Technium Sustainability

Technium Sustainability
Vol. 5, pp 29-60 (2024)
ISSN: 2810-2991
www.techniumscience.com

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

Ahmad Al Fakih - University of Sassari , Italy

Salem Darwish - Lebanese University, Lebanon

Fabio Madau - University of Sassari, Italy

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 .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”. 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 three parts:

First, from the surveys carried out in this area, we will produce a quantitative typology of agricultural farms based on several classification criteria and different approaches to resilience (production, structural elements and the vulnerability of systems to disturbances).

Secondly, 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.

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

Methodology

I - Typology

1. Sample and surveys

This work is based on a sample of 119 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 various topics which are:

- Information about 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 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.

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 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.

Depending on the number of farms, wheat cultivation dominates in this region, followed by tobacco, olive trees and potatoes.

2. Typology of agricultural systems

Typology of agricultural systems is a method of analyzing the diversity and complexity of those 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 ,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.

3. **Choice of variables**

Our first step was to choose the key variables for the multivariate analysis. Based on the criteria developed by Norman (1995) namely "Farm production intensification level", we chose seven variables grouped into three as follows:

a. Criteria explaining the resource allocation

Resource endowment can include a wide range of resources and assets, but just two variables were chosen for this study of most importance. These are the cultivated agricultural area (in ha) per holding (in relation to the environmental potential) and the gross margin of the farmer (in relation to the availability of financial resources and the farmers' purchasing capacity). These two variables are chosen since they influence the most on the performance and decision-making of farmers, especially in an arid zone.

b. Criteria explaining the production goal

These factors include the type of production system (plant or animal) and the choice of crop (between crops, choice of cereals and / or vegetable crops, etc.). In addition, it reflects the orientation of the farmer whether to ensure these subsistence needs or for the market in order to increase his income in terms of essential money. The variable retained is then the share of each type of crop in the yield (in %).

c. Criteria explaining the intensification of production

The two preceding structural criteria can have a significant impact on the decision of households in the choice of sustainable (labor) and non-sustainable (pesticides, seeds, etc.…) production factors (Chenoune et al., 2016).

The chosen variables are shown in Table 1.

Then, to perform this typology, two multivariate statistical techniques were chosen, in particular the Principal Component Analysis (PCA) and the Hierarchical Ascending Classification (HAC).

The first step makes it possible to transform in a linear way the set of initial variables into a smaller set of uncorrelated variables which represent most of the information of the initial variables (Bidogeza et al., 2009).

Criteria		Variables	Source
Criteria explaining the resource allocation	Environmental potential	Cultivated area (dnm)	Survey data
	Availability of financial resources	Gross margin (LL / dnm)	Calculated from farm level survey data
Criteria explaining the production goal	Production goal (Contribution of each crop to yield)	Cereal production in%	Calculated as a percentage of contribution of each type of crop on total yield
		Market garden production in%	
		Arboriculture production in%	
		Olive tree production in%	
Criteria explaining the intensification of production	Factors of production intensification	Production cost (LL / dnm)	Survey data
		Cost of water (LL / dnm)	Calculated from crop and farm level surveys
		Labor cost (LL / dnm)	Survey data
		Water consumed (m3 / dnm)	Calculated from crop and farm level surveys

Table 1: Criteria and variables chosen for the distinction of typical farms.

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).

II. Resilience analysis

1. 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,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.

2. 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.

3. 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.

A. *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).

B. *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 2 below.

Farm Type	Quantity of water available in m^3
PV_North	40,000
PA_North	10,000
PO_North	26000

Table 2: Quantity of water available per typical farm

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

4. 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.

III. 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:

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

2- “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.

