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MAPPING APPLE TREES FUTURE LAND USE POTENTIAL AS A MEANS OF CLIMATE CHANGE ADAPTATION IN EAST-MEDITERRANEAN MOUNTAINS: MOUNT-LEBANON

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ABSTRACT

Agricultural zonal migrations and altitudinal shifts of high chill requirements fruit trees such as apple trees is considered a way of adaptation to climate change in mountain agriculture. This study examines near and far future options (2050-2070) of this local adaptation method in four village clusters in Mount-Lebanon, involving the expansion of agricultural lands to suitable regions under different degrees of climate change scenarios of temperature increase and precipitations regime fluctuation. A Geographic Information System (GIS) mapping calculation model was established for agricultural land evaluation which aims to locate spaces where the agriculture development indicators such as soil type, slope, future temperatures, and future precipitations will be suitable for cultivation under different climate change scenarios and models. The model does not seek the exact delineation of plots as much as the location of areas with a trend of agricultural relevance in the next 30 to 50 years. This classification is a tool to help Mount-Lebanon farmers and apple growers in adapting locally to climate change by choosing the best future spots to migrate their crops to. Results showed that most lands in which agricultural development is viable, are already in use for apple production (mainly) in the 4 clusters, leaving small parcels of land with variable agro-potentials to be developed in the future under favorable climate conditions. The agriculture potential of plots of altitude exceeding 2000 meters is to be validated in the studied area, especially since the climatic and irrigation conditions of there can present serious challenges.

KEYWORDS: Mountain Agriculture, Climate Change, Development of Agricultural Land, Local Adaptation, GIS, Mount-Lebanon.

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1. INTRODUCTION

In agriculture, a climate intimate sector, continual adaptation is an unavoidable path. Agriculture adaptation strategies are not only affected by natural factors such as temperature, water, location etc. but also by social, economic, and political readiness of the concerned locality [1, 2]. The main categories of adaptation in agriculture involve planning for climate change and variability, use and management of water resources, soil management, crop management, farming systems, capacity building with organization of stakeholders and financial management [3].

The possibility of movements towards higher altitudes is a natural behavior in plants biodiversity and can be an adaptation method in agriculture too. It is an adjustment of agriculture to climate change, that normally takes hundreds of years and which man is applying during a short time On the coastlines and at low altitudes near the sea level, temperature conditions may become inconvenient for some crops with climate change. In mountainous regions, where agriculture is already heavily exposed to extreme climatic conditions, the altitudinal shift may also be a way of adaptation, but not without risks, mainly of extreme weather conditions, soil and water availability [4].

Lately, moving to both higher altitudes and latitudes to maintain a certain amount of agricultural productivity and quality has become more frequent in different parts of the world. For example, in Europe, wine producers are shifting their vineyards towards higher latitudes [4,5].

However, the choice of higher altitude shift of crops is not always ideal due to many limitations such as the extreme weather conditions, the availability of favorable soils for agriculture, the socio-economic considerations as well as the difficulty of accessing water resources for irrigation [6].

Therefore, expanding the agriculture surface in mountainous areas by finding the suitable parcels of land with convenient conditions and at the right altitude remains a challenge for farmers.

The main two objectives of this study are: i) defining the land plots of the study area of Mount-Lebanon with the highest potential of use under the current climatic conditions for agricultural purposes of fruit tree growing mainly apples; and ii) determining under future climatic conditions of 2 RCPs (4.5 and 8.5) new possible lands that can serve for agriculture purposes in the years 2050 and 2070 relatively to temperature and precipitations.

2. OVERVIEW AND LITERATURE REVIEW

2.1. Agricultural land development in mountains

In mountain areas, the harsh restrictions of the existing natural environment and climate have led agro-pastoral communities to carry out strict land use planning for centuries, where the persistence of these organizational features of the past landscape such as terracing and hill lakes seems common, especially in the Mediterranean region, and continues to influence the general land use dynamics [7].

In Mount-Lebanon, a Mediterranean mountainous area, ancient agriculture systems dating from the time of the Phoenicians, evolved slowly until the mid-20th century, shaping the landscapes and land uses of the hills. In the second half of the 20th century, significant changes in mountain land use have occurred due to rural depopulation and un-valorization of agriculture. Remoteness and physical disadvantages have continuously limited the structural and technical adaptation of mountain agro-systems in this area.

The terraced cultivation is the main agricultural exploitation system of these mountainous environments with aggressive climate (extreme temperatures, winds, hail, snow). Terraces can be found on steep terrains whereas parcels are present on weak slops, where small areas of agriculture exist. The number of cultivation terraces in Mount-Lebanon decreased during the last century due to demographic, economic and environmental changes. For instance, as landholdings are divided into smaller plots with each generation, apples are now produced on increasingly fragmented plots with new generations inheriting the property. In consequence, agriculture parcels in the study area became fragmented into small plots due to the steepness of the hills and the lack of large adequate areas and limited accessibility. More easily accessed parcels are already invested and managed. Exploring and establishing new plots is not of an easy task especially with the impacts which current land use transformations and climate change are imposing.

2.2. Apples: a climate vulnerable tree

Apple trees, such as most mountain deciduous fruit trees, have a specific affinity to low winter temperatures to initiate buds flowering. These trees accumulate during the cold season a certain amount of coldness calculated in chill units which help begin bud break. This is called the chilling requirement [8]. If winter chill is below the amount required (generally for quality apples between 1000 to 1500 hours below 7°C), bud break is delayed and flowering will occur over a longer period, leading to lesser production as well as extended harvesting date [9]. On the other hand, high summer temperatures can cause direct damages to the apple fruits leaving brownish traces on burnt fruits[10].

