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Concept Paper

Towards Climate Change Preparedness in the MENA's Agricultural Sector

Ajit Govind

International Center for Agricultural Research in the Dry Areas (ICARDA), 2 Port Said, Victoria Sq, Ismail El-Shaaer Building, Maadi, Cairo 11728, Egypt; a.govind@cgiar.org

Abstract: The Middle East and North Africa (MENA) represents a substantial area of the terrestrial landmass encompassing several countries and ecosystems. This area is generally drier and warmer compared to the rest of the world, and has extreme resource limitations that are highly vulnerable to a changing climate, geopolitical instability and land degradation. This paper will first identify the nature of climate change in the region by analyzing a downscaled climate data and identifying the hotspots of climate change in MENA. It was found that the climate vulnerability is quite high, with the mean annual temperature increasing by as much as 4–6 degrees towards the end of the century. The nature precipitation under climate change is quite speculative, with the Maghreb region showing the highest vulnerability. Based on these results, five action points are postulated that may be implemented to rapidly progress our understanding of climate vulnerability and enhance the climate change preparedness in MENA's agri-food sector, to take necessary actions to adapt to a changing climate with a systemic resilience perspective. These include working towards: (1) enhancing the sustainability of the rainfed-desert transitional belt (Rangelands) in the MENA; (2) enhancing the sustainability of agri-food systems in the food baskets of MENA and (3) working towards fostering a collective intelligence to support climate change research in the MENA. (4) The need for foresight advice on resilient food systems under climate change and (5) the need for transformative policies for stabilization and reconstruction under climate change.

Keywords: Middle East and North Africa (MENA); climate change; agri-food system; collective intelligence; rainfed agriculture; irrigated agriculture; rangelands; resilience

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1. Introduction

Food security and related natural resources are being heavily stressed in the dry areas of the world, due to the increased variability and change in climate [1]. The dry areas are expected to be drier, with reduced precipitation [2] and increases in temperatures [3] that may, in many locations, reach 4 degrees centigrade by the end of this century [4,5]. Already, several countries are experiencing notable increases in aridity [4] and higher temperatures, as well as new extremes in drought/floods and heat waves [6]. This is causing secondary impacts, such as increased land degradation [7], salinization [8], changing crop water use [9] and the outbreak or emergence of new diseases and pests, leading to farming communities leaving agriculture and migrating from rural to urban areas [10]. Therefore, there is an urgent need to develop a new understanding of the nature of the likely future climate conditions, the impacts of these changes on natural resources and agriculture, including (soil water, ecosystems, agrobiodiversity and energy sources), crops and farming systems, to protect those communities and socioecological sectors, which are most vulnerable.

The Middle East and North Africa (MENA) represents a substantial area of the terrestrial landmass encompassing several countries and ecosystems. This area is generally drier and warmer compared to the rest of the world, and has extreme resource limitations that are highly vulnerable to a changing climate, geopolitical instability and land degradation [11]. Often, this region is ignored (or underrepresented) in coordinated studies, although a substantial percentage of global population (owing to the large area) resides here. In the MENA, climate change threatens the viability of agriculture, ecosystems and rural livelihoods in MENA [12]. Agriculture (crops and livestock) is a critical source of employment and a potential option for engaging rural youth. However, environmental degradation coupled with declining and variable agricultural productivity may pose a great challenge already beset by instability and decreasing oil reserves [13]. There is ample evidence that environmental factors are already starting to influence migration flows leading to complex socio-economic situations. The MENA region is also subjected to short- and long-duration climate extreme events, and their cascading effects on ecosystems, societies and the economy is still an open question. While the longer-term impacts of climate change on human population distributions in the MENA are difficult to predict, due to scanty (or scattered) field-scale experimental evidence, there are serious potential risks for rural communities dependent largely on natural resources and the agricultural sector for incomes and livelihoods. In this paper, I first provide a preliminary analysis of the nature of climate change trends over MENA. With this as the background, I opine about the various actions that should be taken to better understand and prepare ourselves for our adaption to climate change with a focus on the agri-food systems in the MENA in terms of food security, resilience and environmental sustainability.