IV. 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).

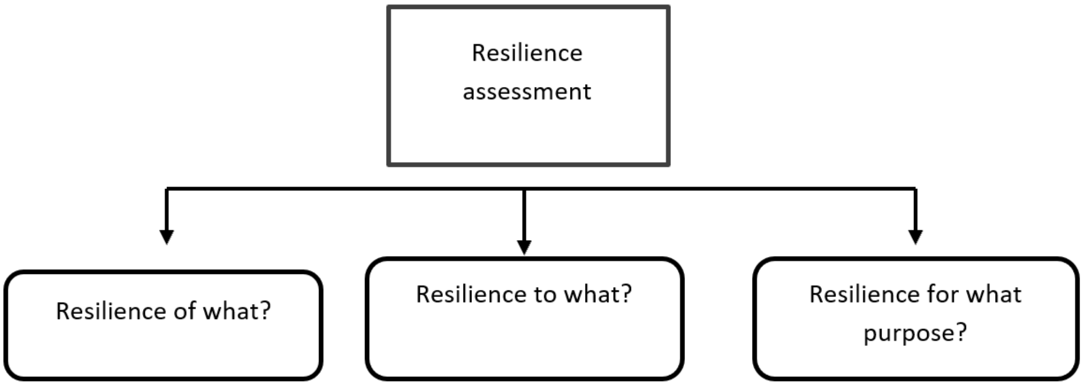

Figure 1: Summary framework of the resilience analysis in the northern Baalbeck El Hermel area

Results

I. Structure of agricultural holdings

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 2). 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.

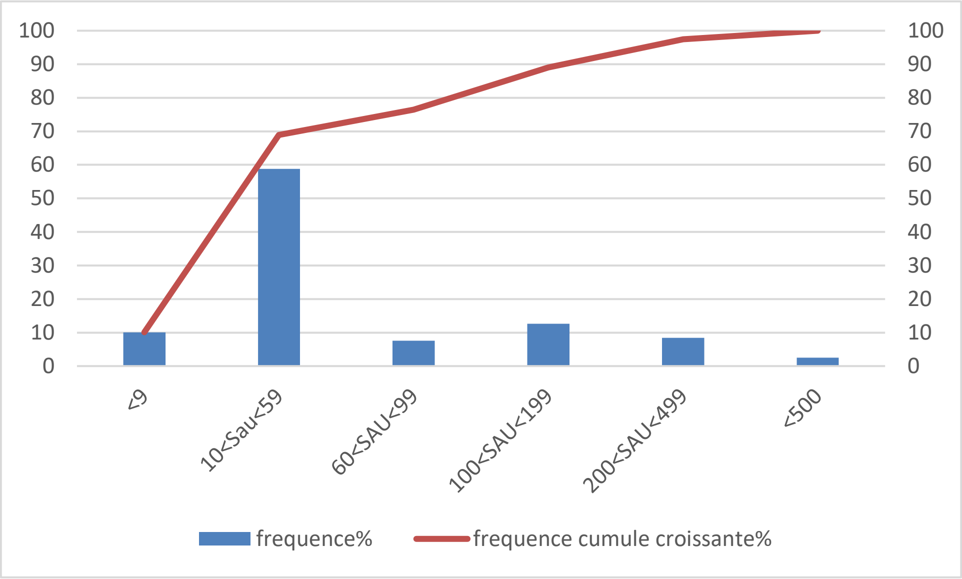

Figure 2: The frequency of farms by UAA

1. 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. Axis 2 (17.74%) is associated with the agricultural area used, the agricultural income per holding and the gross margin (Figure 3).