Apple cultivation is ranked third in terms of production area in Lebanon with approximately 14,000 ha planted and a total annual production of 153,000 tons (23% of total Lebanese fruit production) reaching 3 to 6% of the country's Gross Domestic Product, depending on the quantity and quality of the production.

Geographical location and climate suitability have direct influence on the quantity and quality of the apples produced. Therefore, due to the tree climatic requirements, apple growers in Mount Lebanon tend to be present in the mountainous regions which altitudes are above 1000 m. At the same time, and due to the winter high chilling requirements requested for a quality production, vulnerability of apple trees to climate change is very high, perhaps one of the highest in Lebanese agriculture. As a result, climate change is forcing a shift of apple growers from their "comfort zone" to a dynamic status that involves more climate awareness, readiness, and willingness to take good and planned adaptations decisions at the right time [11].

2.3. Mountain agriculture shift in altitudes and latitudes

With the increase of mean temperatures around the globe, chilling requirements of specific varieties of fruit trees such as apples can be compromised, leading to a decrease in production and quality. In this situation, increasing the altitude of crops turns out to be a nature-based adaptation option that is worth investigating [5]. For example, in India, apple growing conditions are generally available at an elevation of 1,500 –2,700 m above sea level in the Himalaya ranges. Researchers showed that the total cumulative chill units of the coldest months have dropped during the last 20 years by 9.1 to 19.0 units per year in Himachal Pradesh, an Indian state in the Himalayas, thus directly affecting apple productivity. It is expected that the temperature rise will promote the apple orchards to be grown in higher altitude, above 2,300 m from sea level in this area [12,13].

While it may present a way of maintaining good quality apples, shifting up agriculture land parcels in altitudes is not an option without risks especially with limited soil and water resources. Some suitable agricultural conditions, such as chilling requirements, may be met at higher altitudes but the high frequency of severe weather conditions is not to be dismissed such as extreme winter cold and intensive summer solar radiations [14].

2.4. Local adaptation and agriculture

Nowadays, climate change poses an additional substantial adaptation challenge for agriculture, which will likely stimulate further transformations and changes in production locations, techniques, management and research requirements [15–17]. What can be applicable and appropriate in terms of climatic adaptation policies at the global or national level is not necessarily applicable at the local level and vice versa. In fact, climate change impacts vary from a place to another, imposing variations on adaptation strategies and policies depending on the scale of their application [18]. There are several typologies and classifications of adaptation in agriculture, summarized by Smit and Skinner according to their purpose, their mode of execution or the institutional form they take [16,17,18].

Exploring and developing new agricultural land potential is a nature-based option which can increase the biodiversity of marginalized areas and help enlarging their ecosystems [22]. The current study aims to present its findings as a local agro-adaptation on an ecosystem-based approach for helping producers adapt to climate change in a nature-friendly way[20,21].

3. METHODOLOGY

The following section describes the methodology used in this study starting from the geoclimatic features of the 4 clusters of the study area, to the climatic data sources, GIS data treatment and applied calculation criteria and models.

3.1. Study area

Lebanon is a small Mediterranean country on the east coast, reputed for its mountain range. Mount-Lebanon stretches on 169 km and peaks on an altitude over 3000 meters towards its northern part (Qornet el Sawda 3088m). The presence of numerous corridors and valleys generates several microclimate zones in this Mediterranean mountain range, imprinting it with the nearly all bioclimatic zones of the Mediterranean vegetation making Lebanon the highest biodiverse country in the east Mediterranean region [25].

With climate change, Lebanon is expected to witness a rise in average temperatures at the end of the 21st century up to 2 to 4°C (according to the different scenarios) compared to the 90's of the 20th century and a disturb in the rainfall regime [26].

The study area consists of 4 village clusters in Mount-Lebanon, grouping a total of 24 villages of different sizes, forming roughly the biggest region of apple orchard surface and production of the mountain chain of Lebanon.

Agricultural lands which are dedicated for apple production are distributed between 1200 and 1750 m in these clusters. The most northern is Bcharreh zone (cluster B) which includes 6 villages, then Aqoura zone (cluster A) which includes 11 villages, then Mayrouba zone (cluster M) grouping 4 villages and finally the most southerly zone is Jouar el Hoz zone (cluster J) grouping 3 villages (Figure 1).

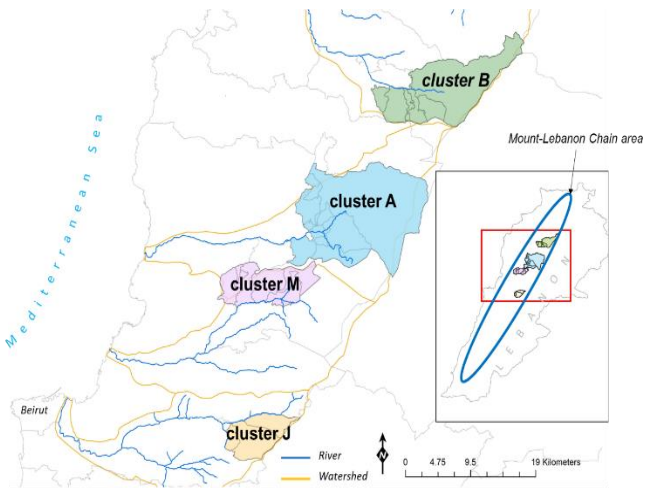

Figure1: Extent of the study areas comprising the 4 clusters of villages (B, A, M and J), each belonging to a unique river watershed.

