumed	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
% Irrigated area	100	100	100	100	100	100	100	100	100	100	100
Job	4880	4880	4880	4880	4880	4880	4880	4880	4880	4880	4880

Table 22 Variation in crop rotations according to different water prices

SA	Technical	0	200	300	400	600	800	1000	1500	2000	2700	3000
Apricot	Irrigated	20	20	20	20	20	20	20	20	20	20	20
Peach	Irrigated	10	10	10	10	10	10	10	10	10	10	10

<u>For type SO operation:</u>

The introduction of a water tariff for this type has shown several behaviors:

4. For a water price of between 200 and 1500 LL / m3, the results show a consumption of the total quantity of water and an irrigation of the total agricultural area. The farmer keeps the same rotation of crops.

5. When the price increases from 1500 LL / m3 to 2000 LL / m3, the irrigated agricultural area decreases by more than 70% and the water consumption decreases remarkably to 8000 m3. The farmer has stopped irrigating the entire surface of the olive tree while keeping the other two crops irrigated.

6. For a price above 2000 LL / m3, just 16.7% of the total area remains irrigated and water consumption decreases to 4000 m3. The farmer reduces the cultivated agricultural area to 60 dnm by keeping just two crops: dry olives and irrigated vines.

These behaviors prove that the vine culture is the most profitable in irrigation, the olive is the most profitable in dry, and that the farmer chooses to reduce his cultivated area if the water price is high by eliminating the less profitable crops.

Regarding labor consumption, the latter remains almost constant with a slight decrease of 440 hours of work per year when the price of water exceeds 2000 LL / m3. This is expected since the farmer decreases the cultivated agricultural area influencing the consumption of labor.

The gross margin is also affected by the variation in the price of water and the results show a gradual decrease in its value with the increase in the price of water. For prices between 200 and 1000 LL / m3, the results show a slight decrease in gross margin of 18% of its value. The more the price of water increases, the more the gross margin decreases to reach 85.75 million Lebanese pounds for a water price of 3000 LL / m3 (decrease of 35% of the gross margin). This decrease in gross margin for this farm type is smaller than for the other types which showed a large loss when the price of water increases. This can be explained by the types of crops chosen for this farm (olive trees), the diversity of crops, and the capacity of the farmer to have several choices to modify his performance (crop diversification).

Table 23 Variation in the quantity of water consumed, the irrigated surface and the quantity of work according to the different water prices for the SO type farm

Water price	0	200	300	400	600	800	1000	1500	2000	2700	3000
Water consumed	23000	23000	23000	23000	23000	23000	23000	23000	8000	4000	4000
% Irrigated area	100	100	100	100	100	100	100	100	28.6	16.7	16.7
Job	3320	3320	3320	3320	3320	3320	3320	3320	3320	2880	2880

Table 24 Variation in crop rotations according to different water prices

SO	Technical	0	200	300	400	600	800	1000	1500	2000	2700	3000
Vine	Irrigated	10	10	10	10	10	10	10	10	10	10	10
Olive	Dry									50	50	50
Olive	Irrigated	50	50	50	50	50	50	50	50			
Molokhia	Irrigated	10	10	10	10	10	10	10	10	10		

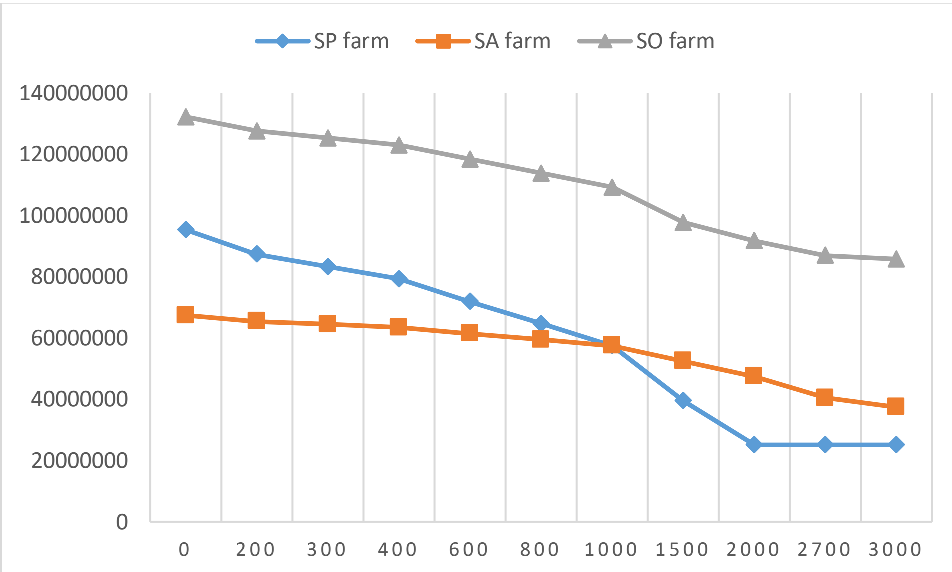


Figure 45 Variation of the gross margin according to the different water prices for the three types of farms