2. Nature of Climate Change in MENA

Climate change, along with post-war geopolitical complexities, have greatly affected MENA in terms of its economy and social balance. Climate change has penetrating effects on MENA's agriculture sector and, hence, its economy, which is mainly manifested via the changes in water resources and extreme weather conditions, such as heatwaves, and a drastic decline in precipitation. Other issues, such as the loss of biodiversity, land degradation and marshlands drying up, and enhanced hydrological perturbations are critical. To better understand the nature of climate change in MENA, various gridded climate datasets by carefully analyzed for the spatio-temporal trends (1980–2100). In order to understand the nature of climate change in the MENA region, an ensemble climate data was used. An ensemble climate product developed under the Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region (RICCAR) project is used for the long-term future climate data inputted into the crop simulation model. RICCAR is an outcome of a collaborative effort between the United Nations Economic and Social Commissions for Western Asia (UNESCWA), the League of Arab States (LAS) and respective specialized organizations in response to the request of the Arab Ministerial Water Council and the Council of Arab Ministers Responsible for the Environment to deepen the understanding of the impact of climate change [14,15]. The RICCAR Initiative aims at assessing the impact of climate change on freshwater resources in the Arab region, through a consultative and integrated assessment that seeks to identify the socio-economic and environmental vulnerability caused by climate change impacts on water resources in the Arab region. There are two generations of RICCAR climate products, as shown in Table 1: (1) the RICCAR-Arab region and (2) the RICCAR-Mashreq region data. The RICCAR-Arab region (Tomaszkiewicz, 2021) consists of the outputs of three global circulation models, GCMs (CNRM CM5, GFDL-CM2 and EC-EARTH), which were downscaled and bias-corrected for different climate change scenarios (RCP 4.5 and RCP 8.5), and the spatial resolution is 50 km at the daily time step from 1951–2100. The RICCAR-Mashreq region consists of the outputs of six GCMs (CMCC-CM2-SR5, CNRM-ESM2-1, EC-Earth3-Veg, MPI-ESM1-2-LR, MRI-ESM2-0 and NorESM2-MM) that were downscaled and bias-corrected for the 8.5-SSP5 climate change scenario. Although RICCAR-Mashreq is available at 10km resolution, it is focused only on a smaller area. In this study, ensemble data from the RICCAR-Arab region was used. Table 1 provides the technical details of this dataset.

Table 1. Characteristics of the RICCAR-Arab domain Climate Data.

	Arab Domain
Spatial Extent	27 W–76 E, 7 S–45 N
Spatial Resolution	0.44° (~50 km)
Temporal Extent	1951–2100
Temporal Resolution	Daily
IPCC Scenarios	RCP4.5, RCP 8.5
Driving GCMs	CNRM-CM5 [16] GFDL-ESM2M [17] EC-EARTH [18]
Downscaling Regional Circulation Model (RCM)	RCA4 [19]
Bias Correction Method	Distribution-Based Scaling (DBS)
Reference	RICCAR, Arab Climate Change Assessment Report Main Report [14,20].

The spatiotemporal analysis of this ensemble climate product (RICCAR) was performed for the selected two intergovernmental panels on climate change (IPCC) scenarios over the MENA region. From the daily data (that spans from 1980–2100), an annual average was calculated for each year. For the temperature, the mean annual temperature (MAT) was calculated and for the precipitation, the annual precipitation was calculated. Further to this, a linear regression was plotted (annual average with time) over the 121-year time frame for each pixel in the domain. The slopes of these linear regressions that were statistically significant (where $p < 0.05$), presented an indication of the hotspots of climate change in MENA. This analysis was performed separately for the temperature and precipitation as these were the fundamental climate change indicators. The analysis indicated that, for MAT, there is a statistically significant increasing trend throughout the MENA region, and all the places show an increasing trend during the 121-year time frame. However, the rates of these increasing trends greatly vary across the region. In general, the climate hotspots of the temperature increase are seen in the Iranian highlands, Eastern Turkey and much of the Saharan desert encompassing Niger, Chad, Southern Libya, Southern Mali, Northern Sudan and Southern Egypt, where the rates of increase were as high as 4 degrees per decade (average of RCP 4.5 and RCP 8.5). This is shown in Figure 1, in which the hotspots of increasing temperature trends can clearly be observed. The lower panels of Figure 1 show the absolute increase in the mean annual temperature at the end of the century across MENA, relative to the baseline (average of 1980 to 2000) values. It is quite interesting to note that under RCP 8.5, the MAT can increase by as high as 6 degrees.