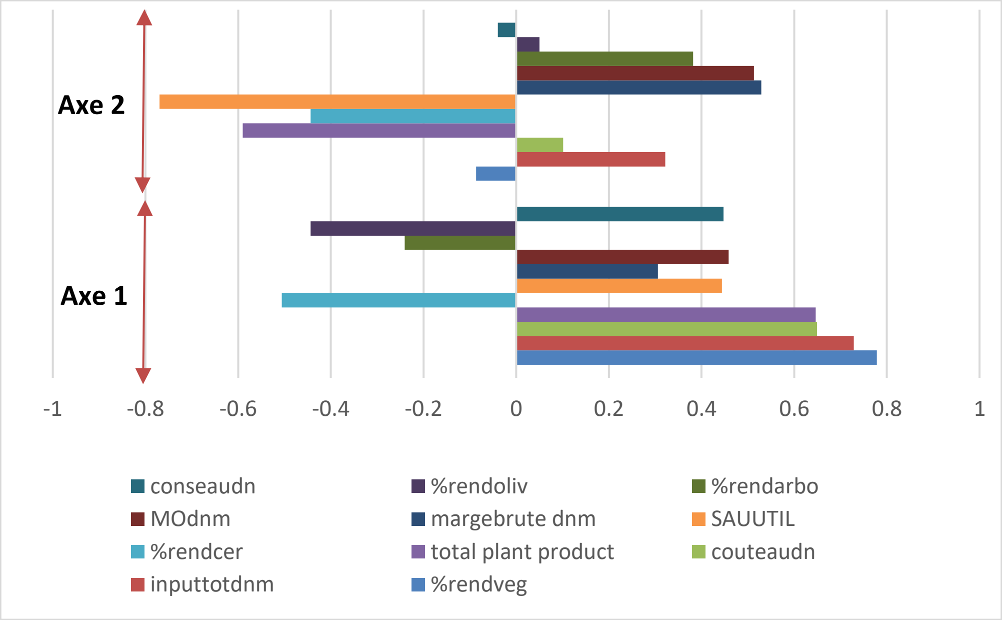

Figure 1: The two correlation axes linked to the tested variables (correlation scatter plot)

2. 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 on 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.

B. 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.

C. Small farms with arboriculture dominance (SA):

This group represents 14.3% of the sample and are 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.

D. 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.

E. 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 3 below represents the average characteristics of the five groups of typical farms according to the variables chosen.

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)	648000	1,270,000	803000	734000	354000
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)	661000	729000	371000	236000	160,000
	Labor cost (LL / dnm)	208000	408000	212000	110,000	100,000
	Water cost (LL / dnm)	99000	83000	70,000	27000	25000

Table 3: Average structural characteristics of the 5 types of farms

3. 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 absence of 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 4 below.

	Type	NB	UAA	Cereals UAA	Vegetable UAA	Olives UAA	Arboriculture UAA	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 4: Average structural characteristics of sub-groups distributed by agro-climatic zone

4. 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 5). 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.

	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)	1500	135000	23000	1500	135000	0
Yield (kg)	6000	11 *	68	3000	7	0
Production cost excluding irrigation (LL / dnm)	605000	515000	370,000	605000	515000	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

Table 5: Characteristics of the SO type farm in dry and irrigation

II. Assessment of the bioeconomic model

1. 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 4 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 6).

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 6 and Figure 4). 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).

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

Table 6: Result of the validation of the bioeconomic model for the 3 types of farms in the North zone

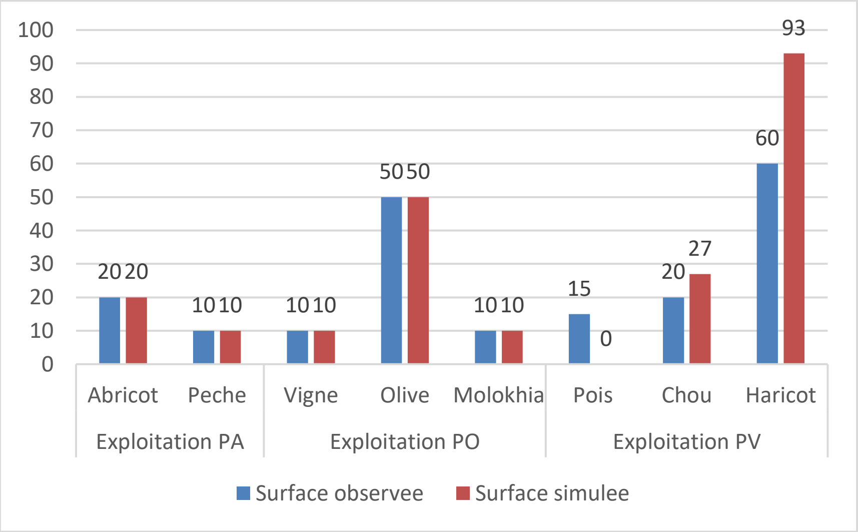

Figure 4: Comparison of the actual rotation and the simulated rotation for the three types of agricultural farms

2. 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.
-

III. 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 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.

For SP farm type:

The introduction of a water tariff has shown a variation in behavior for this type of farm. Three behaviors are observed for this type (Tables 7 and 8):

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 5).