Resilience assessment of typical farms

To understand the behavior of each type of farms and these adaptation strategies when faced with the risk of water resource limits, we compared the three resilience indicators for each farm between two situations: base scenario and water price scenario. This allowed us to identify the level of resilience of these farms if conditions of water scarcity will occur.

The analysis of the results obtained in the previous section allowed us to identify two levels of resilience in this study area:

<u>Non-resilient farms:</u> these are the two SP and SA type farms. These farms have shown a high sensitivity to climate change explained by a very significant reduction in the gross margin to 45% and 58% respectively of its initial value. These are farms that adapt mainly irrigated crops and the water factor is a crucial factor in their agricultural work. Therefore, the limit in water resources has shown a very large impact on crop yield even if the amount of labor increases or the agricultural area increases. To adapt, these farmers have tried to just keep profitable crops on their farms and modify irrigation techniques according to the quantities of water available. The problem for these

farms is the limit of cultivation on the farm and almost the absence of crop rotation and diversification. The choice of the farmer then focuses on a single type of crop. For example, it is expensive for arborists to replace perennial crops with other crops, hence their low flexibility to climate change. It is relevant for these farmers to introduce more diversified crops that consume less water (varieties resistant to drought conditions such as olive trees, pomegranates, etc.).

<u>Little resilient farms: </u>this is the SO type farm adapting diversified crops dominated by olive trees. This operation is less sensitive to the variation in the quantity of water available in terms of gross margin since it shows a slight decrease in the latter (decrease of up to 25% of its initial value). It is considered “not very resilient” in terms of gross margin but “not resilient” in terms of cultivated agricultural area. In fact, the farmer has reduced his UAA to limit these losses by eliminating the crop consuming water. This is expected since he tries to keep the most profitable crops and in a case of no alternatives, he preferred to keep a fallow area. The presence of a drought-resistant crop, the olive tree, has made it possible to maintain its gross margin and limit these losses.

Table 25 Adaptation strategies of agricultural systems according to production activities, the level of resilience and irrigation intensification

Farm Type	Level of diversification	Production system	Resilience indicators	Resilience level	Adaptation
SP	Specialized	Market gardening	↘↘ gross margin ≃ UAA ↗ amount of work	Not resilient	× crop irrigation ↘ diversification
SA	Specialized	Arboriculture	↘↘↘ gross margin ≃ UAA ≃ amount of work	Not resilient	↘ irrigation of less profitable crops No flexibility: cost of replacing perennial crops is high

SO	Diversified	Olive trees + market gardening + arboriculture	↘ gross margin ↘BASK ↘ amount of work	Little resilient	× irrigation of olive crops (profitable in the dry) ↘ surface area of crops consuming water ↘ diversification ≃ fully irrigated profitable cultivation

Discussions

The future of agricultural systems in the Mediterranean area is threatened by several external factors. The scarcity of water resources and the climate changes affecting this area are, according to several authors, the most threatening factors, especially in semi-arid regions. These authors predict a significant decrease in water availability caused by rising average temperatures and variability in precipitation in the future. These conditions will influence the productivity of agricultural systems in these areas and lead to uncertainty about the performance and future of existing farms. However, it is an area characterized by its diversification in terms of production systems distributed in a different way depending on the climatic context of the area.

In this context, the objective of our study is to develop a framework for assessing the resilience and the capacity to adapt to climate change of agricultural systems in the semi-arid region of Baalbeck El Hermel, taking into account the diversification of agricultural systems in this area.

To meet this objective, we have developed a methodology based on several main stages: the characterization of the diversity of agricultural systems in this territory by carrying out a quantitative typology according to precise variables, the design of a bioeconomic model and the simulation of a scenario identified for a single agro-climatic zone of Baalbeck El Hermel and the analysis of the resilience and adaptive capacity of these agricultural systems by comparing the indicators calculated by the bioeconomic model.

