Regional Climate Change Initiative Republic of Cyprus

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Report of the Task Force on

Agriculture and the Food Chain

Eastern Mediterranean and Middle East Climate Change Initiative

Task Force Management Board

Professor Andreas Kanamanos, Agricultural University of Athens (Coordinator)
Dr. Reem Nejdawi, Sustainable Development Policies Division, UN House, Lebanon
Dr. Michalis Omirou, Agricultural Research Institute, Cyprus

Cyprus Institute Liaison Scientist

Dr. Michalis Omirou

Task Force Members

Professor Tayel El-Hasan, Mutah University, Jordan
Dr. Pauline Y. Aad, Notre-Dame University Louaize, Lebanon
Professor Konstantinos Kormas, University of Thessaly, Greece
Professor Ioannis Ipsilantis, Aristotle University of Thessaloniki, Greece
Professor Athanasios Tsikliras, Aristotle University of Thessaloniki, Greece
Dr. Dionysia Fasoula, Agricultural Research Institute, Cyprus
Dr. Georgia Hadjipavlou, Agricultural Research Institute, Cyprus
Professor Mark Tester, King Abdullah University of Science and Technology, Saudi Arabia
Professor Constantinos Kosmas, Agricultural University of Athens
Professor Mohtar Rabi, American University of Beirut, Lebanon

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Abbreviations

ACCCP	Arab Centre for Climate Change Policies
ACSAD	Arab Centre for the Studies of Arid Zones and Dry Lands AMO Atlantic Multidecadal Oscillation
AOAD	Arab Organization for Agricultural Development
AMWC	Arab Ministerial Water Council
CAP	common agricultural policy
CSPPM	Climate-smart plant protection management
EMME	Eastern Mediterranean and Middle East
ESCWA	Economic and Social Council for Western Asia
FAO	Food and Agriculture Organization
GDP	gross domestic product
GHG	greenhouse gases
IPCC	International Panel on Climate Change
LULUCF	Land use change and forestry
MSP	Maritime spatial planning
NAO	North Atlantic Oscillation
RCP	Representative Concentration Pathways
RICCAR	Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region
UAE	United Arab Emirates
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
US	United States

Abstract

The goal of this report is to encourage and facilitate regional coordination so that food production becomes more adaptable and resilient to climate change. The report provides a comprehensive assessment of the impact of climate change on livestock production, food security, land degradation, and fisheries and aquaculture in the Eastern Mediterranean and Middle East (EMME) region, which comprises Bahrain, Cyprus, Egypt, Greece, the Islamic Republic of Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Palestine, Qatar, Saudi Arabia, the Syrian Arab Republic, Turkey, the United Arab Emirates (UAE), and Yemen.

Primary food production is one of the region's most important economic activities, representing 6.03% of the region's mean GDP — ranging from 0.19% in Qatar to 22.5% in Syria. The sector is concomitantly an essential source of employment, accounting for as much as 28.3% of employment in Yemen in 2020 and as little as 0.89% in Israel, with the mean in the region estimated at 9.38%.

Modelling predicts worsening climatic conditions for food production at the middle and the end of the century. Crops, livestock, and aquaculture are expected to be affected by more intense heat waves, higher average temperatures, and deeper and more frequent droughts. Higher temperatures and more variable rainfall are expected to increase the region's aridity, exacerbating the already-low productivity of agricultural ecosystems and shrinking biodiversity. Loss of biodiversity in managed and unmanaged ecosystems will negatively affect ecosystem services, with immense repercussions for the region.

Mobilisation of resources for knowledge transfer and investments in agricultural ecosystems is essential to enhance the sector's adaptation to climate change. Resources for research and development related to crops, livestock, and aquaculture sectors are urgently needed to develop tools and instruments to face the challenges of climate change in the food sector. Access to new knowledge, information, funding, infrastructure, and institutions strengthens the adaptive capacity of people in the food industry. Low-income communities and overexploited natural resources are likely to adapt less well to climate change than farmers and communities in well-connected areas of richer countries.

Knowledge, when translated into policy, will enable farmers to raise the productivity of agricultural ecosystems and the quality of food products, thereby combatting malnutrition, another serious problem in the region.

Executive summary

The goal of this report is to encourage and facilitate regional coordination so that food production becomes more adaptable and resilient to climate change. The report provides a comprehensive assessment of the impact of climate change on livestock production, food security, land degradation, and fisheries and aquaculture in the Eastern Mediterranean and Middle East (EMME) region, which comprises Bahrain, Cyprus, Egypt, Greece, the Islamic Republic of Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Palestine, Qatar, Saudi Arabia, the Syrian Arab Republic, Turkey, the United Arab Emirates (UAE), and Yemen.

All segments of the region's food chain have already been affected by climate change, and future scenarios show that the sector will undergo further pressure from changes in the climate. Ongoing global and regional deforestation owing to devastating forest fires over the past decade has turned major forest ecosystems (e.g. in the Amazon, Siberia, Indonesia, and Australia) into emitters rather than absorbers of greenhouse gases. In the EMME region, additional forest losses due to local fires are expected to worsen the negative effects of drought and high temperatures, with unprecedented consequences for the food chain. Moreover, the EMME countries face rapid urban expansion and population growth while having varying success in economic growth and employment.

Primary food production is one of the region's most important economic activities, representing 6.03% of the region's mean GDP — ranging from 0.19% in Qatar to 22.5% in Syria (FAO, 2018). The sector is concomitantly an essential source of employment, accounting for as much as 28.3% of employment in Yemen in 2020 and as little as 0.89% in Israel, with the mean in the region estimated at 9.38% (World Bank, 2020).

The EMME region faces extreme shortages of water, the most critical component of primary production, while managing conflict and the resulting migration and refugee flows. These facts have aggravated challenges in food production and distribution.

Some countries (and some areas within countries) are more vulnerable than others to the risks and hazards of climate change. Agricultural activities in inland areas will face greater stresses from drought and heat, while agricultural land in coastal areas will contend chiefly with salt intrusion and flooding. Irrigated crops are less sensitive to drought and heat stress than rainfed crops, while fishing activities are more susceptible to storms and other extreme coastal events.

Modelling predicts worsening climatic conditions for food production at the middle and the end of the century. Crops, livestock, and aquaculture are expected to be affected by more intense heat waves, higher average temperatures, and deeper and more frequent droughts. Higher temperatures and more variable rainfall are expected to increase the region's aridity, exacerbating the already-low productivity of agricultural ecosystems and shrinking biodiversity. Loss of biodiversity in managed and unmanaged ecosystems will negatively affect ecosystem services, with immense repercussions for the region.

Responding to the challenges of climate change will require a paradigm shift in the practice of agriculture and the role of livestock in farming systems. Animal production systems trail in key areas, including climatic adaptation, rangeland ecology, and pastoral management. Integrating grain production with pasture plantings and livestock could result in a more diversified system more resilient to higher temperatures, elevated carbon dioxide, uncertain precipitation, and other dramatic effects resulting from global climate change.

The fight to secure food production in the EMME region will hinge on policies and measures adopted mainly at the national level. Still, efforts should be regionally coordinated – especially with respect to fundamental reforms and synergies. At the regional level, key policy guidance should involve institutional interactions, technical upgrades, and science-based solutions.

Mobilisation of resources for knowledge transfer and investments in agricultural ecosystems is essential to enhance the sector's adaptation to climate change. Resources for research and development related to crops, livestock, and aquaculture sectors are urgently needed to develop tools and instruments to face the challenges of climate change in the food sector. Access to new knowledge, information, funding, infrastructure, and institutions strengthens the adaptive capacity of people in the food industry. Low-income communities and overexploited natural resources are likely to adapt less well to climate change than farmers and communities in well-connected areas of richer countries.

Knowledge, when translated into policy, will enable farmers to raise the productivity of agricultural ecosystems and the quality of food products, thereby combatting malnutrition, another serious problem in the region.

1. Scope and objectives

A good deal of research has been done since the 1990s to estimate the effects of climate change on agriculture (for reviews, see [2c], [2d]). Most global and regional surveys indicate that the Mediterranean basin will be heavily affected by climate change ([2], [2b], [2e]).

Agricultural production has been identified as the economic activity most sensitive to the effects of climate change in some countries of the eastern Mediterranean, but similarly detailed studies are lacking elsewhere in the region, raising uncertainty about the type and intensity of adaptation and mitigation measures.

In view of the above, the objectives of this task force are as follows:

- To identify gaps in our knowledge about the effects of climate change on crop, animal, and fish production systems, with special emphasis on the most vulnerable system components and the corresponding natural resources.
- To estimate in quantitative terms – based on the projections of regional climate models through the end of this century – the impacts of climate change on food production systems in the EMME countries under various emission scenarios.
- To prepare a common plan for mitigating and adapting to the effects of climate change in the food sector of the EMME region.
- In parallel, to evaluate the implementation of national plans to identify possible gaps and failures – and to propose policy actions for amending those plans.

2. Geographic setting

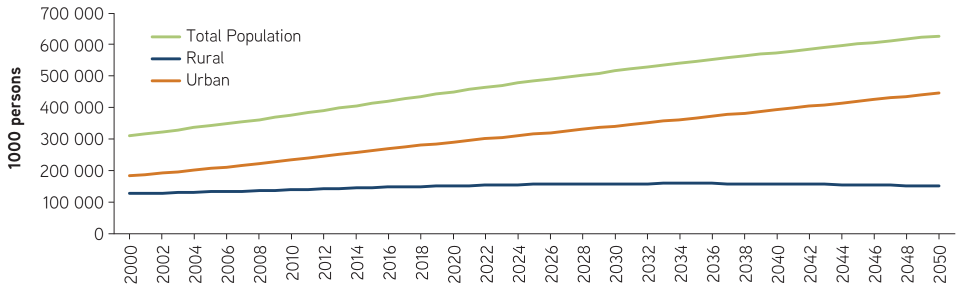
This report focuses on the region of the Eastern Mediterranean and the Middle East (EMME), as illustrated in Figure 1. The socio-economic, cultural and political contexts vary considerably across the constituent countries: Bahrain, Cyprus, Egypt, Greece, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Palestine, Qatar, Saudi Arabia, Syria, Turkey, the United Arab Emirates (UAE) and Yemen.

Often described as "the cradle of civilisation," the EMME region is also where agricultural practices were originally developed and then disseminated to the rest of the world [1]. Yet today the region is among those most vulnerable to climate change [2]. Diverse climates and cultures characterise the densely populated region, whose population of 419 million has an annual growth rate of 1.67%. The GDP of the EMME region is USD 3.6 trillion, with an average annual growth rate of 1.45%. The vast differences among the countries arise mainly from the inherent characteristics of each country. For example, the 2019 economic growth rate in Egypt was 5.5%, whereas in Lebanon it was -5.6%. Figure 2 illustrates the region's rising population, with growth due almost entirely to urbanisation.