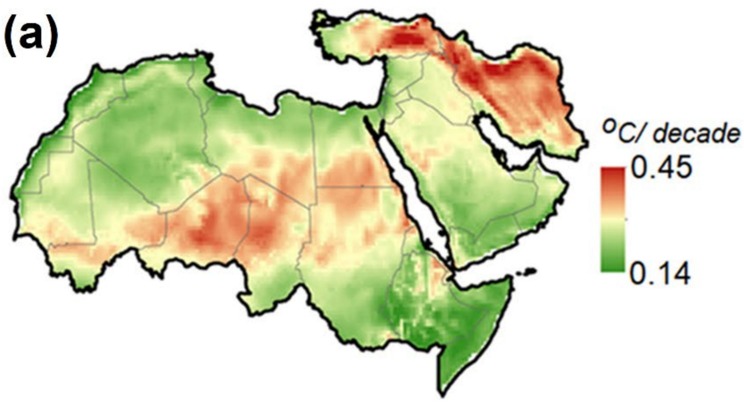

Figure 1. *Cont.*

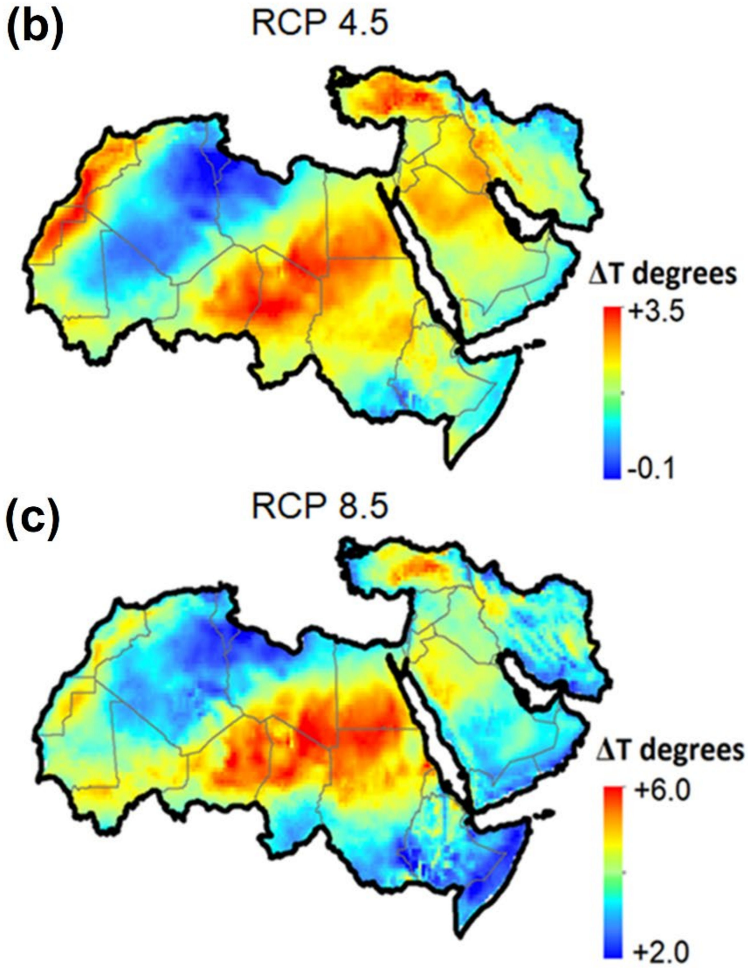

Figure 1. (**a**) Spatially-explicit trends of the mean annual temperature (MAT) as the slope of the linear regression at $p < 0.05$ in the MENA (1980 to 2100, $n = 121$). The lower two figures (**b**,**c**) show the absolute difference in MAT in 2100 from the baseline (1980–2000) for the two IPCC scenarios. The climate data used is the statistically downscaled climate data obtained from 3 GCMS under the RICCAR project.

In the case of precipitation, it is quite complex, unlike MAT, and there is no possibility of making any regional-scale generalizations. The locations where high statistical confidence exists in terms of precipitation trends (specifically for each IPCC scenarios) can be seen in Figure 2. It can be generalized that there is a statistically significant trend of declining annual precipitation around the Mediterranean region of North Africa (Morocco, Algeria, Tunisia and Northern Egypt), the Levant (Lebanon, Jordan and Syria) and the Turkish highlands. On the contrary, a statistically significant increase in the annual precipitation can be noted in Southern Somalia and parts of Ethiopia and the Sahel. This could be due to a general northerly movement of the ITCZ under a changing climate, as postulated in previous studies. The following discourse provides some of my thoughts on what actions we should focus on in achieving sustainability and resilience in MENA's agri-food sector under a scenario of climate change and economic change.