This work has brought out several results concerning the heterogeneity of the agricultural systems studied at the level of the governorate of Baalbeck El Hermel:

- According to the typology produced, the farms in the studied area present a diversity of agricultural production systems. The analysis of the diversity at the level of agro-climatic zones showed a low diversity of agricultural practices at the level of the North zone. Such a result is expected for an

- area receiving the least amount of precipitation and characterized by the highest average temperatures. We also found that despite the dominance of small agricultural areas, agricultural practices are diverse and several types of crops are present in Baalbeck El Hermel.

- According to the modeling carried out, the three types of farms have different adaptation strategies in the face of climate change which reflect different levels of resilience. These three farms do not have a strong capacity to adapt to climate change and they are either non-resilient or not very resilient. These results are in line with the perceptions of stakeholders on the low adaptive capacity and the vulnerability of farmers in the northern zone.

The "not very resilient" farm has the capacity to maintain a slight decrease in its gross margin even if the quantities of water available are very low. That is, even for years of drought, this farm has the capacity to keep a good income. Nevertheless, this type is forced to modify its structure (labor and UAA) to maintain the gross margin and consequently does not keep its initial situation stable. It is the most diversified type of farm in the northern area on the one hand and in the Baalbeck El Hermel area on the other. For this type of farm, the diversification of agricultural practices and the adaptation of crops resistant to drought (olive trees) obviously guaranteed for farmers a more remarkable income than for other farms. These results are similar to those of studies conducted with agricultural systems to prove the importance of diversification in the resilience of agriculture (Aspar, 2019; Lefeuvre, 2018; Souissi et al., 2017).

"Non-resilient" farms are farms unable to maintain their net gross margin under conditions of limited water resources. These are specialized farms producing either arboriculture or vegetable crops. In this group, the significant drop in gross margin is mainly due to the decrease in yields of arboriculture and market gardens unable to maintain their productivity in the absence of irrigation (water stress). These crops, despite their high profitability, are very risky crops and require high amounts of water. The farmer is forced to change his rotation (limit crops by choosing the most profitable in conditions of water stress) and limit his production because of dry techniques since for perennial crops it will be very expensive to replace them.

- In the context of long-term water resource reduction, we have chosen to test an adaptation strategy based on a water pricing policy. This strategy is developed as a scenario of popularization and control over the management of water resources which will be limited in the future due to climate change and overexploitation of the latter.

The simulation results for this strategy are in line with our expectations, but not for all types of farms. We assumed that the introduction of a cost on the quantity of water consumed would push farmers to reduce their water consumption by switching to dry techniques. This behavior was observed for the two SP and SO type farms where the farmer chose to reduce the irrigated area and the quantity of water consumed when the price of water generally exceeds 1000 LL / m3 because the water revenue highly affects its income in terms of net gross margin. However, for the SA farm, we found that the farmer preferred to keep his perennial crops fully irrigated even if the cost of water rises. This behavior can be explained by the role of irrigation in keeping the yield of perennial crops stable and maintaining the profitability of the farm.

The implementation of this strategy has shown that water pricing is important to improve water management in the northern region for certain types of agricultural systems (decrease in water consumption). However, it may affect resilience and the efficiency of farms, especially since they are already vulnerable because of the limited choices and the low capacity to adapt in terms of changes in cropping systems. These findings parallel the work of El Khansa (2017) concerning the sensitivity of farmers in the Bekaa region. Therefore, the farmer in this area is faced with two choices: either accepting the losses and continues to produce with a minimum income; or abandon crops that consume water in favor of crops that are more resistant to heat or are less intensive in water consumption and therefore limit the cultivated area.

It is a question of proposing and developing support strategies for the farmer of the zone. Support can be in the form of policies offering premiums and subsidies on behalf of the government for the most vulnerable farmers especially that the crops present in the North are not subsidized crops (like tobacco and grains in Lebanon). So, this agricultural aid can help them invest in crops that are more resistant to drought.

At the same time, it is necessary to follow strategies to improve institutional procedures for water management and distribution (Khansa, 2017) and to limit water waste and illegal activities (BWE, 2014).

Conclusion

The main goal of this study is to analyze the resilience and adaptive capability of agricultural systems in the governorate of Baalbeck El Hermel, taking into account the diversity of production for this area. To meet this objective, a diversification of agricultural systems according to a quantitative typology followed by the development of a bioeconomic simulation model has been adapted. This approach allowed us to create a decision support tool simulating crop choices.