Food production systems in the EMME countries – agriculture, livestock and fisheries – are important economic activities. In addition, they are rural cornerstones for social cohesion, vital for preserving local communities. Today the contribution of the primary sector to

FIGURE 1. Countries included in the Climate Change Initiative

FIGURE 2. Population growth the EMME region from 2000 to 2050

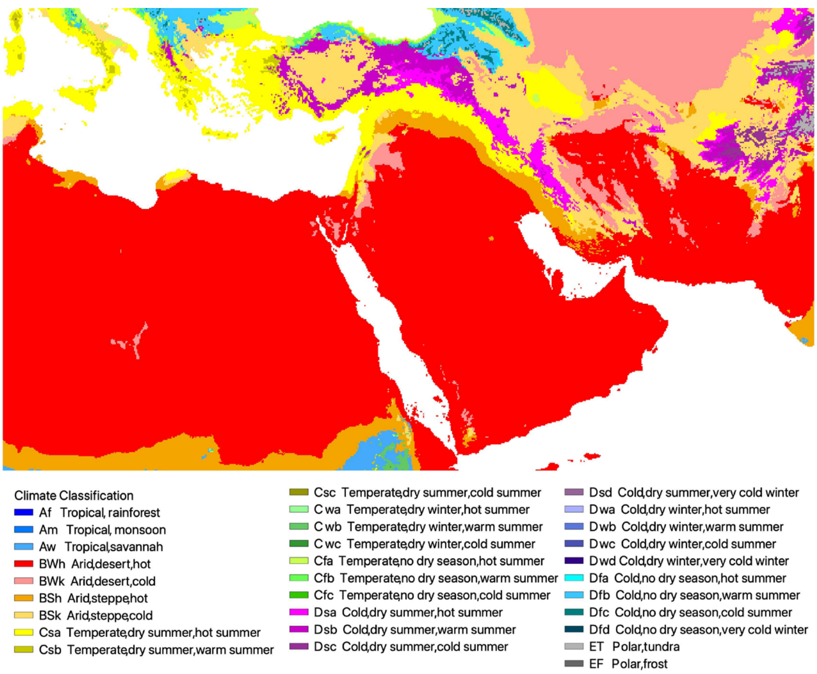


Source: FAO.

GDP is 3.06%, with wide disparities between countries. It is clear from the available data that the contribution of the primary production sector to GDP has plunged in all countries of the region since 1990, though, again, the declines differed from country to country. In Cyprus, for example, the contribution of the primary sector to GDP dropped by 70% and in Israel by 11%. Surprisingly, it grew by 22% in Kuwait.

The region comprises countries with many different climates, ranging from all subtypes of the Mediterranean to semi-arid and arid climates (Figure 3). Temperatures have risen in all countries of the region relative to the baseline of 1951-1980, but they have risen more

FIGURE 3. The EMME region according to the Köppen-Geiger climate classification



in some (Figure 4). Mountains, plains and deserts form an intense relief, and many areas have very long coastlines (Figure 5). The variability in climate, geographical location, geological history and topography is reflected in the rich variety of ecosystems, especially in the Mediterranean parts of the EMME region.

FIGURE 4. Temperature change (˚C) from baseline period of 1951-1980 to 2019

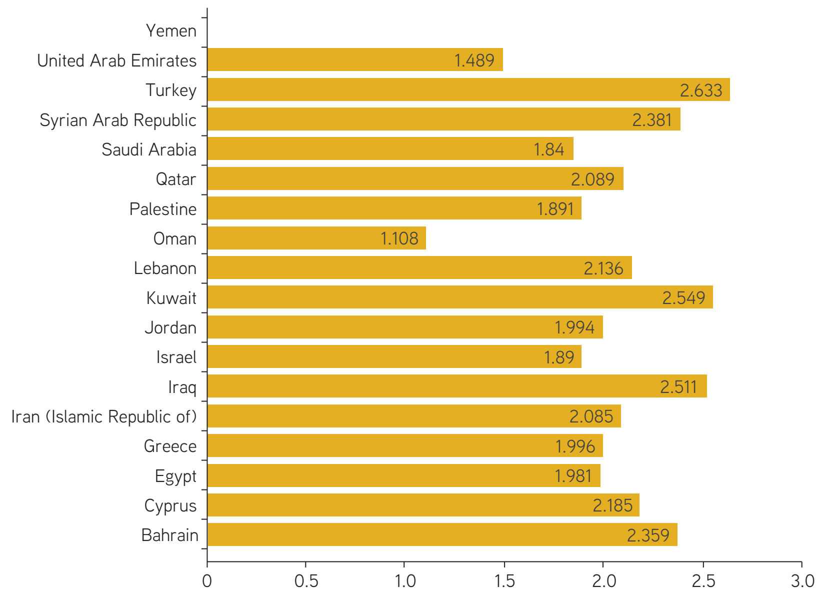


FIGURE 5. Satellite photo of the EMME region

3. Food ecosystems and climate change

This section provides an overview of the current situation in the EMME region. It will identify research gaps related to technology adoption and maturity, as well as peripheral issues such as data availability and data sharing.

3.1. Livestock

Livestock accounts for a substantial portion of agricultural GDP, often more than half, in the EMME countries. Climate change is a major threat to the sustainability of livestock systems globally and will affect livestock performance throughout the region. Most predictive models suggest a detrimental impact. Climate change may manifest itself as rapid changes occur in the short term (a couple of years) or as more subtle changes take place over decades.[1]

Weather extremes – intense heat waves, floods, and droughts – pose the gravest difficulty for livestock. Farm animals are adversely affected by the detrimental effects of extreme weather. Climatic extremes and seasonal fluctuations in the quantity and quality of herbage affect the well-being of livestock and will lead (or already have led) to efficiency declines in production and reproduction [1]

In addition to production losses, extreme events also result in livestock deaths. Animals raised in climate-change hotspots like the EMME region can adapt, given enough time, to hotter and drier weather, but response mechanisms that foster survival may harm performance.

3.1.1. Direct and indirect effects of climate change on livestock

The most significant direct impact of climate change on livestock production comes from heat stress. Heat stress results in a significant financial burden to livestock producers through decreases in milk production, meat production, reproductive efficiency and animal health. Thus, higher air temperatures, such as those predicted by various climate change models, could directly affect animal performance.

But most of the production losses result from *indirect* impacts of climate change, largely through reductions in, or non-availability of, food and water resources. Climate change has the potential to affect the quantity and reliability of forage production, the quality of forage,

1. Generally, climate change is associated with increasing global temperatures. Various climate model projections suggest that by the year 2100, mean global temperature may be 1.1–6.4 °C warmer than in 2010.

the availability of water for the cultivation of forage crops, and broad patterns of rangeland vegetation. In the coming decades, crops and forage plants will continue to be subjected to warmer temperatures, elevated carbon dioxide and wildly fluctuating water availability due to changing precipitation patterns.

Climate change can adversely affect the productivity, composition, and quality of forage species, with potential impacts not only on forage production but also on other ecological landscapes. In several world regions, wide fluctuations in distribution of rainfall during the growing season greatly affect forage production.

Changes in temperature and weather affect the quality, quantity and distribution of rainfall, snowmelt, river flow and groundwater. Climate change can increase the intensity of precipitation, leading to greater peak runoffs. Longer dry spells may lessen groundwater recharge and shrink river flow, thereby reducing the availability of water for agriculture and drinking. The deprivation of water disrupts animals' physiological homeostasis, leading to a loss of body weight, low reproductive rates and lower resistance to diseases. More research is needed into water resource vulnerability to climate change in order to support the development of adaptive strategies for agriculture. In addition, emerging diseases, including vector-borne diseases that may arise because of climate change, will result in severe economic losses.

Animals reared in arid or extreme environments such as those found in the EMME region are generally subjected to more than one stressor at a time. Multiple stressors greatly affect animal production, reproduction and immune status. Most studies that have investigated the effects of environmental stress on livestock have generally studied one stressor at a time because comprehensive, balanced multifactorial experiments are technically difficult to manage, analyse, and interpret [2]. When the animals were subjected to heat and nutritional stress as separate events, the impact of a single stressor was not as detrimental to growth and reproductive performance, as was the case when the animals were subjected to both stressors at the sameme [2]. The combined stressors had major effects on growth and reproductive parameters. In addition, the adaptive mechanisms exhibited by these animals were different for individual stressors compared with combined stressors (heat and nutritional) [3]. Hence, when two stressors occur simultaneously, the impact on the biological functions necessary for adaptation and maintenance during the stressful period may be severe [1]. Hence, research into climate change effects on livestock must address multiple stressors.

3.1.2. Impact of climate change on livestock production, reproduction, adaptation, and disease

Animals exposed to heat stress reduce feed intake and increase water intake, and there are changes in endocrine status, which in turn increase the maintenance requirements and reduce performance [4]. Environmental stressors reduce body weight, average daily gain and body condition of livestock. Declines in milk yield are pronounced. Milk quality is affected: reduced fat content; lower-chain fatty acids; solid, non-fat, and lactose contents; and increased palmitic and stearic acid contents are observed. Generally, animals with high productivity are the most affected. Adaptation to prolonged stressors may be accompanied by production losses. Increasing or maintaining current production levels in an increasingly hostile environment is not a sustainable option. It may make better sense to look at using adapted animals, albeit with lower production levels (and lower input costs), rather than trying to infuse "stress tolerance" genes into non-adapted breeds [4].

Reproductive processes are affected by thermal stress. Conception rates of dairy cows may drop 20-27% in summer, and heat-stressed cows often have poor expression of estrous due to reduced oestradiol secretion from the dominant follicle developed in a low luteinising hormone environment. Reproductive inefficiency due to heat stress involves changes in ovarian function and embryonic development by reducing the ability of oocytes to be fertilised [5]. Heat stress compromises oocyte growth in cows by altering progesterone secretion, the secretion of luteinising hormone, follicle-stimulating hormone and ovarian dynamics during the estrous cycle. Heat stress has also been associated with impaired embryo development and increases embryonic mortality in cattle. Heat stress during pregnancy slows the growth of the fetus and can increase fetal loss. Secretion of the hormones and enzymes regulating the reproductive tract may also be altered by heat stress. In males, heat stress adversely affects spermatogenesis, perhaps by inhibiting the proliferation of spermatocytes.

Thermal stress also affects the hypothalamic-pituitary-adrenal axis. Corticotropin-releasing hormone stimulates somatostatin, possibly a key mechanism by which heat-stressed animals exhibit reduced growth hormone and thyroxin levels.

To maintain body temperature within physiological limits, heat-stressed animals initiate compensatory and adaptive mechanisms to re-establish homeothermy and homeo-stasis, which promote survival but may impair productive potential.

The stress imposed on livestock manifests in various physiological responses – respiration rate, pulse rate and rectal temperature. Animals thriving in hot climates have acquired genes that protect cells from the increased environmental temperatures. Using functional genomics to identify genes that are up- or down-regulated during a stressful event could help in the detection of animals genetically adapted for coping with stress and in the creation of therapeutic drugs and treatments that target affected genes [6]. Studies evaluating genes known to be involved in the cellular acclimation response (e.g. as detected in microarray analyses or genome-wide association studies) indicate that heat shock proteins are playing a major role in adaptation to thermal stress.

As noted, variations in temperature and rainfall are the most significant climatic variables affecting outbreaks of livestock disease. Warmer and wetter weather (particularly warmer winters) will increase the frequency and severity of animal diseases, because certain species that serve as disease vectors, such as biting flies and ticks, are more likely to survive year-round. New disease vectors such as malaria and tick-borne diseases (babesiosis, theileriosis, anaplasmosis), Rift Valley fever, and bluetongue disease have been documented [7-9]. Certain existing parasitic diseases may also become more prevalent, or their geographical range may spread if rainfall increases. This may contribute to the spread of livestock diseases such as ovine chlamydiosis, caprine arthritis, equine infectious anaemia, equine influenza, Marek's disease and bovine viral diarrhea. Outbreaks of diseases such as foot-and-mouth disease or avian influenza affect very large numbers of animals and contribute to further degradation of the environment and surrounding communities' health and livelihood.

To summarise, although there is considerable evidence that heat stress can severely impair animal performance, inflicting heavy economic losses, molecular biotechnology offers new opportunities, through gene expression, to improve cellular responses to heat stress. The results of systematic assessments of the effects of climate change on livestock production may prove valuable in developing appropriate adaptation and mitigation strategies to sustain livestock production in the changing climate scenario. Livestock is an important source of livelihood in the EMME region, so suitable solutions must be found, not only to maintain the industry as an economically viable enterprise but also to enhance its profitability and decrease environmental pollutants by mitigating the ill effects of climate change.