In the study area, an increase in temperature has already begun and is expected to range between 16% and 25% of the actual mean temperatures in 2070 (Table 1). This will induce the search for cooler lands to grow fruit trees of high chilling requirements. Altitudinal shifting is possible to a certain extent in 3 of the 4 studied clusters (A, B and M). In one cluster (J), apple orchards are already on the highest altitude of the region, limiting the altitudinal shift as shown on Figure 2.

3.2. Climatic data

Due to the complexity of climate models, we focused in this study on 2 climate indicators for future forecasts: the average annual temperature and precipitation. Future projections were downloaded and retrieved from the WorldClim platform [27] which provides gridded climate data for the entire world for the 2050s and 2070s and for the 4 most common RCPs (2.6 – 4.5 – 6.0 – 8.5).

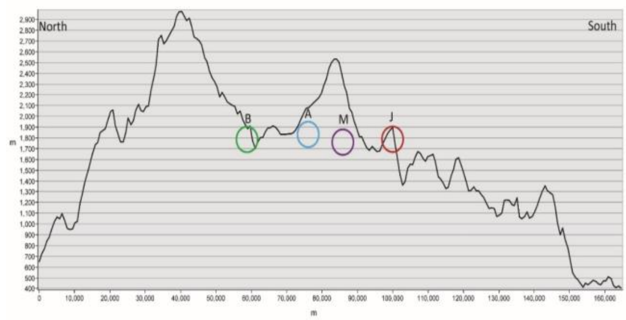

Figure 2: Elevation profile of Mount-Lebanon western chain from the NE to SW following the highest point peaks near the studied clusters. Apple trees plantation of the 4 studied clusters are marked by colored circles.

WorldClim offers future projections based on small-scale data from the CMIP5 Global Climate Model / Global Circulation Model (GCM). The climatic conditions simulated by these models depend in part on the assumed atmospheric concentration of GHGs.

Among the 19 models WorldClim 2.0 offers, 3 different models were selected: CNRM-CM5, MIROC5 and NorESM1-M. According to several comparative studies [28], these 3 models ranked well among the available global models.

The data extracted allowed to determine the level of potential future temperature and precipitation changes due to climate change in the study areas of this research. They are presented in Table 1 according to two scenarios (RCP4.5 and RCP8.5) for the years 2050 and 2070.

3.3. Geographical and climatic data treatment and calculation models

The geographical data treatment was performed in ArcMap 10 for the current and forecasted mean temperatures and precipitations parameters for the 2050s and 2070s. Models CNRM-CM5, MIROC5 and NorESM1-M were used based on the 2 scenarios RCP4.5 and RCP8.5. The current temperatures and precipitation were extracted from WorldClim and from the Lebanese National Center for Scientific Research (NCSR).

The current study encompasses two complementary phases; the first phase targets the mapping of new unexploited areas with agricultural potential (Phase1) and the second phase determining whether these areas will have suitable climatic conditions in the future for fruit trees growing (Phases2).

Table 1: Precipitation and temperature variations in the study area

	Precipitation (mm)				
	Actual	2050		2070	
Cluster		RCP4.5	RCP8.5	RCP4.5	RCP8.5
A	1157	1099	1090	1059	1016
B	1007	935	927	902	865
J	1102	1070	1060	1026	987
M	1179	1172	1167	1136	1092
	Temperature (°C)				
	Actual	2050		2070	
Cluster		RCP4.5	RCP8.5	RCP4.5	RCP8.5
A	13	14.5	15	15	16
B	12	13.7	14	14	15
J	13	15	15.5	15.5	16.5
M	13	14	15	15	16

3.4. Phase 1: mapping agricultural potential of unexploited lands

In this phase a model of layer filtering and score calculation is applied to the 4 clusters of villages included in the study zone, involving geographical, land use and soil parameters. The model is based on selected criteria for agricultural land development, applied by the Green Plan, a governmental institution assisting the development and planning of agricultural parcels and hill lakes on the nation level. The criteria used during this phase are the occupancy of the land or land cover, the slope, and the soil stoniness.

Land cover

Pre-existing agricultural lands were excluded from the model by land cover cartographic filtering performed on the national land use map [29]. The map was used to exclude any existing agricultural land, bare rocks, built environments, and any other land not suitable for agriculture such as natural reserves or water bodies. Only plots with herbaceous or shrubby vegetation were retained. The classification of land cover was made on 3 classes, each assigned by a coefficient (0 to 2).

Slope

The slope percentage is used to describe a terrain by expressing the ratio between the difference in level and the horizontal distance. For example, a slope of 10% corresponds to a drop of 10 m over a horizontal distance of 100 m. The lower the slope, the less work the plot will require for landscaping and will have easy access and work for heavy machinery. According to the development criteria for new agricultural lands of the Green Plan, the slope of the land is preferable to be less than 40% to be adequate for agriculture. In this study the slope range is pushed to the 50% since agricultural land based on plots of similar slopes have been identified during site visits to the study area. The slopes of the terrain of the 4 clusters were calculated on ArcMap from the contour lines map (10 m) provided by the Green Plan. The slopes were classified into 6 classes, each assigned a coefficient (0 to 5).