First, we were able to identify five agricultural production systems distributed in the study area. We then characterized the diversification of agricultural practices according to the agro-climatic zone in which they are located. Finally, the simulation is carried out on three typical farms representative of a single agro-climatic zone that we have chosen and verified by the actors of the zone.

From this simulation we observed a low resilience of agricultural production systems in the North zone. The three typical farms have shown sensitivity to climate change, more particularly to the limit of water resources. The adaptation of a water pricing strategy has shown an improvement in water management in these farms but a decrease in their efficiency. In this regard, it seems essential to strengthen the resilience of agricultural systems in this area by adapting agricultural innovation strategies. These strategies may be accompanied over time by water and soil management policies. All these must be put in place by consulting stakeholders in the area so that the work is closer to reality.

This study deserves to be deepened and the limitations concerning the crops cultivated in the area as well as the limitations of the data can be compensated by more detailed analyzes in the field.

This modeling approach could be adapted in several Lebanese regions having the same context by insisting on the importance of the role of actors and policies in the supervision of agricultural work.

General Conclusion

This chapter will conclude the study by summarising the key research findings concerning the research aims and questions and discussing the value and contribution thereof. It will also review the limitations of the study and propose opportunities for future research.

This study aimed to assess the resilience of agricultural systems in the semi-arid region of Baalbeck El Hermel, and to investigate the adaptation strategies of farmers to limit the impacts of climate change. Based on a quantitative typology of multivariate statistical analysis, it can be concluded that there are three distinct types of typical farms in the agro-climatic zone chosen for study, the North Zone: SP, SA, and SO farm type. By simulating scenarios and analyzing the performance of agricultural systems after designing a bioeconomic model, the research has shown that the behavior of farming systems in response to each scenario depends on the characteristics of the holding and the types of crops. After the introduction of the "decrease in water availability" scenario, the irrigated area of the total cultivated agricultural area of the three farms decreased. Further findings show that SA is less sensitive to the variability of the price of irrigation water than the SP, while in SO farm type, the farmer chooses to reduce his cultivated area if the water price is high by eliminating the less profitable crops.

Furthermore, the analysis of these behaviours concluded to identify two levels of resilience in the study area. The first is the "non-resilient" farms (SP and SA) that have shown a high sensitivity to climate change explained by a very significant reduction in the gross margin. To adapt, these farmers have tried to just keep profitable crops on their farms and modify irrigation techniques according to the quantities of water available. The problem for these farms is the limit of cultivation on the farm and almost the absence of crop rotation and diversification. The second level of resilience is "little resilient" farms (SO) and is less sensitive to the variation in the quantity of water available in terms of gross margin since it shows a slight decrease in the latter. Nevertheless, this type is forced to modify its structure (labor and UAA) to maintain the gross margin and consequently does not keep its initial situation stable.

The major constraint in this work was the lack of sufficient data, and farmers keep no records of their agricultural work. Furthermore, water consumption per farm was mostly based on estimates from farmers and not measured by the water establishments. Moreover, the choice of farms for modeling was limited to a single agro-climatic zone. That can be explained by the lack of necessary information gathered by the surveys and the difficulty of carrying out new surveys after the outbreak of the coronavirus.

Nevertheless, despite the challenges and limitations, this study offers a decision-support tool for analyzing farmers' choices and their resilience in a semi-arid zone. In addition, Lebanon suffers from a lack of effective policies for the management of water resources, especially for fairly vulnerable areas, and a lack of planning for the development of resilient agriculture in the face of the various risks that threaten it. Thus, the importance of this study is because it proposes a method allowing farmers to test their choices and their adaptation strategies under conditions of limited water before applying them in the future.

To better understand the implications of the research results, future studies could address the improvement of the bioeconomic model by the combination of a biophysical model simulating the variability of crop yields and taking into account the risk on the market especially since the marketing channels for agricultural products are limited in the region of Baalbeck El Hermel and price variability is important. In addition, the analysis should not be limited to the scale of the farm but rather analyze the resilience and adaptation capacities at the regional level by taking into account the capacity for the exchange of land and labor between farms at the regional level. Further research is needed to improve the resilience analysis framework by dealing with more indicators in relation not only to the farmer's income but also to the other environmental and social resilience indicators.

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