3.2. Food security and crop systems

The United Nations Committee on World Food Security has defined food security as "the process during which people have at all times, physical, social and economic access to sufficient, safe, and nutritious food that meets their food preferences as well as dietary needs for an active and healthy life".

Food insecurity in the EMME region is imperiled by the reduced capacity of food production systems to meet the needs of a growing population. Rising food prices as a consequence of poor economic growth and market fluctuations in the region also lead to food insecurity [3]. Although cereal and meat production in the region has risen by 17% since 1990 (see Figure 6 for cereal production), absolute production lagged growth in food demand, widening the gap between domestic production and imports (Figure 7).[2]

And now, climate change looms as a growing threat. Climate models predict more unfavourable conditions for food production through the end of the century, irrespective of cropping system. The relevant climatic parameters affecting crop growth and yield are the rise in temperature, the rise in CO_2 concentration, erratic patterns of precipitation (and less of it), a rise in evapotranspiration, and more frequent droughts, floods, and heat spells. Crops will be also affected by new pests and pathogens, invading weed species, and changing patterns in epidemiology and competition induced by the change in climate.

FIGURE 6. Cereal production in the EMME region, 1990-2017

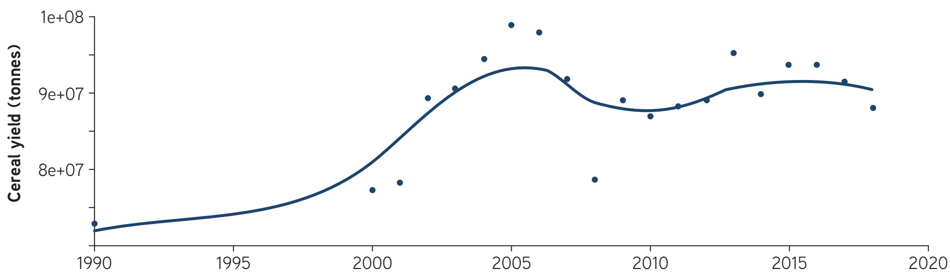
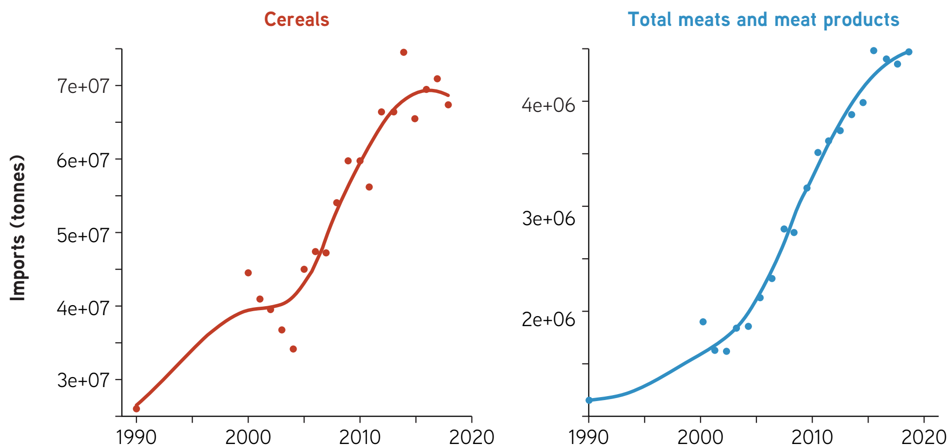


FIGURE 7. Imports of cereals and meat into the EMME region, 1990-2017



2. It is also true that the Middle East and North Africa depend heavily on water from outside the region in the form of the water embedded in food imports and accessed through trade [4].

The predicted increase in water deficits caused by the drop in precipitation, combined with the likely rise in evapotranspiration, will be a critical factor affecting the productivity of food systems. Rising living standards, industrial activity, and population will all boost demand for food, abetted by the dietary shifts among the population toward water-intensive, animal-based products.

Estimates of the impacts of climate change on crop production in the eastern Mediterranean are based either on crop simulation models or on compilations from the literature. In Greece, Kapetanaki and Rosenzweig [10] predicted decreases of up to 15% in Greece's maize yields. Giannakopoulos, et al. [11] estimated in their worst-case scenario a 1% decline in maize yields; decreases of between 5.4% and 9.3% in sunflower, pulse, and potato yields; and an increase of up to 4.4% in wheat and barley yields in Greece, Serbia and Turkey.

However, negative impacts ranging from 4% to 23% were predicted for the same crops in south-eastern Mediterranean countries (Egypt, Libya, Jordan). Karamanos, et al. [12] estimated the impacts of climate change on field, tree, and vegetable crops all over Greece (12 climatic zones); they found zero or positive effects on productivity in the northern and western Greece for most crops. On the other hand, production tended to decrease by more than 10% in the eastern and southern zones and on the Greek islands.

Voloudakis, et al. [13] predicted positive impacts on cotton yields of between 10% and 30%, while maize yields were expected to vary between -5.7 to +5%, depending on the region of Greece and the GHG-emissions scenario. Georgopoulou, et al. [14] predicted significant variations in yields of several crops in the same Greek climatic zones through 2050, under a moderate emissions scenario. In particular, increases in yield compared with 1961-1990 were predicted for wheat (4.3 to 26.7%), cotton (9.8 to 46.5%), and rice (14.9 to 29.9%). Negative impacts were found for beans (-7 to -47.5%) and sunflowers (-64 to -65.3%), whereas vegetables, olives, and grapevines exhibited significant yield variations, either positive or negative, depending on the region.

Further results on Mediterranean crops such as olives, grapevines and durum wheat are available for the Mediterranean region, especially for Italy [15-17]. It seems that climate change may positively affect cool-season (C3) crops due to the predicted high CO_2 levels. Maize, sorghum and other C4 crops may be adversely affected because they are less responsive to the rise in CO_2. Cool-season crops could behave better in northern latitudes and higher altitudes; little impact is expected on warm-season vegetable and tree crops.

All assessments involve a degree of uncertainty, since they are based on meteorological models for the prediction of future climate, as well as on the crop simulation model chosen for the predictions. Accordingly, to achieve the goals of the initiative of which this report is a part, it will be important to select common meteorological and crop simulation models, so as to achieve comparable results for all participating countries. Furthermore, since the expected outcome of the common exercise will be estimates of productivity rather than yields, soil desertification trends should also be considered. Estimates from Greece pointed to a significant loss of fertile agricultural land caused by climate, salinisation and poor agricultural practices [12].

3.2.1. Water management and sustainability

Several studies have shown that water scarcity and population dynamics are the main constraints on food production in the eastern and southern Mediterranean [18, 19]. Drought peaked in the EMME region in 2009, affecting half the region and hampering production of agricultural ecosystems [20]. There is growing pressure on the distribution and allocation of good-quality water for agriculture and an urgent need to improve the efficiency of water use for food production. Agricultural ecosystems, and food systems in general, should respond and adapt to the region's scarce water resources through strategic planning. According to the UN Food and Agriculture Organization (FAO, 2017), agricultural water accounted on average for 64.9% of of total water withdrawals for the period 2013-2017, with significant differences among countries. The highest irrigation shares in the region are in Iraq (91.5%), Saudi Arabia (82.2%) and Oman (85.8%); the lowest are found in in Qatar (31.9%) and Bahrain (33.3%). These disparities demonstrate that a country-specific framework must accompany the regional strategy.

To increase food availability in a sustainable way and enable the agricultural system to meet the challenges of climate change, policies backed by scientific evidence are needed to improve water-use efficiency all along the food chain. This will include greater investments in wastewater treatment and reuse to support agricultural production in the marginal farmlands of EMME's arid and semiarid areas [21].

A hundred years ago, when water-use efficiency was introduced into plant science [22], it was defined as the amount of biomass produced per unit of water used by a plant. Recently, Basso and Ritchie [23] showed that maize productivity could be increased with no change in water use, an important finding for the EMME region, as it suggests that higher plant yields do not necessarily depended on more water. Accordingly, plant breeders should aim to select genotypes with high assimilation rates under higher temperatures and water-limited conditions. Several features related to plant growth and physiology have been identified. For example, phenotypes exhibiting a fast initial growth stage or a shorter biological cycle could be combined with increased water-use efficiency through reduced soil evaporation and water consumption [24]. These still must be validated in the EMME region.

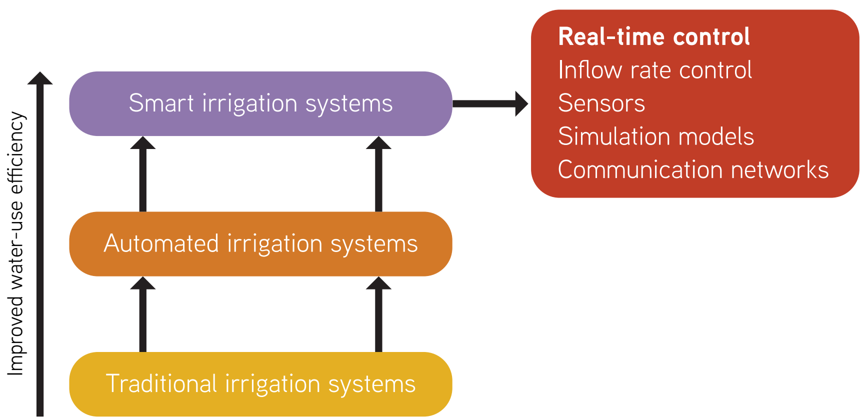
Just as urgent is the need to explore and perfect management practices to improve water-use efficiency for irrigated systems. Many studies have shown that an estimated 44% of irrigation water is lost through evaporation or leakage during storage and transportation to fields, as well as through runoff or drainage during irrigation [25]. The installation of modern and innovative irrigation systems (such as water-deficit irrigation, see below) is indispensable to the water-use efficiency of agricultural ecosystems (Figure 8), while also upgrading and maintaining the systems already in place.

Water-deficit irrigation can save water without a significant reduction in yields. Yet this approach has been overlooked [27, 28]. The design of a deficit-irrigation program must be based on knowledge of the correlation of crop yield and water consumption; however, the strength of that correlation in differing locations and for specific crops and climatic conditions is not yet known with sufficient precision.

Under water scarcity, the crop response to water-deficit irrigation should be diligently assessed, given its potential to ease the impact of climate change on agricultural ecosystems [29] (Box 1). Studies on olives have shown that regulated deficit irrigation resulted in 72% water savings and decreases of yield and oil production of 26% and 17%. Respectively [29, 30]. Similar findings exist for other crops, such as sunflowers [31], cotton [32, 33], and citrus fruits [34]. Again, the practice must be adapted for each crop and climate to avoid major yield losses due to water stress during sensitive phenological stages.

In addition to innovations in irrigation, numerous studies have shown that a variety of practices – mulching, nutrient management, microbial inoculants and biostimulants, plant spacing, seeding timing, crop type, rotations, and intercropping – could improve the water-use

FIGURE 8. The impact of new technologies and advanced irrigation systems on water efficiency



Source: Koech and Langat, 2018 [26]

BOX 1. Application of water-deficit irrigation on selected crops in four Arab countries

Within the framework of an initiative on "Promoting Food and Water Security through Cooperation and Capacity Development in the Arab Region" supported by the Swedish International Development Cooperation Agency, the UN Economic and Social Commission for Western Asia assessed the impacts of changing water availability due to climate change on agricultural production in selected Arab countries.

Deficit irrigation simulations were carried out on irrigated crops in Egypt, Iraq, Jordan and the State of Palestine. Table 1 shows result for climate change scenarios (Representative Concentration Pathways 4.5 and 8.5).