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).

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 7: 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

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			

Table 8: Variation of crop rotations for different water prices

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

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.

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 9: 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

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

Table 10: Variation in crop rotations according to different water prices

For type SO operation:

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).

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 11: 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

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		

Table 12: Variation in crop rotations according to different water prices

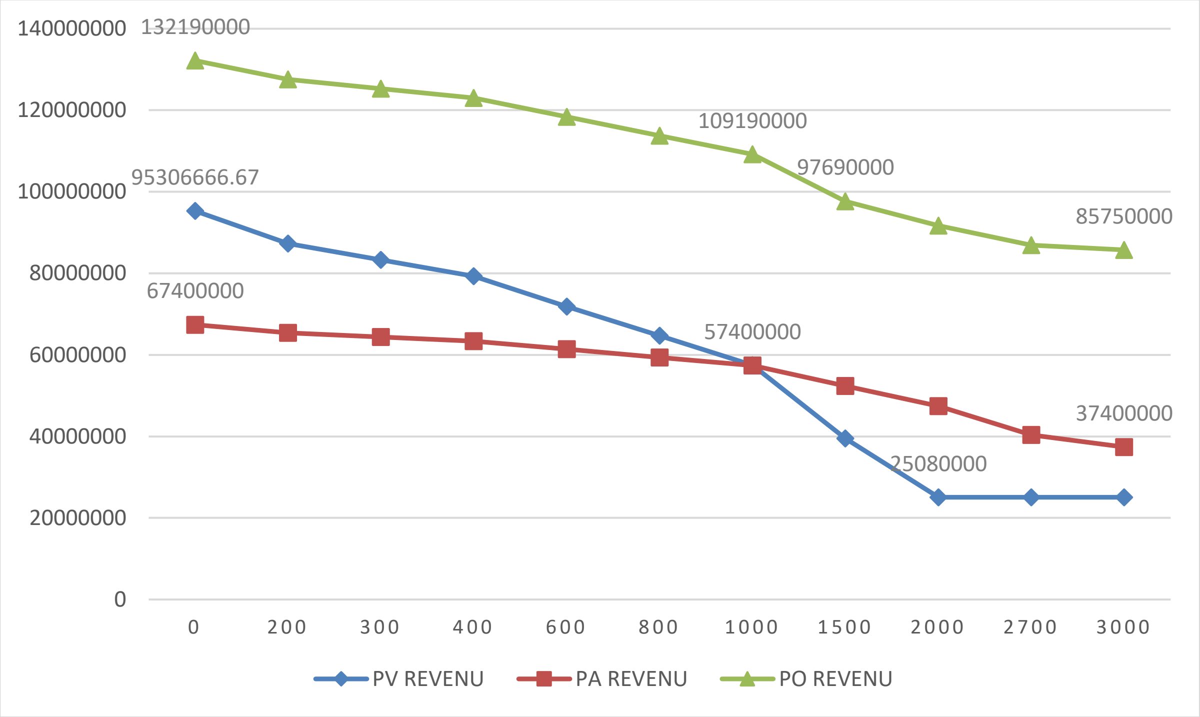

Figure 5: Variation of the gross margin according to the different water prices for the three types of farms

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:

Non-resilient farms: 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.

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

Table 13: Adaptation strategies of agricultural systems according to production activities, the level of resilience and irrigation intensification

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 .

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.