Soil stoniness

The stoniness of a soil is determined by the quantity of coarse elements in that soil. Even at high coarse elements, reaching 80%, the soil remains satisfactory for agricultural development according to the criteria of the Green Plan and this soil stoniness limit was adopted by our study. The lower this percentage is, the easier the manual work in the field will be and will take less time. The stoniness was calculated from the soil map of Lebanon at 1:50 000, extracted from the "Soil Map of Lebanon" [30]. The classification of soil pity was made on 5 classes, each assigned a coefficient (0 to 4). The classes of land cover, slopes and stoniness of the model are presented in Table 2.

3.1. Phase 2: mapping the identified new lands under future climate change conditions

The purpose of Phase 2 of the model is to identify the clusters, among those already potentiated in Phase 1, which have the enabling characteristics or elements to offer favorable climatic conditions (temperature or precipitation) in the 30 and 50 years to come, presenting a possible means of adaptation by migration towards new grounds [31]. To the above methodology, phase 2 of the model incorporates future temperature and precipitation parameters from WorldClim - each separately - into the outcomes of the first phase. Scores of the classes of parameters were multiplied using the tools of the Raster Calculator in ArcMap.

Scores varying between 0 and 120 are obtained for each parameter (Figure 3).

Table 2: Classification criteria and score ranges for the various land characteristics, future temperatures and future precipitation considered in both phases of the model (Herbaceous Vegetation = Herb. Veg.).

Slope (%)	0-15%	15-22%	22-31%	31-40%	40-50%	50%
Slope classes	5	4	3	2	1	0
Stoniness (%)	0-5% Very low	5-15% Low	15-40% Medium	40-80% Strong	80% Very Strong	
Stoniness Classes	4	3	2	1	0	
Land cover	Herbaceous Vegetation	Shrub Vegetation	other			
Land cover classes	2	1	0			
Scores Phase 1 – Agro-potential	31 – 40 Very high	20 – 30 High	8 – 19 Medium	1 – 7 Low - Very Low	0 Null	
Future Temp. classes	3 (6-12 °C)	2 (13-18 °C)	1 (18-26 °C)			
Future Precipitation classes	3 (850 mm)	2 (600-850 mm)	1 (600 mm)			
Scores Phase 2 – future suitability	101-120 Very strong	81-100 Strong	51-80 Medium	26-50 Low	1-25 Very Low	0 Null

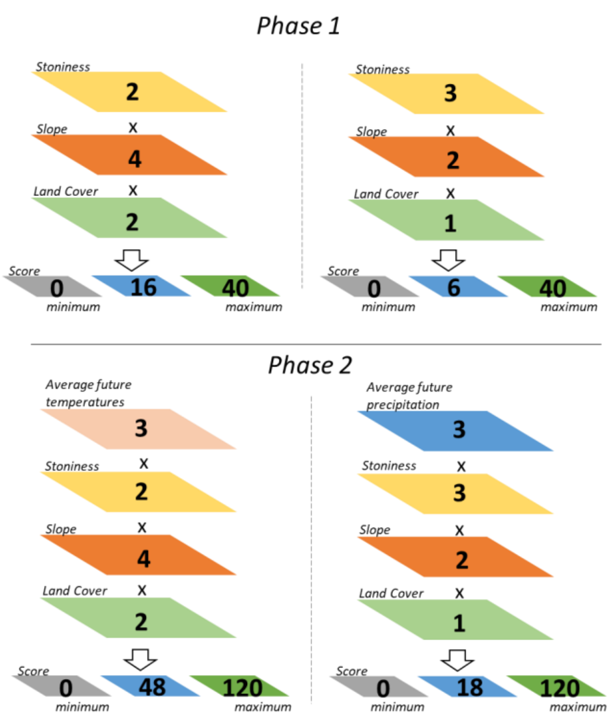

Figure 3: Illustrative examples of Phase 1 and Phase 2 of the model; product of the Stoniness x Slope x Land cover factors and those of future temperatures or future precipitations.

The future temperatures of the CNRM-CM5, MIROC5 and NorESM1-M circulation models were merged to obtain an average value for the 4 climate change scenarios RCP4.5-2050, RCP 8.5-2050, RCP4.5-2070 and RCP8.5- 2070 and that for the 4 cluster zones. Likewise for precipitation, the data of the three models were merged and the values of the above scenarios calculated.

The product of the second phase of the model is a raster format where each pixel has a value according to the products of the factors shown in the example of Figure 3. The result is a score varying between 0 and 120 indicating areas with agricultural potential where temperature and precipitation conditions could be suitable for agriculture in the future 30 and 50 years (2050 and 2070), according to the RCP4.5 and RCP8.5 scenarios. In the classification of the scores of the second phase, scores close to "0" indicate a null potential for the development of the plot for agricultural uses in the future, whereas "120" indicate a very high potential, even with the extreme scenarios of climate change.

4. RESULTS AND DISCUSSION

4.1. Results of Phase1

The outcomes of phase 1 show different results from one cluster to another. Thus, the areas of future potential agricultural land in relation to the study area differed greatly between cluster A which had the highest relative percentage (relative to the existing agricultural lands) of 27% and cluster J with the lowest percentage of 9%. Clusters B and M scored 19% and 16% respectively of land with non-zero agricultural potential. These ratios indicate the fraction of land produced by the model and whose score varies between 1 and 40 compared to the total area of the cluster. The above results can be observed on the maps of Figure 5, by comparing the density of the different colored squares or dots on the map of each cluster. White areas on the map are parcels with score "0".