In Egypt, the agricultural sector consumes 80% of the country's water resources. For that reason, applying deficit irrigation on a large scale for wheat and maize could ease Egypt's water pressures, as scenarios suggest limited to no adverse effects on both crops. In Iraq, the application of deficit irrigation verified the actual quantities of water required to achieve comparable rates of productivity.

TABLE 1. Change in crop yield under deficit irrigation scenarios

Country	Change in crop yield (%)	
Egypt (Sakha)	20% deficit irrigation	40% deficit irrigation
Wheat	<1%	<1%
Maize	No change	No change
Tomato	–22%	–45%
Iraq (Al Suwaira)	20% deficit irrigation	40% deficit irrigation
Wheat	–2 to –4 %	–8 to –10 %
Tomato	–7 to –14%	–34%
State of Palestine (Marj Ibn Amer)	20% deficit irrigation	25% deficit irrigation
Potato	–8.5 to –20%	–24 to –28 %
Jordan (Mafraq)	17% deficit irrigation	
Tomato	–6 to –9%	

efficiency of agricultural ecosystems [35, 36]. For example, the meta-analysis of Mbava, et al. [37] concluded that under optimal growing conditions the most water-efficient crop was maize, whereas sorghum was most efficient in semi-arid environments. Soil texture also affects water-use efficiency, and several studies have reported a negative association between the clay content of soils and water-use efficiency [38-41]. The more-efficient water use noticed in these soils is correlated with higher water availability [38] and the development of denser root systems, raising the capacity of plants to take in water [42]. These findings suggest that improving soil fertility and soil texture could substantially improve the performance of agricultural ecosystems under water-limited conditions.

3.2.2. Temperatures and CO_2 concentrations

High temperatures lower crop yields when they exceed the optimal thermal range of many physiological processes [43]. Negative impacts from higher global temperatures will be observed mostly in cool-season crops, which have lower cardinal temperatures in principal physiological processes such as photosynthesis and respiration, in comparison with warm-season crops. Specifically, high temperatures are inducing early growth by accelerating crop growth and development [44], accelerating senescence [45], degrading seed-set by reducing pollen production and viability, and producing lower grain weights by shortening the duration of the grain-filling period [46-49]. Higher winter temperatures will slow floral initiation in cool-season crops through their effect on vernalisation [50]. As a result, many investigators predict yield declines for most crops, both rainfed and irrigated, throughout the 21st century [51, 52]. For example, an increase in temperature by 3ºC could cause a decline in barley production in Jordan ranging from 22% to 51% [53] [50]. In Israel a rise in average temperature, combined with lower precipitation and no adaptation measures, will diminish wheat and cotton yields [54]. However, the simulation effects of high temperatures on crop yields show considerable uncertainties. Comparisons of crop models show differences between models that are greater than the differences across climate projections [55]. To overcome this uncertainty multi-model ensemble studies have been proposed [48, 55, 56].

A recent review based on experimental results – not simulations – showed that only 14 greenhouse or field trials on the impact of increasing temperature on yield of vegetables are available [57]. The review revealed average yield reductions of 31.5% in areas where the baseline temperature was above 20˚C, common in the EMME region. These findings emphasise the need for further study of how these crops can adapt to higher temperatures. Surprisingly, no parameters related to the nutritional quality of fruits and vegetables have been reported in these studies, creating a significant gap in knowledge.

Carbon dioxide contributes to global warming. The rate of increase in CO_2 concentrations, now more than 1.5 ppm (μmol/mol) per annum, is likely to continue for the foreseeable future owing to fossil fuel consumption, rapid population growth and the destruction of forests and grasslands – unless drastic mitigation measures are taken. The levels of CO_2 by the end of the century are likely to rise to 700-850 ppm, depending on the emission scenario [206]. Carbon dioxide is a major determinant of crop yields, as it is the main substrate for photosynthesis (Box 2). In principle, increasing air CO_2 concentration brings about an increase in the rate of photosynthesis [207]. Indeed, increased dry matter production and yields have been observed in many crops grown under higher CO_2-levels [58, 59]. The responses differ by crop, depending on the metabolic pathway of carbon fixation:

C3-crops are more responsive to higher CO_2 levels than are C4 crops [59]. However, there are strong interactions between CO_2 concentration and rising temperatures, plant-water status and internal factors (such as source-sink relationships), which complicate predictions of crop responses to the rise in CO_2 [60, 61]. Any study of rising-temperature effects on crop production may lead to erroneous conclusions if elevated CO_2 concentrations are not considered.

BOX 2. Impact of changing CO2 concentration on crop yields

The UN Economic and Social Council for Western Asia, the UN Food and Agriculture Organization, and ACSAD (The Arab Centre for the Studies of Arid Zones and Dry Lands) trained a team to conduct assessments of the impact of projected climate change (expressed in terms of changes in water availability, temperature and carbon dioxide) on selected crops in nine Arab countries using AquaCrop simulations. Climate change projections from the Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region were used. The projections correspond to two Representative Concentration Pathways (RCP) – that is, the greenhouse gas concentration trajectories – adopted by the Intergovernmental Panel on Climate Change: RCP 4.5 and RCP 8.5.

To analyse the effect of elevated CO_2 on crop yields, two sets of projected CO_2 concentration changes were simulated; one considered the effects of increasing CO_2 concentrations (RCP 8.5), and another kept CO_2 concentrations at the baseline level (RCP 4.5). This made it possible to disaggregate the mitigating effect of increased CO_2 on yield from adverse impacts of temperature rise and water scarcity, and to account for related uncertainties.

In Egypt's Sakha area, rising temperatures had limited impact on the productivity of irrigated wheat and maize in the case of stable CO_2 concentration, whereas the increase in CO_2 concentration increased productivity for both crops (Table 2). The effect of rising CO_2 concentration had less-significant positive effects on maize yield than on wheat. This can be explained by the fact that maize belongs to the C4 group, which reacts less strongly to higher CO_2 concentrations, whereas wheat falls in the C3 group. In Nubaria, the results of changes in CO_2 concentration on the productivity of irrigated tomatoes had varied results. The higher CO_2 concentration raised productivity by enhancing the photosynthetic rate of plants while reducing transpiration. However, studies refer to the low nutritional value of crops produced under conditions of increased CO_2, especially when combined with rising temperatures. The loss in nutritional value resulting from the increase in CO_2 concentration may offset the advantage of increasing quantity.

Similarly, in Iraq, the assessment shows that rising temperatures will reduce irrigated wheat and tomato yields in the case of stable CO_2, while yields of both crops will rise in all scenarios with rising CO_2 concentration. The projected increase in yield is the result of the mitigating effect of the elevated CO_2 concentration. However, results should be considered carefully, since other non-linear limiting factors may counteract the positive effect of changing CO_2 on yield.

(Continued next page)

BOX 2 (continued)

TABLE 2. Main findings of assessment in Egypt for the 2040-2050 period

	Wheat	Maize	Tomato
Average total cultivated area (million hectares)	1.1*	0.84*	0.11**
Average production for the total area (million tonnes/year)	6.8	6.7	3.9
Change in productivity as a result of climate change [%] * **			
Stable CO2 concentration	–4.8	–2.9	–1
Increased CO2 concentration	+12.8	+0.4	+28
Average production for the total area (million tonnes/year)			
Stable CO2 concentration	6.5	6.5	3.9
Increased CO2 concentration	7.7	6.7	5
Self-sufficiency ratio of the crop (%)			
Present value	47.7	56.3	103
Stable CO2 concentration	45.4	54.7	102
Increased CO2 concentration	53.8	56.5	132.4

* Average of production area in old lands only
**Average production area for new lands only
*** Average values from the three crop simulations using the AquaCrop model.

In Yemen, the average wheat productivity in both Sana'a and Dhamar regions is shown to decrease with stable CO_2 and to increase with rising CO_2. Results have shown that sorghum yield is expected to show a greater drop in productivity than wheat in the studied areas of Sana'a and Dhamar (Table 3). This may be attributed to the fact that wheat is a C3 crop and appeared to benefit positively from CO_2 concentration, whereas sorghum is a C4 crop. Further, sorghum crop production in Sana'a was projected in conditions with less supplementary irrigation than that for wheat, while in Dhamar, the simulation was carried out under rainfed conditions, thought to be most sensitive to climate change. In addition, sorghum cultivation dates at Sana'a and Dhamar precede those for wheat.

TABLE 3. Changes in wheat and sorghum yield in Sana'a and Dhamar

Region	Emission Scenario	Wheat yield change (%)		Sorghum yield change (%)	
		2025	2045	2025	2045
Sana'a	RCP 4.5	–4.24	–6.11	–6.71	–11.93
	RCP 4.5*	+8.33	+12.56	–3.05	–6.03
	RCP 8.5	–3.81	–7.62	–8.22	–13.88
	RCP 8.5*	+13.12	10.25	–4.18	–8.26
Dhamar	RCP 4.5	–7.02	–14.57	–26.45	–29.81
	RCP 4.5*	+5.64	+2.89	–21.63	–24.29
	RCP 8.5	–5.21	–22.35	–3.12	–10.3
	RCP 8.5*	+9.8	–3.96	+2.64	–2.47

Plant breeding has a crucial role to play, as new varieties may respond better to climate change (in the form of biotic and abiotic stresses, including heat and drought), and consume fewer productive resources, including water and fertilisers. The fundamental basis of historical breeding progress in all crops has been the incremental accumulation of beneficial alleles for complex quantitative traits, such as yield, stability and quality. This process will continue to play a major role in crop adaptation to climate change in the future, assisted by novel field methods and technologies, such as plant root and canopy phenotyping, remote sensing and image analysis [62, 63]. The involvement of microbial communities in the plant rhizosphere to acquire or enhance novel breeding traits, such as improved exploitation of mineral resources, is one field of current research. Additional important factors in the adaptation to climate uncertainty include methods of "participatory" plant breeding – undertaken with the active involvement of local farmers.

3.2.3. Pest and disease management

Pests and diseases are major factors in agriculture productivity. In fact, up to 40% of the world's food losses are attributed to pests. At the same time, in many areas of the globe, new invasive species are appearing because of climate change [64]. This is particularly true for the Mediterranean, where the high-density traffic in the region's shipping ports and airports lowers barriers to invasive species, as illustrated by the arrival and establishment of agricultural pests such as *Tuta absoluta* [65-67].

Gregory, et al. [68] finds that problems related to pests and diseases will become more unpredictable and intense. This and other studies have shown that climate change could affect pest- and disease-related patterns in more complex ways than expected [69].

Climate change has both direct and indirect effects on the distribution of plant pathogens and pests, with a shift toward the poles of almost 2.8 km per year since 1960 [70]. The complicated direct effects on pests and diseases of the key components of climate change (i.e., temperature, CO_2 levels, water availability) makes prediction a challenge. For example, when a pest or a disease is present, plant infestations increase when synchronised with the changes in the susceptible plant's development [69]. Higher temperatures may speed up the generation rates of insect species, leading to population increases and more infestations. These changes in population dynamics could lead to more pesticide applications, posing serious environmental risks [64]. Moreover, the effect of climate change on host crops, plant pathogens and insects' natural enemies further complicates any attempt to project the impact of climate change. For example, differences in the thermal preferences of crop pests could increase the risk of pest outbreaks owing to exclusion of parasitoids from areas where they are currently found [71].

To better understand pests and diseases in the EMME region, a better assessment of the dynamic interactions of the tripartite systems (plants and pests; pathogens; and natural enemies) is urgently required. To design the best strategies for pest and pathogen management in the region's ecosystems, the impacts of climate change on crop phenology must be projected alongside and in close relation to the development and infestation of pests and diseases, a process known as climate-smart plant protection management (Box 3). So far, only a few modelling studies have considered these interactions; of those, few have included the EMME region [72-74].