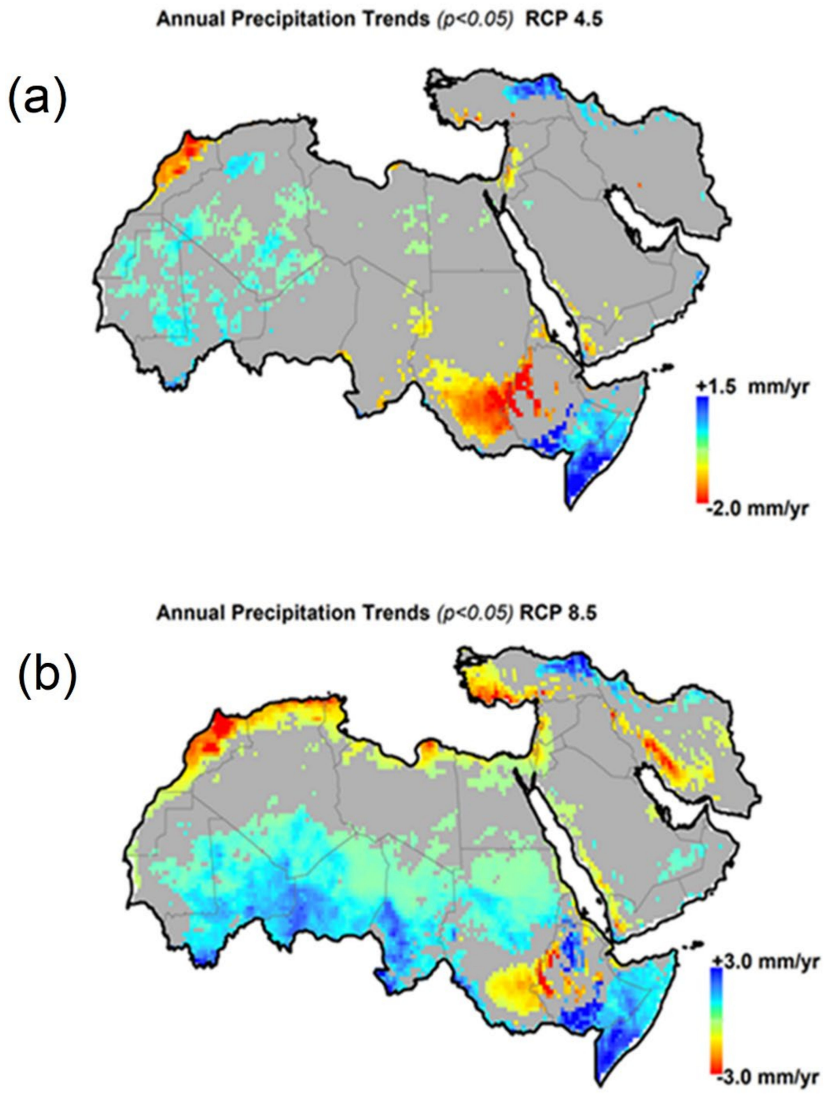

Figure 2. Statistically significant hotspots (slope of the linear regression at $p < 0.05$) of the mean annual precipitation in the MENA (1980 to 2100, $n = 121$) for the two IPCC scenarios RCP 4.5 (**a**) and RCP 8.5 (**b**). The climate data used is the ensemble of the statistically downscaled climate data obtained from 3 GCMS under the RICCAR project.

3. Sustainability of the Rainfed-Desert Transitional Belt (Rangelands) in the MENA

There is a transitional belt in the northern part of the Sahara in the MENA, similar to the Sahel region, which is a transitional belt in the southern boundary of the Sahara. This ecosystem is composed mainly of rangeland and extends to the Levant and the Arabian Peninsula. These rangeland regions are an integral part of the MENA (and its culture) and consist of semi-desert, steppe types of biogeography that have been highly ignored in global-scale evaluations of climate change on agroecosystems. This region is located in a highly dynamic transitional zone (rainfed to desert), from a climatological perspective. This is one of the most vulnerable regions in the MENA under a changing climate (direct and indirect effects), and issues, such as land degradation, desertification, irreversible migration, social conflicts and biodiversity erosion, are rampant here. In areas of undulating topography, water conservation efforts are traditionally operational at the watershed and landscape scales (e.g., Marabs and Badia in Jordan) that are used for supplemental irrigation during dry spells [21]. Thus, crop husbandry is erratic, and the population relies mainly on livestock. Rangelands used to be a major source of food for the livestock production system, but, due to degradation, their contribution to livestock feed has dramatically reduced.