In fact, almost all spaces which have any type of potential are relatively small due to the prior occupation of the land by agricultural land or hill lakes. The limited availability of agriculture land in high mountains is well reflected in the results.

Although being relatively low (18% of the land with potential) the "very high" potential is most prominent in cluster B considering the very high altitudes which can exceed 2000 m. While cluster J does not have any fraction of its land with “very high” potential (0%). On another hand, cluster A includes 7% of future land with “very high” agricultural potential, cluster M has only 2% of the future land which may be of “very high” potential. The land with “high” potential varies for the 4 clusters between 18 and 32%, cluster J having the highest fraction. Cluster M contains the largest relative percentage of “low” potential land with 50% and cluster B contains the smallest fraction in this category with 12%. In all areas, land with “Medium” potential formed around 40%.

The cartographic analysis shows that for the 3 clusters A, J and M, most of the non-zero score regions generated by the model are located below 2000 m while cluster B has most of the potential terrains at higher altitudes (>2000 m). According to site visits, multiple areas of cluster B, currently are attempting to develop agricultural lands at higher than usual elevations.

This model affirms the suitability of these observations. Being the most northernly among the studied clusters, this area has the greatest potential for high-altitude migration of agricultural land. While in cluster J the potential for altitudinal migration is nearly zero.

Regarding the future agricultural potential scores of the generated maps, the strongest general trend of potential land for all 4 clusters presents a score of “Medium” potential for development (1.66 / 4) followed by the “Low” potential (1.11 / 4) followed by the “High” potential (0.95 / 4) and finally the “Very high” potential (0.27 / 4). In addition, the combination of “Low” and “Medium” potentials is dominant over the “High” and “Very high” one.

Thus, the study area’s agricultural potential lands which can be explored in the future and be suitable for growing crops, will require big mechanical efforts and financial investments in most lands Figure 6.

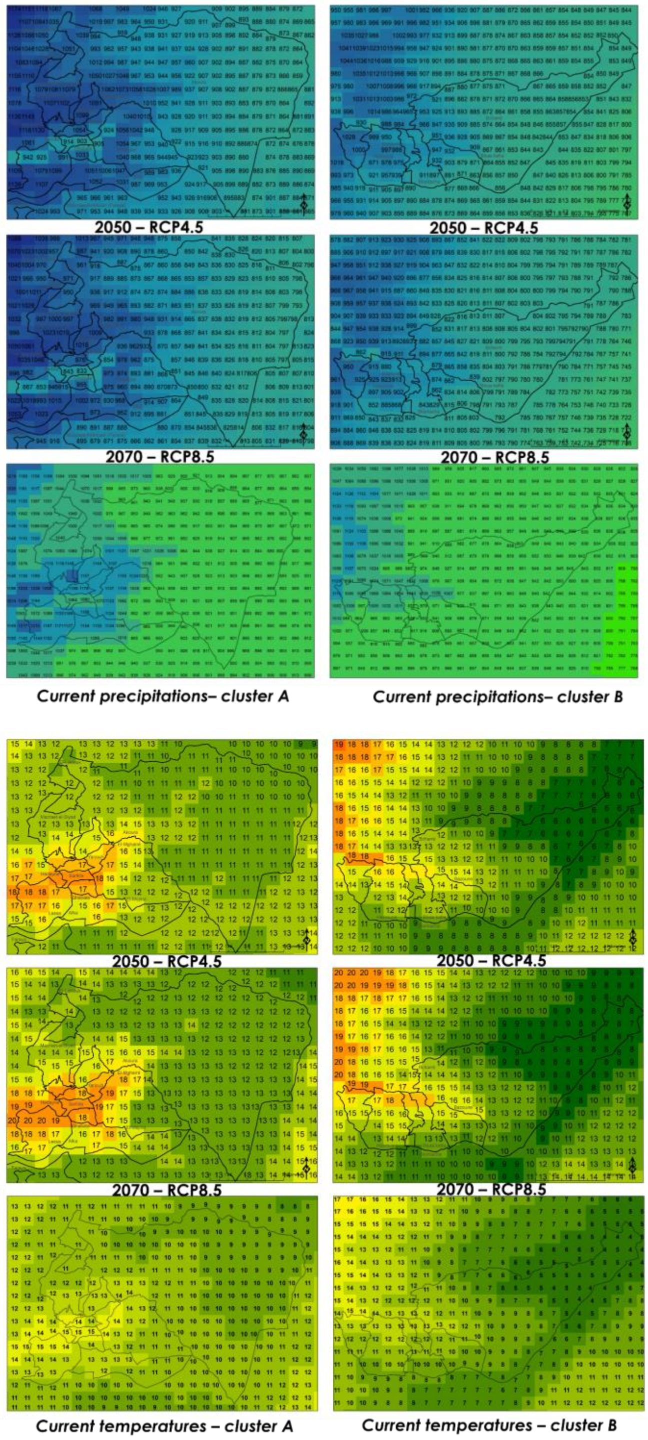

Figure 4: Current precipitations and temperature values in (mm/year) and (°C) for the models CNRM-CM5, MIROC5 and NorESM1-M for 2050 RCP4.5 and 2070 RCP8.5 in the clusters A and B.