BOX 3. The principles of climate-smart plant protection management

Climate-smart plant protection management (CSPPM) involves the widespread application of management methods to achieve the co-benefits of enhanced mitigation of, and strengthened resilience to, climate change. A toolbox has been developed under this conceptual framework to provide detailed and focussed pest-management guidance [59]. The toolbox draws on currently available interdisciplinary approaches and strategies ready for use by the critical actors in agricultural ecosystems (farmers, extension services, researchers, policy makers). CSPPM is not a stand-alone process or strategy, but a holistic approach that includes other relevant aspects of agricultural ecosystem performance. In addition to enhancing adaptation, CSPPM could help mitigate climate change by improving the overall balance of emissions of greenhouse gases, particularly when calculated per unit of food produced.

Adapting agricultural ecosystems to climate change is an ongoing process of deploying strategies to reduce the risks of climate change. These strategies include measures and activities that may or may not require significant changes to agricultural ecosystems. For example, the countries of the EMME region already apply biopesticides or chemical pesticides in response to emerging pests and diseases. The use of varieties and genotypes that are more resilient under the "new" climatic conditions would be critical for reducing the risk of infestations. Moreover, adopting specifically designed crop rotations and intercropping strategies, or shifting to a new crop, may be necessary to protect crops from pests and diseases.

Local institutions, competent authorities, and research centres should develop more efficient diagnostic processes to identify emerging pests and diseases. This will facilitate the prompt development of management strategies. The development of efficient plant protection strategies to support agricultural ecosystems against future pest and disease outbreaks also include investigating multitrophic interactions using appropriate modelling. The higher adaptive responsiveness of pest and diseases to climate change highlights the importance of developing plant protection action plans, including actions that raise farmers' awareness of emerging pests and diseases threatening their crops. Early detection and rapid-response action plans are essential for minimising crop losses. Capacity building should support these plans.

3.3. Land degradation

Land in the EMME region is extremely vulnerable to damaging human activities, chief among them deforestation, overgrazing and unsustainable agricultural practices.

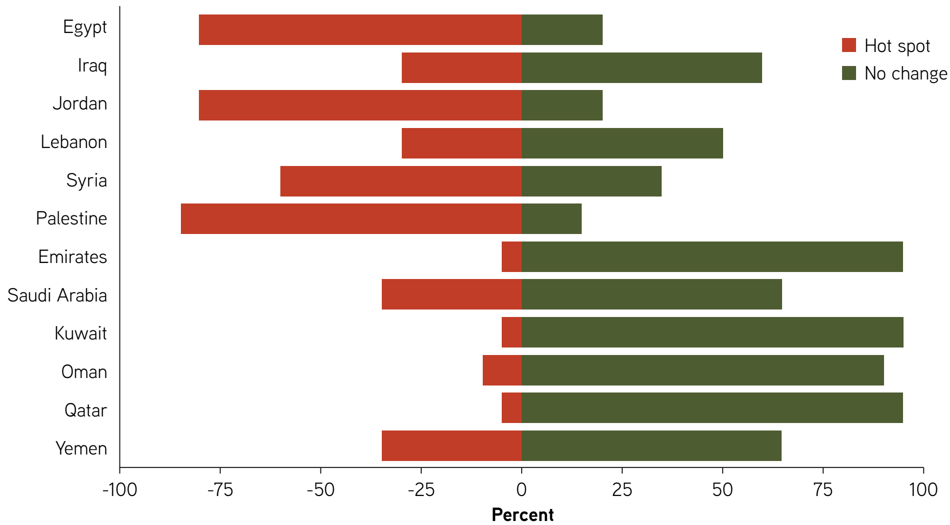
The soils of the EMME region are diverse. Most receive low amounts of precipitation or abundant rainfall for only short periods during the year. In addition, most EMME countries see widely varying annual precipitation. The low availability of water, combined with high temperatures, accelerates the mineralisation of organic matter, which makes soils sensitive to desertification despite their general adaptability to climatic variability and drought. In the more humid parts of countries like Greece, Turkey, Syria and Lebanon, and in the mountainous regions of several countries, soils are generally richer in organic matter.

The main cause of land degradation in the arid, semi-arid and hyper-arid areas of the region is desertification, defined as the loss of the biological or economic productivity of land. Desertification greatly hampers agricultural productivity, worsens droughts and increases human vulnerability to climate change. The loss of biodiversity in arid and semi-arid soils (meaning the loss of bacteria, fungi and insects living in the soil) is a major cause and outcome of land degradation. Irrespective of climate, the level of desertification is driven by many factors such as erosion, salinisation, and the presence of certain chemicals and pollutants.

Studies in the Middle East and North Africa reveal land degradation of 40% to 70% over the past few decades. Sustainable land-management strategies can preserve soil biodiversity, restore ecosystem functions, and control land degradation.

Faour [75] demonstrated land degradation in the Middle East and North Africa using the Normalised Difference Vegetation Index (Figure 9). The study highlighted that most countries had experienced substantial land degradation, regardless of land-management efforts. Lebanon, for example, has suffered moderate land degradation estimated at 32%, while 68% of the land remained unchanged. In Cyprus, 9.68% of the country faces environmental risk closely related to land degradation. Kolios, et al. [76] used the Environmental Sensitivity Area Index, based on four indices (climate quality, demographic, soil quality, and vegetation quality [77]), to distinguish environmentally sensitive areas of the country at a spatial resolution of 30 x 30 metres. In Israel, 95% of the country is hyper-arid, arid or semi-arid; 60% is covered by the Negev desert and faces constant risks of soil degradation and desertification. About a third of Iran's arable land is threatened by salinity [78]. In Greece, 26.5% of the land is categorised as highly vulnerable to drought and desertification [79].

FIGURE 9. Degraded land as a share of total land area in selected EMME countries



Source: Faour, 2014.

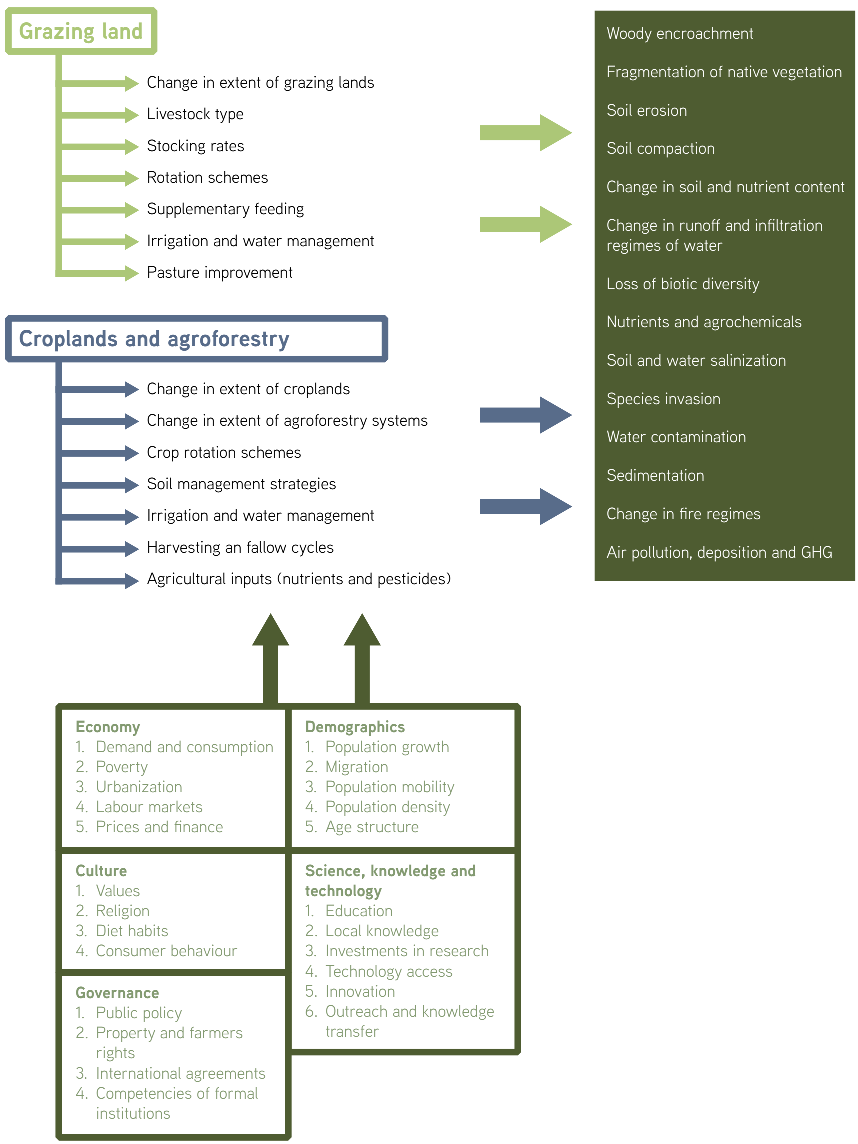
Although findings clearly show prevalent land degradation, the results of many studies are not comparable. Moreover, attempts to estimate soil productivity are hindered by missing or unreliable information [80]. A regional analysis of land degradation, using reliable data from all countries and common methodologies to identify the extent and intensity of land degradation in a comparable way, would enable policy makers and the research community to adopt measures and practices specifically designed for each region to stop land degradation [81].

Work is under way. To build a composite index of land degradation over time and space [82-84] several indicators will be needed. Some studies have attempted to identify appropriate soil-quality indicators [85-88]. In 2015, the United Nations Convention to Combat Desertification introduced the concept of "land degradation neutrality", the main objective of which is to achieve "no net loss" of land-based natural capital in comparison with a baseline value, using three global indicators (land cover, land productivity and carbon stocks) [89]. Although efforts have been initiated in the Middle East and North Africa, the concept of land degradation neutrality is still in its infancy. Coordinated efforts should be undertaken to support it.

3.3.1. Processes driving land degradation

Land degradation is driven by both natural and anthropogenic processes interacting on local to regional scales [90]. Direct anthropogenic drivers are found in the management of agricultural ecosystems (crop lands, agroforestry, grazing land); levels of urbanisation, infrastructure and development; changes in fire regimes; the introduction of invasive species; and non-timber natural resource extraction. Soil smuggling to other countries has also been reported [91]._Demographic, economic, cultural and governance elements have all been identified as indirect drivers of land degradation. Moreover, science and technology transfer are also critical factors indirectly related to land degradation. The major direct and indirect drivers are schematised in Figure 10.

FIGURE 10. Direct and indirect land-management practices affecting agricultural ecosystems



Direct and in direct processes of land degradation often combine to form a vicious cycle. Significant population growth, combined with high population density in urban centres and industrialisation, have hiked demand for food and water resources. In turn, these needs, in the absence of strong political will, have prompted governments to tolerate or even promote unsustainable practices for food production. Unsustainable resource management in rural ecosystems has degraded soils to the point where they have lost their productivity. The reduction of soil productivity has been addressed (where possible) with increased applications of external inputs, which in turn speeded deterioration through increased salinity. Indeed, soil salinity is affecting 20×10^6 hectares in the Middle East [92, 93]. Salt accumulation in soils affects 1×10^6 hectares in the Nile basin, seriously constraining agricultural activity. An increase has been recorded in the Jordan River, affecting irrigated agricultural areas of both Syria and Jordan [92]. Moreover, land degradation in some areas is expected to be further exacerbated by the violent conflicts in these regions. Thousands of refugees and displaced farmers have abandoned their land, with immeasurable consequences for agriculture and the economy. Steps must be taken to avoid further aggravation of the EMME region's already burdened agricultural land.