Rangelands also provide vital ecological resources that include nutrient cycling, the filtering of pollution, medicinal herbs and the preservation of biodiversity for millions of resource-poor agro-pastoral farmers. Cultivated Marabs gradually lose their inherent fertility and are subjected to erosion due to over-exploitation and inappropriate management practices, following over grazing by the livestock managed by seasonally visiting shepherds. As a result, the grazing areas have decreased, the available biomass has reduced and species biodiversity has declined under a changing climate (mainly due to desertification). The reduction in vegetative biomass seriously affects livestock production, natural resource conservation and the well-being of pastoral and agro-pastoral communities. Thus, there is a pressing need to explore the complex functioning and the sustainability of the rangelands in MENA under a changing climate. Strategic livestock management options needs to be explored in combination with traditional dryland farming practices under CC and land degradation scenarios. The optimal options of rangeland governance, in terms of water and pasture availabilities, will be explored towards conflict resolution for the different types of land uses in the Badia, such as mono-cropping, livestock management and sometimes horticulture. Alternative options, such as value-added dryland horticulture, apiculture and the involvement of multiple stakeholders (and NGOs) in the socio-ecological sustainability of MENA rangelands under a changing climate, need to be studied in those climate change hotspots. Irreversible rural migration (especially the youth) is a major problem in the rangelands. Keeping rural communities in place is important for development purposes, as large urban migration can cause a myriad of problems. These migrants, if they stay in place and engage in profitable vocations, can contribute to the household's income through the production of food, feed, fuel and medicinal plants, and other services (honey production, recreation, ecotourism and hunting). In particular, studies on female empowerment and the opportunities for self-help groups towards alternative sources of income generation need to be examined from a climate change and sustainability perspective. We need to explore the governing factors and intricacies of demographic dynamics in the MENA rangelands under a changing climate and explore the strategies of reducing migration problems towards attaining social and ecological sustainability. The ideal modus operandi should rely on studies that deal with the ground observations of biophysical, socioeconomic and demographic factors, in addition to modeling and earth observation. Table 2 provides an overview of the important datasets that should be collected in the rangelands. To implement such an action, a strong collaboration of various national agencies, NGOs, and international agencies is imperative.

Table 2. Parameters to be observed in a regionally coordinated manner.

Parameters	Irrigated	Rainfed	Rangeland	Desert
Hydrometeorology				
Precipitation	x	x	x	x
Radiation Components	x	x	x	x
Net Radiation	x	x	x	x
Air Temperature at various heights	x	x	x	x
Relative Humidity	x	x	x	x
Surface Pressure	x	x	x	x
Wind Speed and Direction	x	x	x	x
Soil Heat Flux	x	x	x	x
Soil Temperature at various depths	x	x	x	x
Soil Moisture at various depths	x	x	x	x
Ecosystem Fluxes				
Sensible Heat Flux	x	x	x	x
Latent Heat Flux	x	x	x	x
CO_2 Flux	x	x	x	x
Methane Flux	x	x	x	
NOX Flux	x	x		
Hydrological Processes				
Surface Runoff	x		x	
Sub-Surface Runoff	x		x	
Water Table Dynamics	x	x	x	
Evapotranspiration		x	x	

Table 2. *Cont.*

Parameters	Irrigated	Rainfed	Rangeland	Desert
Soil Parameters				
Soil Carbon Stocks and Fluxes	x	x	x	x
Static Soil Physical Properties	x	x	x	x
Static Soil Chemical Properties	x	x	x	x
Soil Biological Properties	x	x	x	x
Soil Depth to Bedrock	x	x	x	
Vegetation Parameters				
Leaf Area Index	x	x	x	
Plant Phenology	x	x	x	
Biomass Dynamics	x	x	x	
Vegetation Density	x	x	x	
Species Composition	x	x	x	
Spectral Reflectance	x	x	x	x
Livestock Parameters				
Ruminant Density			x	x
Ruminant Spatial Dynamics	x		x	x
Animal Herbivory		x	x	x
Animal Population Dynamics		x		
Biotic Invasion.	x	x	x	