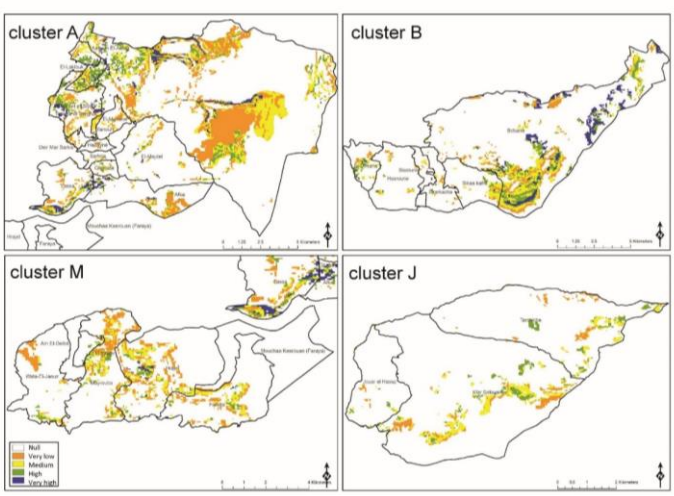

Figure 5: Results for Phase 1 of the model - Current mapping of agricultural potential of unexploited lands.

Regions above 2000 m

Generally, at altitudes above 2000 m, agriculture becomes difficult for the considered Mediterranean region as water resources become very limited and root temperatures unsuitable. The highest elevation where agricultural land was spotted was in Cluster B at around 2060 m above sea level. The current model did take into consideration terrains with an altitude above 2000 m, mainly in clusters A and B. For clusters J and M the maximum altitude does not reach the 2000 m. Indeed, and according to the criteria of the model, sites with "very high" potential have been identified at an altitude of 2130 m in cluster A and 2920 m in cluster B.

In these plots which belong to the Cenomanian plateau, the potential water supply appears to be limited to precipitation, runoff, and snowmelt. In fact, the area greater than 2000 m is upstream of watercourses and springs and there are no sources or watercourses higher in altitude and sufficiently close to supply the plots. Electrical water pumps from the nearest continuous source or water cisterns are the only expensive means of irrigation at these altitudes. Despite having great agricultural potential, these very high-altitude lands may never be used as actual agricultural lands.

In brief, the lands which agricultural development is easy and economically viable have already been taken in the 4 clusters, leaving a small margin of lands with varying agro-potential to be developed in the future. Clusters J and M have less potential land than clusters A and B, given the factor of altitude and the greater surface area of the latter. The potential of land in altitude exceeding 2000 meters can be questionable in terms of agriculture, especially since the climatic and irrigation conditions of these plots can present serious challenges.

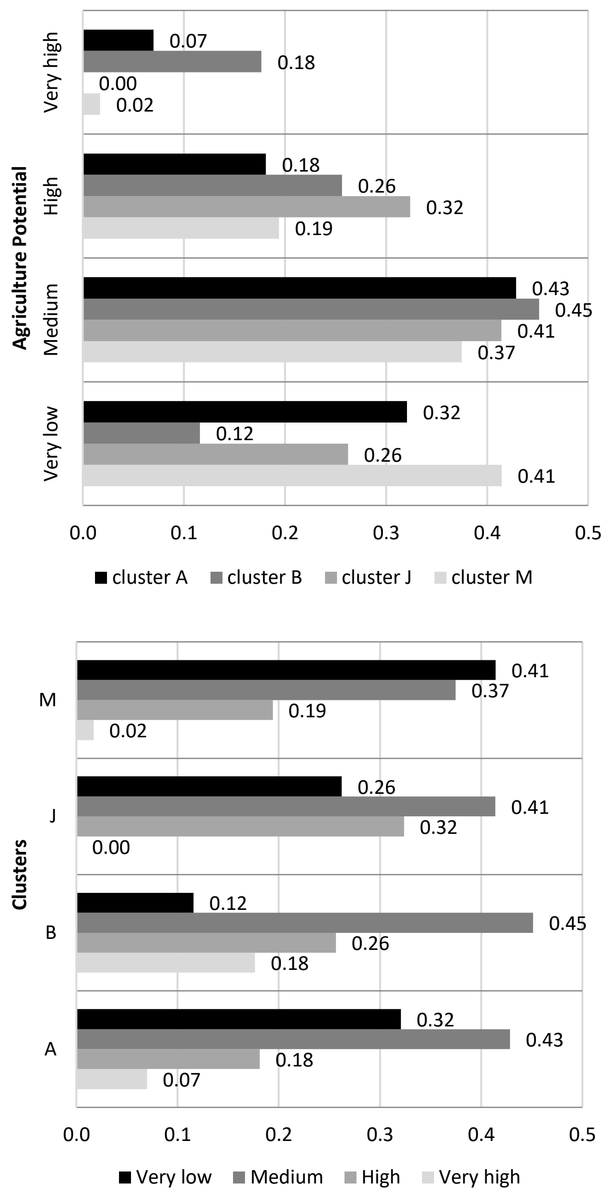

Figure 6: Ratio of land with future potential / land with non-zero potential grouped by score and by cluster.