Soil erosion

Climate change is expected to increase the frequency of storms and heavy rainfall in the EMME region, which may lead to soil loss of up to 10 tonnes per hectare [94, 95]. Recently, Wei, et al. [96] showed that intensified rainfall would magnify land degradation through erosion, irrespective of soil structure and stability. Soil erosion has a detrimental effect on soil productivity through its effects on physical and chemical properties, including aggregate stability and size [97, 98]. Previous studies have shown that soil erosion reduces organic carbon and nitrogen content and increases bulk density, thereby reducing soil fertility and production capacity [99-102]. The EMME region also suffers from wind erosion, which lowers fertility and productivity by removing soil particles, organic matter and nutrients [103, 104] [90, 91]. Sand and dust storms also harm human health [105-107]. The lower rainfall and higher temperatures expected in the EMME region will further exacerbate wind erosion.

Although soil erosion mainly depends on the intensity and duration of rainfall and wind speed, other factors, such as land inclination, as well as land-use management also determine the severity of the process. For example, overgrazing and cultivation in arid and desert regions has worsened wind erosion not only on vulnerable (sloping) land, but also in more productive areas [87]. Indeed, on cultivated land in mountainous agricultural ecosystems, the net soil erosion was higher than that of forested areas. Agricultural terracing is reducing soil erosion in these areas [95]. These findings suggest that the creation of new terraces and the maintenance of those already established will substantially reduce soil erosion.

Tillage practices in established agricultural systems are another threat to land degradation, because the erosion they can cause is sometimes comparable to that caused by water erosion [108]. Conventional tillage practices in arid and semi-arid areas exposed to water and wind erosion pull out significant amounts of organic carbon and nitrogen from the soil [109], accelerating land degradation. Conservational tillage practices have been proposed as components of a more sustainable cultivation system, particularly to reduce soil and wind erosion, increase water storage and ameliorate ecological pressure in semi-arid regions [110, 111]. However, research is scarce on soil nutrients and systems productivity in sloped agricultural ecosystems in the EMME region. Maleki, et al. [112] found that the phase of the geomorphic surface of hillside landscapes may control soil organic carbon deposits.

Organic carbon stocks and changes

Three-quarters of the earth's organic carbon pool is found in the soil, making soil a critical component of the carbon cycle globally [113] [100]. An accurate assessment of soil carbon dynamics is required to estimate the carbon budget at the regional level [114]. The fate of organic carbon and its accumulation in the soil depends on the balance between inputs and losses. Biotic, abiotic and anthropogenic factors (tillage, land-use, cropping systems) control the interactive processes involved, which are complex and changeable. The expected rise in temperature and decline in rainfall could further degrade the region's already low levels of organic carbon [115].

Several models have been used in the Mediterranean region to assess the effect of management practices as well as the impact of climate change on soil organic carbon [116-121].

For example, 70% of Iran's agricultural soils have less than 1% soil organic carbon and only 4% have more than 2%. The descending trend since 1960 is attributed to climate change [122]. Egypt's natural soils are so low organic matter that any conversion to agricultural land, with the resulting increase in plant biomass, *increases* soil organic carbon [123, 124]. In agricultural areas of Egypt, a decrease in soil organic carbon was correlated to an increase in land surface temperature [125].

In Israel, the amount of soil organic matter is gradually decreasing in semi-arid to arid zones of the country [116]. A warmer climate may accelerate microbial activity and soil organic matter degradation, but a drier climate may decrease it; the balance may also depend on the quality of the added organic material, resulting in predictions of lower future soil CO_2 with more recalcitrant organic residues [126].

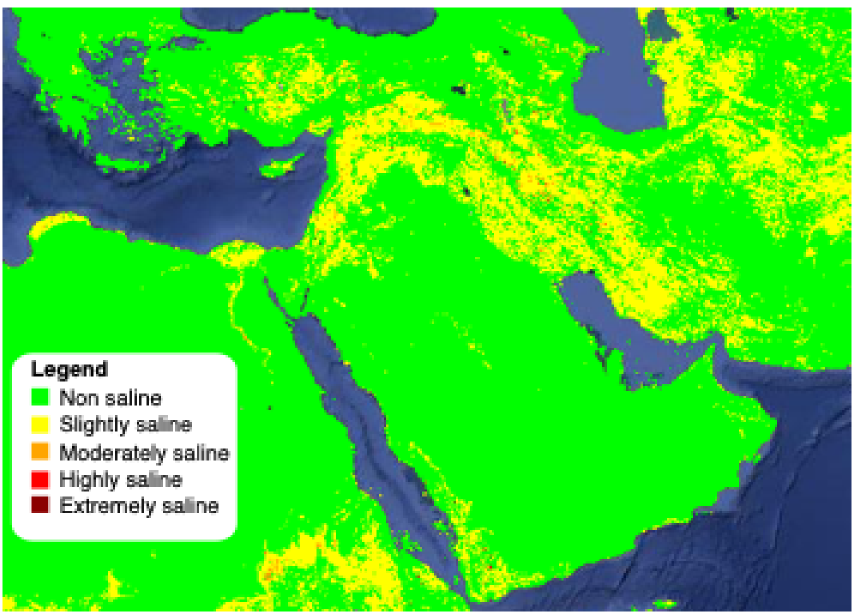
Conversion of land uses may release or store carbon. Converting forest or rangeland to farmland rapidly releases soil organic carbon. While several studies in the EMME region have examined the effects of different organic amendments and management practices on soil properties and soil carbon stocks, more systematic, long-term studies are required [127], as it takes decades for carbon stocks to build and show stable effects. For instance, 139-271 Kg C ha^{-1} were stored at the 0-30 cm depth 14 years after establishment of a tree-planting program in central semi-arid Iran [128]. Such long-term studies have been conducted in other regions of the world and their overall conclusions are valuable, but results vary with soil and climate.

Soil salinity

The distribution of soil salinity in the EMME region varies by country and land type [35, 129] (Figure 11). The high degree of variability is related to climate, agricultural activities and established irrigation practices. The main factors affecting soil salinity and sodicity in the region are the following:

- Improper functioning or absence of drainage systems on agricultural land
- Increases in groundwater salinity owing to the intrusion of seawater into coastal aquifers
- High rates of evapotranspiration
- High concentrations of salts in irrigation water
- Overuse of low-quality wastewater.

FIGURE 11. Soil salinity in the EMME region, 2016



Source: Modified from Ivushkin, et al. [129].

Agricultural land, coastal areas and irrigated land are adversely affected by salinisation. The food production areas of the EMME region most affected by soil salinisation include irrigated lands along Nile in Egypt, the Euphrates River basin and the Jordan River basin. In Iran, 14.2% of all land is salt-affected [130, 131]. In the Gulf states saline soils are found principally in coastal areas due to seawater intrusion and the extensive use of saline and wastewater irrigation [92]. Soil salinisation data are also available for Kuwait [132] and the United Arab Emirates [133].

In most cases, however, the available data are outdated, and there is an urgent need to estimate the rate of change in areas affected by salinisation and sodication, as both processes accelerate desertification. The proper management of salt-affected soils is critical to maintain – and perhaps even to improve – the productivity of these areas. Several practices have been proposed. They include:

- Direct salt leaching
- Improvement of drainage
- Promotion of salt-tolerant crop species and varieties
- Domestication of native halophytes
- Increased use of organic soil amendments.

A main component of the management strategy is the removal of salts from the root zone. However, this method is not consistent with water scarcity in the EMME region. The development and promotion of novel practices for the prevention and management of salinity are essential for the region. Immediate action is needed.

Soil biodiversity and land degradation

The semi-arid, arid and hyper-arid soils of the EMME region support an impressive array of biodiversity above and below ground, including wild plant and animal species as well as numerous cultivated plants and livestock species. Biodiversity in the region's soils is also extremely diverse; the functional communities found are uniquely adapted to the harsh conditions of water scarcity, increased salinity and temperature extremes. Soil biodiversity is fundamental for soil functioning and is tightly connected with the soil ecosystems services.

Climate change is affecting the above-ground ecology in both agricultural and natural ecosystems, altering the cornerstone processes of nutrient cycling and accumulation and composition of organic matter. These driving forces are expected to affect the functioning and composition of soil microbial communities, both directly (warming, salinity, aridity) and indirectly (elevated CO_2). Water availability, coupled with temperature and resource availability, drive microbial functioning in arid and hyper-arid environments [134]. Recently, a global study on drylands demonstrated that low precipitation and high evapotranspiration reduce the diversity and abundance of bacterial and fungal taxa [135]. The study attributed these changes to the negative impact of aridity on soil organic carbon [119, 121], which is positively associated with the abundance and diversity of bacterial and fungal communities in soils [136-138].

In arid environments, any further increase in aridity magnifies the loss of microbial biodiversity and abundance and decreases co-occurrences of bacterial taxa, suggesting that further deterioration of drylands will have harmful effects on the potential fertility and functioning of these soils [139] (see Box 4). Recently, multivariate analysis of available next-generation sequencing data confirmed that, besides temperature, climatic water content affects global patterns of microbial diversity [140]. The reduction of water availability and the overuse of fertilisers, coupled with higher temperatures, cause salts to accumulate in the soil.

Salt accumulation intensifies osmotic stress and taxa that can survive under these conditions and to become dominant, while sensitive taxa may gradually be excluded from the community [141]. The overall response of the microbial communities to the different drivers is taxa-specific and depends on their life strategies. For example, the relative abundance of *Acidobacteria* and *Verrumicrobia* has been shown to plummet as aridity increases, while *Chloroflexi* and *-Proteobacteria* followed an opposite pattern [135]. *Chloroflexi* exhibit multiple adaptations to severe environmental conditions such as high salinity and desiccation [142], while *Acidobacteria* and *Verrumicrobia* rapidly decline under drought conditions [143].

The effect of climate change on soil microbiome and biodiversity necessarily affects plants, since the interaction between them is fundamental for ecosystem functioning and shapes impacts on both components. For example, aridity and drought frequency are shifting interactions among plant species, thereby influencing the plant composition and cover in drylands [144-146].

Changes in plant composition and growth as a result of drought alters rhizodeposition, which in turn affects microbial composition and functioning [148]. Rhizodeposition enables plants to alleviate stress caused by drought by enhancing nutrient uptake from the rhizosphere [147]. Moreover, elevated CO_2 increases carbon allocation from photosynthetic tissues to roots, resulting in a significant increase of root biomass and changes in the chemical composition of roots exudates [148, 149].

More labile carbon in the rhizosphere could encourage microbial biomass and proliferated genes associated with carbon decomposition [150-153]. A positive feedback of soil microbial communities exposed to elevated CO_2 and warming has been noted in semi-arid ecosystems [154], suggesting accelerated soil carbon decomposition varying with plant physiology and species.

BOX 4. International research on ecosystem services and soil biodiversity

Global research has demonstrated that microbial diversity is tightly associated with ecosystem functioning and performance Microbial communities are key components in nutrient cycling, primary production, litter decomposition and climate regulation of terrestrial ecosystems [161, 162]. Recently, Wagg, et al. [163] showed that microbial richness, functional redundance (number of taxa supporting a specific function), diversity, complexity and inter-kingdom associations are strongly related to maintaining ecosystems' multifunctionality.

Nutrient cycling. Microbial communities play a pivotal role in the processes by which nutrients are made available to plants. Mineralisation is the main microbial process influencing the transformation of nutrients and their availability in soils. More than 90% of the dissolved nitrogen found in the soil derives from the mineralisation of organic matter of the soil, while free-living nitrogen-fixing bacteria are significant contributors in the nitrogen-budget of natural and agricultural ecosystems.

They are particularly important in dryland ecosystems, since nitrogen-fixing cyanobacteria are significant contributors to the addition of nitrogen. Drylands are extremely heterogenous ecosystems; non-cultivated land in these areas is often covered by biocrusts and sparsely distributed plants. Bacteria, fungi, algae, lichens and mosses are the main components of biocrusts and play central roles in nitrogen-cycling processes in dryland ecosystems [146, 164].