4. Sustainability of Agri-Food Systems in the Food Baskets of MENA

Owing to the current trends in global trade, great regional economic perturbations and geopolitical instabilities, countries in the MENA have formulated policies to achieve food self-sufficiency to reduce the dependency on food and feed imports. In recent times, in the MENA countries, there has been increasing economic shifts from completely oil-based economies to increased contributions from agriculture and allied sectors in their economies. Food self-sufficiency policies primarily focus on the wheat-based agri-food systems, "the bread baskets", which are dominated by irrigated agriculture and dryland systems with access to supplementary irrigation. These areas are mostly located in places in which there is an availability of groundwater often bolstered with rainfall (the Nile river basin in Sudan and Egypt, and the Euphrates-Tigris river basin). In addition to the issue of climate change, there are other factors that operate simultaneously and interactively. These include factors such as population growth, youth migration, changes in the local economy, changing food habits, changing trends in value addition in the supply chain, food loss and wastage and market forces, all of which collectively affect the nature of agri-food systems in the region. Thus, it is important to analyze the sustainability of these food systems in MENA under a changing climate, employing a multi-criteria approach with emphasis on a value chain perspective that links small holder farmers with large-scale macroeconomics. Although, in the irrigated systems, the focus is mainly on wheat-based systems (including agronomic, integrated pest management, socio-economic, market forces and supply chains), it is also important to pay attention to the livestock production systems that are supported by irrigated forages such as maize and barley, in the wheat-based systems. Issues, such as water productivity, GHG emissions and carbon footprint, nutrient and water use efficiency, food loss and wastage, the water-energy nexus, supply chain economics and the environmental footprint, all of these should be analyzed holistically under a scenario of changing climate. An integrated approach should be employed using observations, data analysis and modeling and life cycle analysis. Table 2 shows the important datasets that should be collected and studied in the irrigated systems in the MENA region. The urgent need is to focus on the prospects of the sustainability of wheat-based systems given their significance in value chains, safety nets and insurance, market forces and policies. Sustainable solutions for the food baskets under a changing climate range from breeding for higher water use efficiency, tolerance to heat, pest and drought (in all the crops involved in the wheat-based cropping systems), reducing food wastage, optimized cropping systems and integrated farming systems (including pulses, horticulture and inland fisheries). The spatio-temporal dynamics of water (especially groundwater) resources in the MENA will also be explored, as it is the main factor responsible for the sustainability of irrigated food and fodder production. The prospects of supplementary irrigation and wastewater reuse under an increasing urbanization and its ecological and human health impact on agri-food systems, as well as peri-urban horticulture sectors, will also be evaluated. The role of private parties and industries in various projects in the agrifood domain, tailored towards the economic and ecological sustainability of agroecosystems in the MENA, should be carefully evaluated. The results obtained from these studies can be solid recommendations to policy makers for formulating long-term policies to undertake sustainability goals in their national agenda under a changing climate.

5. The Need for a Collective Intelligence to Support Climate Change Research in the MENA

The knowledge of how the climate is changing, what components of the agroecosystem are sensitive to a changing climate and the locations of the hotspots, are open questions in the MENA [22]. The region has not been the focus of the international efforts studying the impact of CC. It is therefore critical to explore the impact of CC at local-to-regional scales, and to identify options of CC adaptation. This warrants the development of a collective intelligence in the future of the region through institutional collaboration, network development, database building and capacity development. There is an urgent need to develop a MENA-scale platform for a network of actors collaborating with different national agencies and other organizations. This platform will accumulate diverse types of ground data to enable multiscale modeling and scenario analysis to decipher the individual and interactive effects of CC in the short and long term. The ground data will span across a wide domain, from hydrometeorology, agrometeorology, agronomy, pests and diseases, livestock, rangeland, demography, socioeconomics, soil processes and ecosystem processes. Such a platform can help to create an invaluable database on how various ecosystems or agroecosystems in the MENA function in terms of hydrometeorology, ecohydrology and biogeochemical process, which have implications on the ecosystem-crop-livestock functioning in a changing climate. Information generated vis this data can be used for international negotiations, capacity building activities and fostering institutional partnerships. The strategy is to adopt the lessons learnt from similar coordinated environmental observatories in the world, such as the CarboEurope, ICOS (Europe) and FluxNet (USA) [23], and to employ such an initiative in the region with an emphasis on agroecosystems, socioeconomics, livestock and rangelands. Still, there is a lack of regional efforts in developing a regional network of monitoring various hydrometeorological, ecohydrological and biogeochemical processes in a coordinated manner. It is necessary to perform continuous observations of these processes (using various methods of measurements and observations) with a consistent protocol of measurement, consistent protocol of data processing and quality control, and consistent protocol of data archiving and dissemination through a centralized database. This database can consist of observational products obtained at several scales, such as: (1) point scale (biometric observations, canopy and soil profile scale observations, such as crop physiology, soil hydrology, soil texture and soil carbon stocks); (2) ecosystem or landscape scale measurements (ecosystem flux measurements using micrometeorological techniques and watershed scale observations, such as runoff and remote sensing-based observations using high spatial resolution sensors) and (3) regional scale data (mostly using decametric and coarser scale remote sensing sensors). One major component of agricultural sustainability in the MENA is water productivity (i.e., the amount of water required to produce a given biomass), for which a proper understanding of evapotranspiration is the key. There is also a need to disseminate modeled spatial datasets pertinent at the regional scale that can be used for progressing scientific research and policy actions. One such data is the spatially-explicit modeled climate and weather data sets at the regional scales. Although many climate datasets are available from many meteorological portals, we still need to bring these data to this centralized MENA platform for operational use. The downscaling of long-term climate scenarios to the farm scale will be used it to run farm-scale biophysical or socioeconomic models and to deduce optimal combinations to adapt to