4.2. Results of Phase 2

The importance of temperature and precipitation parameters on agriculture and their synergy can be dissimilar depending on the apple variety. For this reason, the model scores of these two parameters were kept separated to be evaluated according to the requested need of the cultivation and the producer. This phase revealed the trend of future temperatures in the studied clusters where it is clearly rising and can reach +27% compared to current temperatures while the model trend of future precipitation is in decrease reaching -14% relatively to current precipitations quantities and regime.

Types of land superposition obtained

Despite the difference in resolution between the potentials' map and that of the scores, (climate scenario maps were coarser than land use maps) it was remarkable that the superposition of the potential lands and their score for future temperature and precipitation formed 4 types:

Type 1 - Superposition of "Very high" to "High" potential land with high scores of temperatures or precipitations. These are the "super terrains" of the future. However, land greater than 2000 m even with the highest scores will be subject to future investigations for apple trees viability and water resources.

Type 2 - Superposition of "Very high" to "High" potential land with medium to low scores of temperatures or precipitations. These lands are easy to develop from an agricultural point of view, but future climatic conditions may be unfavorable for certain varieties which require low average temperatures.

Type 3 - Superposition of "Medium" to "Very low" potential land with high scores of temperatures or precipitations. These are the areas that will be suitable from a climatic point of view for crops that require low average temperatures. But the agricultural development of these lands poses challenges from a technical and economic point of view.

Type 4 - Superposition of "Medium" to "Very low" potential land with medium to low scores of temperatures or precipitations. These are the areas to be avoided due to their low agriculture potential as well as the unfavorable climatic conditions for apple trees requiring a great need for low chilling temperatures.

In each cluster, the type of superposition can change between temperatures and precipitations scores for the same squares, depending on the scenario considered. For instance, areas with a good temperature score may not have a good precipitation score and vice versa.

Future temperatures

The comparison between the 3 GCM models for the same cluster, shows that the temperature curves differ from one model to another, but the general trend of isotherms - calculated from WorldClim 2.0 data - is the same: the trend is an increase in temperatures in the 4 clusters ranging from 7.7% to 19.2% for the year 2050 and 15.4% to 26.9% for the year 2070 for RCP4.5 and RCP8.5 respectively.

According to the 3 models CNRM-CM5, MIROC5 and NorESM1-M, the trend of annual temperature averages is increasing because of the increase in temperatures of the warmer months and those of the colder months. The changes in seasonal thermal averages affect mountain agriculture directly and in ways distinctly in winter than in summer. The general results show a rise in temperatures (isotherms) towards higher altitudinal stages, thus changing the conditions currently existing and which may be limiting for some crops that require cold winter temperatures such as apple trees and cherries.

Thermal changes are different from area to area. They are most pronounced in cluster J with +15.4% and +19.2% change for RCP4.5 in 2050 and 2070 and +19.2% and +26.9% for RCP8.5 for the years 2050 and 2070, respectively. The changes are less pronounced in cluster B by -1.9% compared to cluster J while clusters A and M are both at -3.8% compared to cluster J.

Cluster A affected with future temperatures:

According to the lands score maps and with the consideration of temperatures for the RCP4.5 scenario in 2050, the northwestern regions of cluster A, between Laqlouq and Aaqoura, have great potential in the future given several overlaps of Type 1, as well as their suitable altitude (1720-1870m). There is also an area to the west (Mazraeet el Siyad) whose altitude is 1600m and which also carries a good potential. Other Type 1 areas are not always viable areas for agriculture. For advanced warming scenario (RCP8.5 2070), this western area which was Type 1 is transformed into a Type 2 area, where climatological conditions will not be ideal for some crops in this region (Figure 7).

Cluster B affected with future temperatures:

For the RCP8.5 2070 scenario, cluster B presents small Type 1 plots at altitudes below 2000m. Type 1 lands exist towards the east of the area at altitudes of 2840 to 2990 m (Cenomanian plateau), where agriculture is almost impossible. The only areas to be considered will be those located to the south of the area, at the boundary of Bcharré - Beqaa Kafra, located at altitudes of 2300 m.