Nutrient storage at the ecosystem level is achieved through microbial uptake. It has extremely important implications for the fate of nutrients in the environment. For example, its immobilisation in combination with plant uptake significantly reduces the amount of nitrogen that is likely to be lost.

Microbial communities are also responsible for the availability of phosphorus and potassium in soils. Microbial species control the release of phosphorus from recalcitrant inorganic matter; organic phosphorus forms in the soil through the activity of organic acids and enzymes [165]. Similarly a wide range of microbial taxa can release potassium from clay minerals and organic matter, thereby raising the availability and cycling of potassium in soils.

Plant productivity and diversity. Microbial communities are important regulators of plant productivity in natural ecosystems and wherever plant symbionts are responsible for acquiring limiting nutrients. This is particularly important for nutrient-poor ecosystems where microbes may enhance the supply of limiting nutrients such as nitrogen and phosphorus. Specific microbial groups such as mycorrhiza and nitrogen-fixing bacteria may provide up to 90% of both elements in plants. At the same time, soil microbes act as pathogens and compete with plants for nutrients, with negative effects on plant productivity. Early studies demonstrated that in nutrient-poor grasslands three-quarters of plants could not survive in the absence of mycorrhizal fungi; a quarter could not survive without symbiotic nitrogen-fixing bacteria [166, 167].

(Continued next page)

BOX 4 (continued)

However, the role of microbial communities on plant diversity in the natural ecosystems of the EMME region has not been explored, while the effect of climate change on their diversity – and the related side-effects on plant communities in these areas – have been overlooked. Because microbial inoculants may be useful for the restoration of degraded terrestrial ecosystems [168], future efforts should focus on developing them specifically for drylands [169].

Carbon sequestration. The pool of soil carbon is twice as large as the atmospheric pool. The Calvin-Benson-Bassham cycle is the main route for CO_2 fixation, and the *ccbl* gene marker has been widely used to assess the abundance and the diversity of microbial autotrophs. Several studies have showed that autotrophic bacteria make a significant contribution to CO_2 fixation in diverse soils [170]. In agricultural soils, CO_2 fixation is related to the fertilisation strategy, tillage, land-use changes and crop rotation [171, 172]. Chen, et al. [173] demonstrated that microbial CO_2 fixation substantially contributes to primary production in dry grasslands. Zhao, et al. [170] showed that CO_2 fixation was higher in desert soils than in meadow soils, while autotrophs were much more abundant in desert soils. These findings strongly suggest microbial CO_2 fixation should be taken into account in large-scale studies for the assessment of carbon dynamics and gross primary production [173]. The contribution of microbial communities to CO_2 fixation in agricultural and natural terrestrial ecosystems of the EMME region is ripe for further exploration; coordinated efforts should be made to fill this gap.

Nitrous oxide emissions. Nitrous oxide (N_2O) is an ozone-depleting compound and an important greenhouse gas, with 298 times greater warming potential than equivalent masses of CO_2. At global scale, terrestrial ecosystems emit annually approximately 6.8 Tg N-N_2O and are the largest contributor to the global N_2O budget. Soil microbial communities are key drivers of terrestrial N_2O emissions; understanding how they are linked with emissions is a prerequisite for developing effective mitigation strategies [174].

In drylands, several studies reported N_2O emissions in different cropping systems despite low water availability and soil fertility [175-178]. Rewetting soil by irrigation or rainfall stimulates N_2O emissions in arid and semi-arid regions [175]. These events of drying and rewetting can lead to niche separation of N_2O-relevant microbial communities. It has been suggested that fungal denitrification and ammonia oxidation regulated by ammonia-oxidising Archaea are the dominant sources of N_2O fluxes under dry conditions, while heterotrophic bacterial denitrification is the main source during soil rewetting [174]. Despite emerging knowledge on the pathways responsible for N_2O fluxes, the interaction effects of abiotic and biotic factors on N_2O emissions in dryland ecosystems are largely unknown.

It has been shown that soil respiration in desert ecosystems under elevated CO_2 concentrations derives mainly from microbial respiration [155]; the response of bacterial communities is taxa specific [156]. This study showed that *Firmicutes* and Gram+ bacteria were much less abundant in soils (bulk and rhizosphere) exposed to higher CO_2 concentrations in the Mojave Desert ecosystem. Moreover, the differential response of plant species to elevated CO_2 affects rhizodeposition in the soil. For example, C4 plants could allocate more carbon to their roots compared with C3 plants owing to differences in their photosynthetic efficiency [157], which in turn affects the microbial community. Interestingly, the interaction between climate change–related drivers was evident in the archaeal community of the C4 and C3 rhizospheres. Specifically, the archaeal community structure was affected by elevated CO_2, whereas higher temperatures promoted archaeal abundance for C4 plants and a decrease for C3 plants [158].

These findings reveal the interactive effect of environmental variables in plant communities on microbial community structure and composition. They also show that much about the interplay between increased aridity and temperature, as well as elevated CO_2 on soil microbial communities, remains unknown. Much more research is needed to better understand the responses of plants and soils to climate change. Future studies should examine the responses of microbial communities in the various ecosystems of the EMME region [159]. Careful experimental design should be applied, since the methods of CO_2 enrichment could bias findings. Indeed, Klironomos, et al. [160] have already shown that an abrupt increase in CO_2 caused an immediate decline of mycorrhizal diversity and functioning compared with a gradual increase of CO_2, which brought changes no different from the control treatments.

3.4. Fisheries and aquaculture

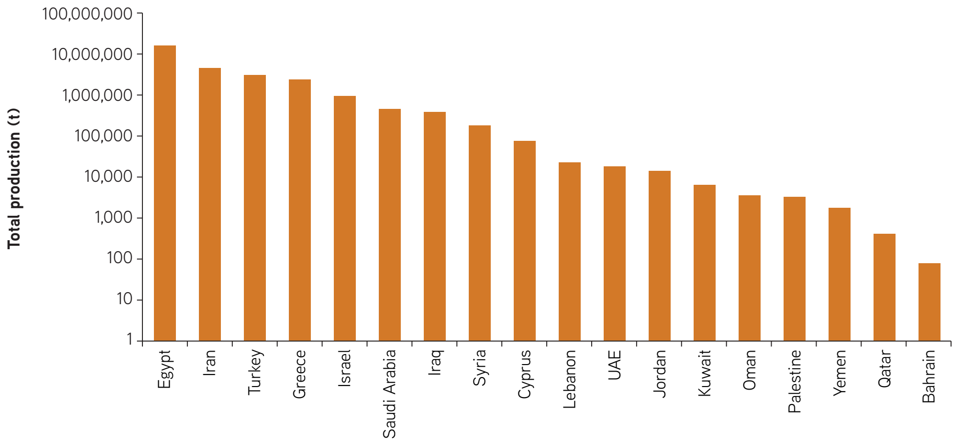
3.4.1. Aquaculture

Climate change imposes direct and indirect effects on aquaculture [179], most with negative effects on production. Chief among these are 1) loss of biodiversity, mostly through warming, ocean acidification, sea-level rise and extreme weather events; 2) pests and pathogens (known and emerging); 3) decreases in water supply; and 4) increases in soil erosion.

Marine environments are especially sensitive to natural and man-made environmental change affecting their biota [180]. As the current global scenarios for gas em issions appear largely confirmed [163] and sea-level rise is proceeding faster than predicted [181], the likely impacts on biota are severe. One of these detrimental effects is biodiversity loss. A recent study [182] reports on the loss of biodiversity in the East Mediterranean Sea, threatening fisheries and aquaculture. Of course, both sectors depend on the functioning of marine food webs dependent on biodiversity [179].

The EMME region includes countries with highly variable aquaculture activities, both in terms of production (Figures 12 and 14) and farmed organisms (Figure 13). The region has steadily increased aquaculture production for human and animal consumption.

FIGURE 12. Total aquaculture production in individual EMME countries, 1950-2018



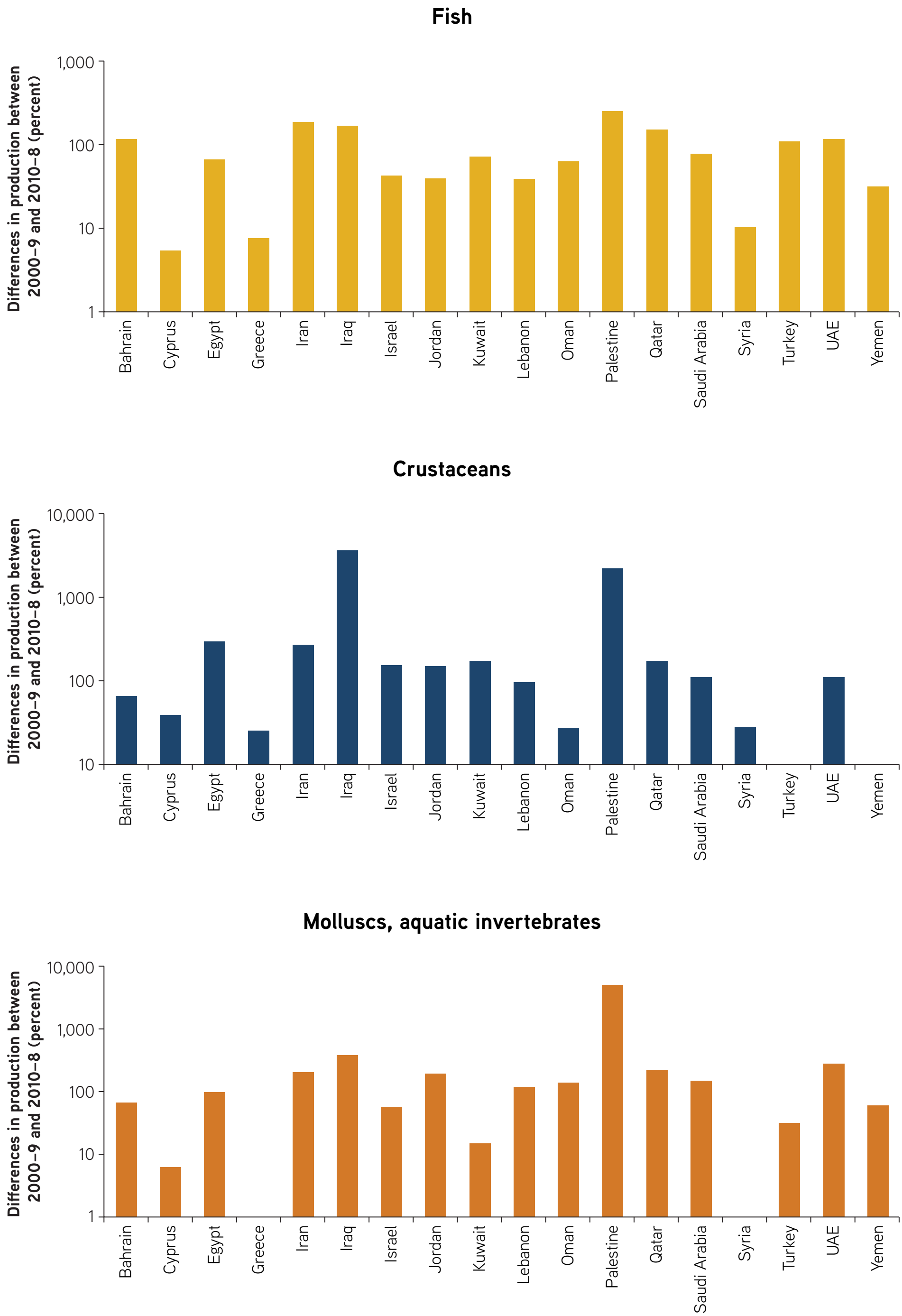
Source: FAO,2018

The major and direct mechanisms of predicted climate change affecting marine organisms through the end of the present century are related to higher temperatures, higher sea levels (including resulting changes in ocean circulation) and decreases in salinity. Most aquaculture takes place in coastal zones, where it has been estimated that temperature increases are expected to be slightly lower than the IPCC projected increases for land yet are still rising. Sea levels are expected to rise between 0.09 and 0.88 metres in the following decades [183].