CC. A conceptual figure of this regional network is shown in Figure 3. Such a platform in a precursor study has been recently established by ICARDA and FAO partnering with five national organizations under the regional water scarcity initiative. This network is called the NENA-ET Network, where evapotranspiration and allied agrometeorological observations are conducted under a consistent protocol in five different countries in the MENA [24]. In addition to the biophysical datasets, we also need to accumulate diverse datasets pertaining to socioeconomic elements, market forces and demography in relation to the agri-food system in MENA, as affected by climate and socioeconomic drivers. In this context, a regional effort to monitor and model the issue of migrations and demographic transitions in the MENA region, as a direct and indirect cause of CC, is increasingly becoming relevant in MENA, especially in the rangelands [10]. Livestock population is an inherent component of the MENA's rangeland agroecosystems and this is tightly linked to crops, climate change and human migrations. Thus, we also need a solid understanding of livestock dynamics in terms of mass migration, grazing behaviors, GHG fluxes and its role in regional resilience in a changing climate. The overall outcome of this regional collective intelligence is the enhanced knowledge about climate vulnerability in various MENA agroecosystems, as perceived from different angles, bolstered with solid ground data. This observed datasets could also serve as calibration and validation datasets while using models for ex ante asessments. This knowledge will be used to address the long-term goals of various countries in the region in the increased livelihoods of the poor population, decreased migrations, decrease in land degradation and enhanced food security. Such a platform should ideally be built on a strong partnership in the region, based on networking, synergistic collaboration, capacity building, infrastructure deployment and the use of multi-scale decision support systems.

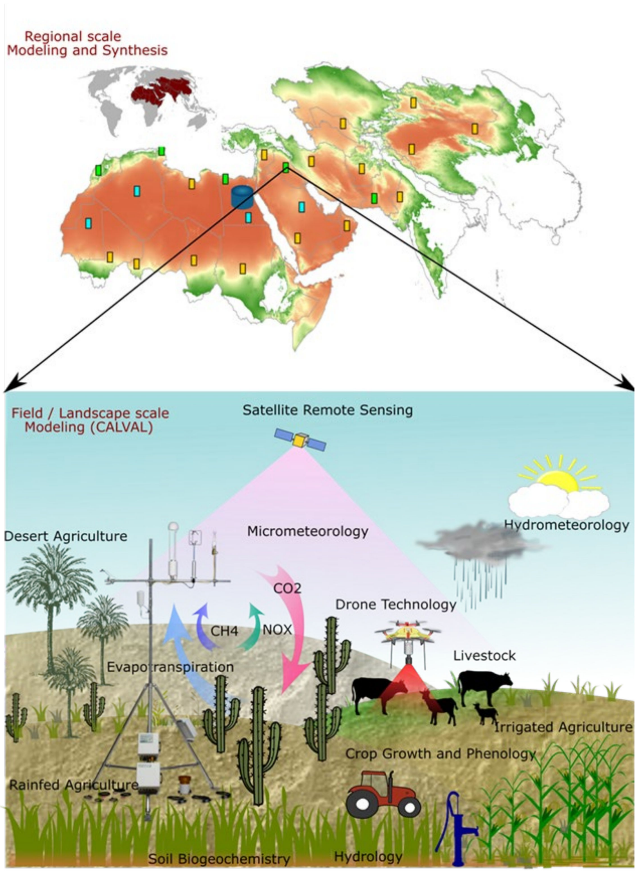

Figure 3. A conceptual representation of a multi-disciplinary, multi-methodological, multi-scalar and multi-national coordinated observational platform that should be implemented in the MENA region with synergistic institutional partnership involving national agencies, academia, international organizations, NGOs and civil society.

6. Need for Foresight Advice on Resilient Food Systems under Climate Change

The food systems of MENA's middle-income countries need urgent reforms to meet food and nutritional security. Efforts should specifically focus on the food systems of the urban agglomerations of MENA, in which the population density is high, with the goal of providing people with nutritious and affordable food in a changing climate scenario. The foodsheds of the MENA cities usually comprise of peri-urban and urban irrigated agriculture, on the one hand, and produce coming from the rainfed and rangeland systems elsewhere, implying an integrative role of food productivity, socioeconomic and econometric dynamics. Thus, foresight advice is vital towards having sustainable food systems in MENA, where there is an urgent need for policy reforms to meet food and nutritional security. Foresight activities can provide a good understanding of future dietary trends in order to design efficient food systems. This should consider future resource availability (water, soil fertility and capital), and the gap between future supply-and-demand under the projected dietary trends and increasing quality and safety standards.