References

[1] Börjeson L., Höjer M., Dreborg K.-H., Ekvall T., Finnveden G. (2006). Scenario types and techniques: Towards a user's guide. *Futures*, vol. 38, n. 7. p. 723–739.

[2] Chenoune R. (2014). What levers to promote the production and consumption of rice in Sierra Leone? Fro characterization to simulation of the performance of rice-growing households. Doctoral thesis in Operation and Management of Tropical and Mediterranean Cropping Systems: Montpellier SupAgro, France. 169 p. SIBAGHE doctoral school / UMR SYSTEM / LAMES du CIHEAM-IAMM

[3] Chenoune, R., Belhouchette, H., y Paloma, S. G., & Capillon, A. (2016). Assessing the diversity of smallholder rice farms production strategies in Sierra Leone. *NJAS-Wageningen Journal of Life Sciences*, vol. 76, p. 7-19.

[4] Darwish T., Atallah T., El Moujabber M., Khatib N. (2005). Salinity evolution and crop response to secondary soil salinity in two agro-climatic zones in Lebanon. *Agricultural Water Management*, vol. 78, n. 1–2, p. 152–164.

[5] Hoegh-Guldberg O., Jacob D., Taylor M., Guillén Bolaños T., Bindi M., Brown S., Camilloni I.A., Diedhiou A., Djalante R., Ebi K., Engelbrecht F., Guiot J., Hijioka Y., Mehrotra S., Hope C.W., Payne A.J., Pörtner H.-O., Seneviratne S.I., Thomas A., Warren R., Zhou G. (2019). The human imperative of stabilizing global climate change at 1.5°C. *Science*, vol. 365, n. 6459, p. eaaw6974

[6] El Khansa M. (2017). *Finding pathways for enhancing irrigated farming systems in Lebanon.* Thèse (Dr d'Université en Sciences de l'Eau) : Université Montpellier (France). 165 p. École doctorale ED 584 : GAIA - Biodiversité, Agriculture, Alimentation, Environnement, Terre, Eau. UR HSM-Hydrosciences Montpellier. Plateforme doctorale du CIHEAM-IAMM

[7] Landais E. (1998). Modelling farm diversity: new approaches to typology building in France. *Agricultural Systems*, vol. 58, n. 4, p. 505–527.

[8] Menike L.M.C.S., Arachchi K.A.G.P.K. (2016). Adaptation to Climate Change by Smallholder Farmers in Rural Communities: Evidence from Sri Lanka. *International Conference of Sabaragamuwa University of Sri Lanka 2015 (ICSUSL 2015)*, vol. 6, p. 288–292.

[9] Nasser T., Faour G., Touchart L. (2020). Suivi de la sécheresse dans un territoire agricole du Liban : la plaine de la Beqaa. *Méditerranée,* n. 131. http://journals.openedition.org/mediterranee/11621.

[10] Parsonson-Ensor C., Saunders S. (2011). *Exploratory research into the resilience of farming systems during periods of hardship.* New Zealand Agricultural and Resource Economics Society Conference, 25-26 August 2011. Nelson, New Zealand: New Zealand Agricultural and Resource Economics Society.

[11] Radwan A., Gil J., Diab Y., Abo-Nahoul M. (2011). *Determinants of the Adaption of Organic Agriculture in Egypt Using a Duration Analysis Technique*. United Kingdom: 85th annual Conference.

[12] Souissi I., Boisson J.M., Mekki I. et al.(2018). Impact assessment of climate change on farming systems in the South Mediterranean area: a Tunisian case study.*Environ Change*. Springer Berlin Heidelberg. P 637-650. [Consulté en 2018] https://doi.org/10.1007/s10113-017-1130-8

[13] Verner D.A. Maximillian Christensen, Jen Mcdonnell, Rachael Redwood, John Jomaa, Ihab Saade, Maurice Massad, Randa Chehade, Ali Bitar, Ahmad Treguer, David. (2018). *Droughts and Agriculture in Lebanon*. World Bank. (Other papers). 1 p. https://doi.org/10.1596/30595.