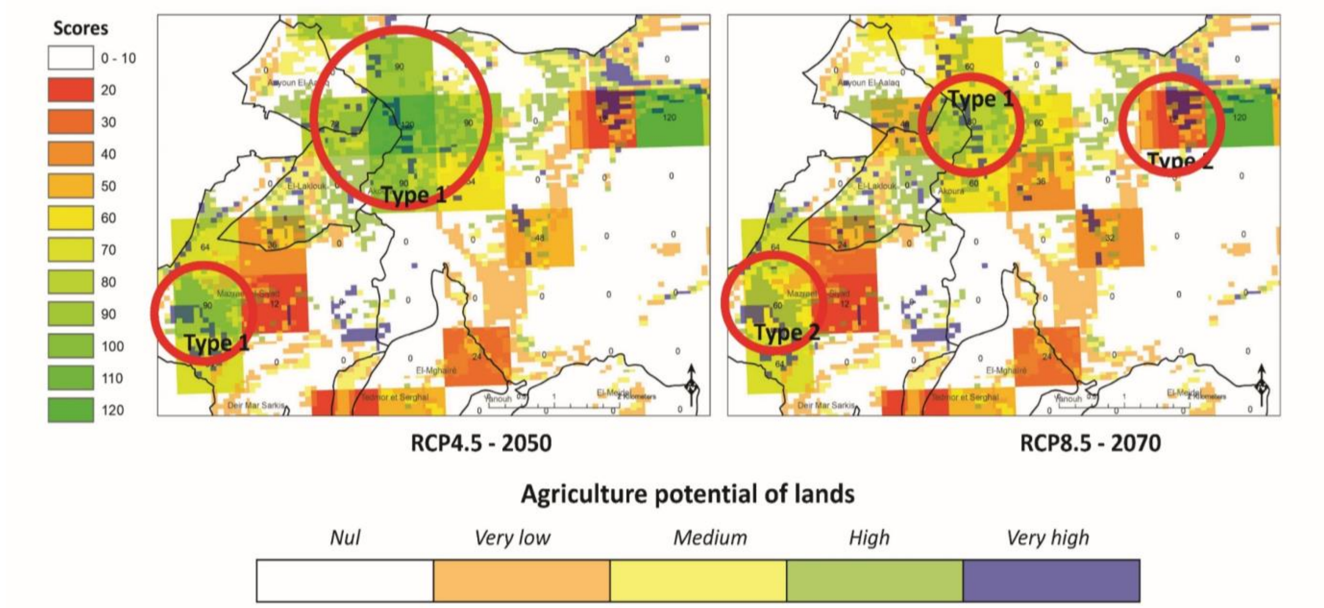

Figure 7: Sample result from cluster A showing the change in the type of plot according to the scores of future temperatures, agricultural potentials, RCP and years.

Cluster J affected with future temperatures:

This area is the poorest in terms of altitude, land with agricultural potential and future temperatures when compared to the 3 other clusters. For the RCP8.5 2070 scenario, there is only one Type 2 plot at the limit of Tarchich at an altitude of 1710 – 1820 m.

Cluster M affected with future temperatures:

The plots with potential are very limited in cluster M as the best plots have already been agriculturally developed. The high potential lands do not have good scores for future temperatures thus resulting towards the centers of the cluster of plots of Type 2 for the RCP8.5 2070 scenario.

Future precipitations

The rainfall trend is in general regressive in the study area for RCP4.5 and RCP8.5 in the 2050s and 2070s. The isohyets of the future scenarios of the 3 models are presented in Figure 5. Similarly, and although minor, differences exist between the models but the trend of change in precipitation is the same: a decrease in precipitation in the 2050s and 2070s ranging from -0.6% to -14.1%. Table 1 shows the rate of change in precipitation by area, RCP and year.

Phase 2 revealed that in the 2050s and 2070s (medium to long term) the change rate will be almost doubled for temperature compared to precipitation. Thus, for the same cluster (for example cluster A) the temperatures could increase by 23% while the precipitations could decrease by 12%.

In addition, and according to the classifications of the proposed model, precipitation reductions of up to -14% compared to the current rate do not change much in the square score in the future. While for 27% of change (the case of temperatures), the scores have significantly changed and even the plots have moved from one category to another.

Cluster A affected with future precipitation:

Concerning the rainfall of the RCP8.5 2070 scenario, very low are the Type 1 terrains in cluster A. Most of the Type 1 is found at low altitudes (1500 m in Lassa and 1700 m in Mazraeet el Siyad).

***Cluster B affected with future precipitation*:** From a precipitation perspective, the areas with the highest scores are at elevations not viable for agriculture. Areas with good potential are also rare in cluster B under the RCP8.5 2070 scenario.

***Cluster J affected with future precipitation*:**

A single Type 1 plot in cluster J could be explored from the precipitations point of view in 2070 for the RCP8.5 radiative forcing scenario.

***Cluster M affected with future precipitation*:**

cluster M presents in its central part (Mayrouba village) Type 3 lands, considered suitable in their future precipitations as per the model. A Type 2 area is located to the east on Hrajel village side, offering plots that are easy to develop but where rainfall conditions will not be favorable in 2070.

For some areas, the type of superposition does not change for the parameter considered between the different RCPs and years. This does not mean that no change will take place in terms of temperatures and precipitations in these places, but it is due to the margins of the Phase 2 scores of the concerned plots which are not exceeded by the category limits for the scenario and year considered. The complete mapping results of the potential overlays with the future temperature and precipitation scores can be found in the annex of this article.

CONCLUSION

In Mediterranean mountains, adaptation of agriculture to climate change has become inevitable. Where possible, land expansion and migration can be applied as a way of adaptation of the sector to the harsh expected conditions of climate change.

In brief, the lands in which agricultural development is easy and economically viable have already been in use for agriculture production of apples (mainly) in the 4 clusters, leaving a small margin of lands with variable agro-potentials to be developed in the future. Clusters J and M have less potential land than clusters A and B, given the factor of altitude and the greater surface area of the latter. The agriculture potential of land in altitude exceeding 2000 meters can be questionable, especially since the climatic and irrigation conditions of these plots can present serious challenges.

The impacts of changing temperature and precipitation parameters on agriculture and their synergy can be dissimilar depending on the cultivated apple variety. Thus, the presented model scores of these two parameters were kept separated in this study, to be evaluated according to the requested need of the cultivation and the producer.

Taking crop migration decision as an adaptation option on the local level does not come without risks. Getting irrigation water to reach high altitudes at acceptable prices and low energy consumption is a challenge that needs to be tackled in case altitudinal shift adaptation are opted for with altitudes higher than the water sources.

Research on increasing the productivity of apple trees on their existing agriculture lands under future climate change scenario is also a challenge to be addressed due to the low quantities of potential lands suitable for a good production especially in areas where altitudinal migration is not possible.

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