Moreover, policies and economic research to identify the optimal investments supporting the adaptation and resilience build-up in food systems, health and nutrition services and food subsidy schemes need to be evaluated. Evidence generated through this work, tested in collaboration with partners, will help to strengthen food supply chain resilience and meet the needs and risks of poor consumers. The foodshed approach that integrates consumers and supply chains in the cities on one hand, with producers in different agro-ecosystems (irrigated, rainfed and rangelands), on the other, will also help in designing job creation plans for the youth. The focus of foresight analysis should be on all the major value chains in the food basket, that includes cereals, pulses, vegetables, fruits, meat, poultry and fish. Alternative climate-resilient options, such as the promotion of composite cereal flour for bread and related economics, are particularly relevant for countries, such as Egypt, from a policy perspective.

7. The Need for Transformative Policies for Stabilization and Reconstruction under Climate Change

Due to the fragile situation and ongoing conflicts in the region, significant reconstruction efforts will be needed in post-conflict areas in the future. It is expected that the post-conflict reconstruction in countries, such as Iraq, Syria and Yemen, will cost hundreds of billions of dollars. At the same time, countries, such as Tunisia and Morocco, are in dire need of investment that foster long-term resilience and stability. These reconstruction and stabilization investments will shape the patterns of agriculture, food and water security, and climate resilience for decades to come. Therefore, post-conflict reconstruction and broader efforts to improve resilience and stability are strategic opportunities to enhance food and water security, agricultural sustainability, equity and poverty reduction, while mainstreaming climate change considerations [25]. The first step is the mainstreaming of climate adaptation and resilience innovations towards the reconstruction and stabilization of rainfed areas in the MENA, focusing on the agriculture-based production systems that are crucial to ensure food security, the resilience of livelihoods and sustainability of natural resources. In particular, the focus should be on supporting frameworks for successful water (e.g., [26,27]) and seed governance (e.g., [28]) in the region. The second step centers around institutional arrangements to achieve equity and sustainability in agricultural reconstruction. In particular, the focus should be on supporting frameworks for successful water and seed governance in the region. Both actions should combine the provision of evidence with informing policy and institutional reforms for climate-smart reconstruction, resilience and stabilization investments [29]. The goal should be to help mitigate the risks of further conflicts by strengthening institutions, natural resource management and minimizing climate-induced land degradation.

8. Conclusions

Despite the geographically extensive area, the MENA region is often ignored while addressing ecological and agricultural vulnerabilities and to develop solutions to enhance the sustainability and resilience under climate change. Although arid degraded lands of MENA may seem to be extremely challenging to reintegrate into intensive agricultural production systems, they present investment potential for soil carbon storage, making these lands invaluable for ecosystem services. Especially in the dry areas, those lands form the majority of the agro-pastoral ecosystems that are directly or indirectly impacted by climate change, need special attention to enhance the ecosystem services that can enhance the livelihoods of communities. There are many tested tools, technologies and management practices that can be brought together to build/support climate resilient agriculture and provide an effective adaptation to climate change while minimizing greenhouse gas (GHG) emissions. Those include the introduction and promotion of new crop varieties, new crop rotations, appropriate options for the control of diseases/pests, integrated crop livestock systems and water, nutrient and land management systems. The associated changes in the policy and institutional frameworks would facilitate improved insurance, planning and information dissemination to help build the resilience of the socio-ecological systems and reduce risks. Yet, some rural communities may opt to migrate, whereas some communities may be able to undergo transformative changes in their livelihood systems as an alternative to migration, while increasing their resilience. The scientific and technological insight from many years of research conducted by several organizations in the region, offer important possibilities for developing climate resilience in the arid and semi-arid areas of the world. New ideas for agriculture and water management, well-tested in laboratory and field experimentation, should be integrated with data modeling, ecologic, economic and social analysis and policy development to bring climate-resilient agricultural technology packages for targeting specific agroecologies. This set of practices will be further refined by combining in situ observations with downscaled future climate conditions. The challenge would be to integrate these packages in farming systems adapted to the specific conditions of the vulnerable dry areas, assess them with regards to the climate-smart agriculture concept and support its large-scale implementation by farmers, stakeholders and governments. There is a need to work on aspects of drought and the risks associated with climate variability and change within many projects and other global initiatives. Future research needs to tackle the specific changes in climate parameters and the impacts on various parts of agriculture, and the components of the natural resources in the dry areas of MENA.

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