Disease caused by pathogens pose a distinct threat to aquaculture. Many pathogens of wild and farmed marine organisms are sensitive to temperature, rainfall, and humidity. Warming can increase pathogen development and survival rates, disease transmission, and host susceptibility to infection. Warming is predicted to increase disease outbreaks in most systems, especially in colder waters. Some pathogens may be negatively affected by warming, thus lowering their disease risk [184]. A good example of a link between higher ocean temperatures and pathogens applies to cholera in humans [185]. Similar cases pose risk for aquaculture as well.

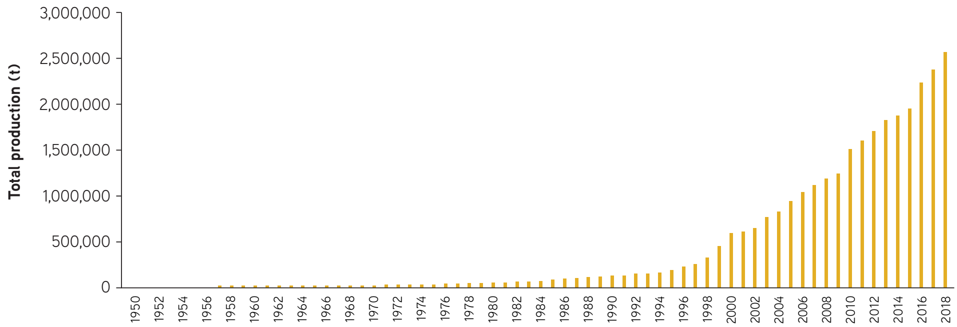
The impact of marine disease agents – viruses, bacteria, protists and metazoan parasites – ranges from reduced growth to mass mortality of cultivated populations, causing severe economic losses in the latter case. The biological cycles of disease agents depend on environmental factors which, when disturbed, may favour or even eliminate them. Aquaculture farms tend to manage disease through treatment (which is not related to climate factors), adjusting stocking density and ensuring good water quality. Recently, the development of organic aquaculture has been proposed as an effective transition to aquaculture practices

FIGURE 13. Changes in aquaculture species in the EMME region, 2000-2018



Source: FAO,2018

FIGURE 14. Aquaculture production in the EMME region, 1950-2018

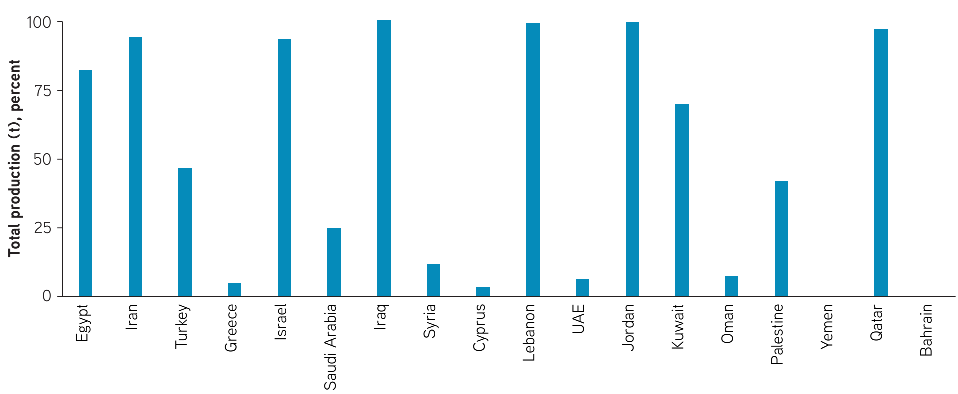


Source: FAO,2018

which more effectively confront the health issues of the populations [186]. The risk of disease agents in aquaculture is reciprocal, as expansion of pathogens in nature could result in transfer from farms to the wild via escapes or by water outflow (effluent) to the environment [187]. Some diseases are transferred to aquaculture from wild hosts.

The countries of the EMME region have different priorities in what is farmed and where. For example, aquaculture production in Greece is dominated by two species of marine fish, with invertebrates being a much smaller fraction; inland aquaculture in Greece accounts for just 4.8% of total aquaculture production from 1950 to 2018 (Figure 15). On the other hand, eight EMME countries produce more than half of their aquaculture in inland waters; in two other countries, aquaculture is exclusively marine. This trend could intensify in the years to come as freshwater aquaculture is expected to develop faster than marine aquaculture [188].

FIGURE 15. Inland aquaculture production in the EMME region, 1950-2018



Aquaculture systems can be adapted to climate change by 1) improving cultivation environments; 2) lowering risk (e.g. by choosing the cultivation environments that are least vulnerable to the impacts of climate change); 3) enhancing resilience (by managing rearing environments under conditions that mimic nature); and 4) building capacity through continuous learning [189].

Within that broad framework, given the country differences in aquaculture in the EMME region (inland vs. marine aquaculture and the types of species farmed), actions should be customised to reflect each country's circumstances.

The European Union has proposed a unified strategy on adaptation to climate change. The new Common Fisheries Policy is designed to make fisheries and aquaculture environmentally, economically and socially sustainable [190]. Twenty-three countries have adopted national climate adaptation strategies, and another eight are developing them. National action plans have already been adopted or are under development in most European countries, and all have ongoing research programs into climate change and warming [191].

Drawing on Europe's actions, the EMME region could focus on the topics described below. In all cases, field data should be combined with experimental manipulation in the laboratory.

Much more can and should be learned about the diseases of farmed species through monitoring against reliable baselines (as in the oyster case [192]); 2) monitoring wild populations of farmed species using standardised methodologies; 3) distinguishing the climate parameters directly and indirectly related to disease outbreak and appraising the effects of each on farmed species; 4) prioritising pathogens of interest, since those with simple (bacterial) vs. complex (metazoan parasites) life cycles will be affected differently; and 5) developing and applying tools for predicting disease outbreaks and pathogen responses to climate change factors.

As different farmed species are differentially affected by various aspects of climate change, the monitoring of their physiological tolerance limits must be systematically reported. For example, bivalves are most likely to suffer from both water acidification and temperature abnormalities owing to their calcareous shells. Recently, Blanchet, et al. [193] put together the temperature range of growth and biological sensitivity of European aquaculture species. Such efforts need to be expanded in a country-specific manner, while they can be run in parallel for fisheries production.

It has been proposed that marine seafood production is more vulnerable to global warming than freshwater production [193]. Each country must decide which to pursue, considering the climate change factors that most affect its aquaculture. The types of farmed organisms also need to be prioritised in light of the differential impact of climate change on aquatic plants, freshwater or marine fish, and invertebrates. Organic aquaculture should be favoured, as it is much more eco-friendly than conventional aquaculture.

Collaboration with climate change agencies is recommended. Such collaboration allows countries to benefit from the most recent knowledge on climate change and its impacts on aquaculture, and to provide information that can be used to build aquaculture-specific climate change models.

Future reconsiderations of optimised maritime spatial planning on a national scale should incorporate climate change risks and predictions specifically related to aquaculture. Such actions will require cross-border cooperation as spatial modelling typically extends well beyond national borders (e.g. Papageorgiou, et al. [194]).

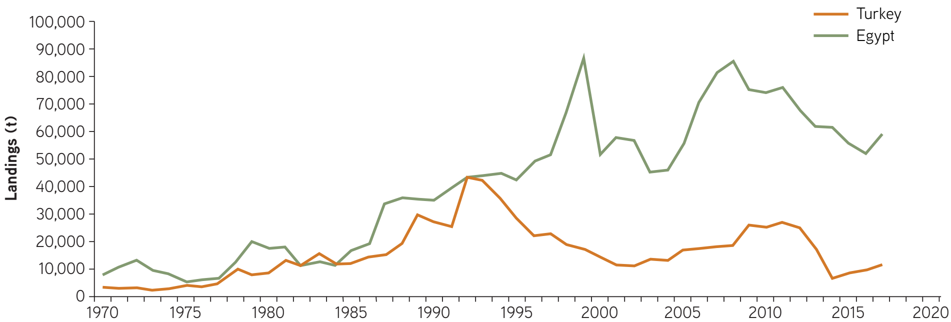
Close dialogue among stakeholders, governmental authorities and scientists involved in aquaculture and climate change favours all parties seeking to enhance the adaptability of farmed aquatic species.

3.4.2. Fisheries

The fisheries of the Mediterranean Sea feature diverse environmental, oceanographic, cultural, social and economic conditions [195], dominated by small fleets operating low-tonnage vessels, while large industrial fleets are uncommon. Total fish landings are reported by region and subdivision [196]. In the eastern Mediterranean, comprising the Aegean and Levantine seas, landings grew from 66 318 tonnes in 1970 to 295 870 tonnes in 1994, and fluctuated around 200 000 tonnes thereafter, with catches of 216 804 tonnes reported in 2017 [197], while in the Levantine Sea total landings increased to a maximum around 2010 and declined to 75 000 tonnes thereafter [196]. European sardine (*Sardina pilchardus*) and European anchovy (*Engraulis encrasicolus*) are the main species landed in the eastern Mediterranean accounting for 15% and 10%, respectively, followed by natantian decapods (mainly *Aristeus* spp. and *Aristeomorpha* spp.), bogue (*Boops boops*) and sardinellas (*Sardinella* spp.). In the Levantine Sea the mean trophic level of the catch declined continuously from 1970 to a minimum in 2015, indicating that the proportion of the high trophic-level species in the catch decreases [196]. According to the most recent FAO fisheries statistics [198], Turkey and Egypt land higher quantities of fish (Figure 16), followed by Lebanon, Palestine, Syrian Arab Republic, Israel, and Cyprus (Figure 17).

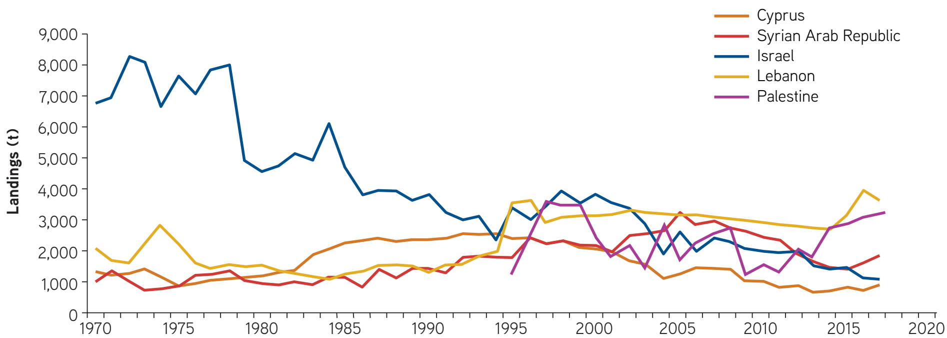
Recent publications on landings [199], scientific surveys and stock assessments generally agree that the Mediterranean fisheries are overexploited and the majority of the stocks are declining in biomass. Local overexploitation has also been reported in Greek and Turkish seas and in the Ligurian Sea [200, 201] and is often attributed to bad or inadequate management practices and less-selective fishing gear [202]. The overall stock and exploitation

FIGURE 16. Landings of fish in Turkey and Egypt (Mediterranean), 1950-2020



Source: FAO, 2020

FIGURE 17. Landings of fish in Cyprus, Syrian Arab Republic, Israel, Lebanon and Palestine, 1950-2020

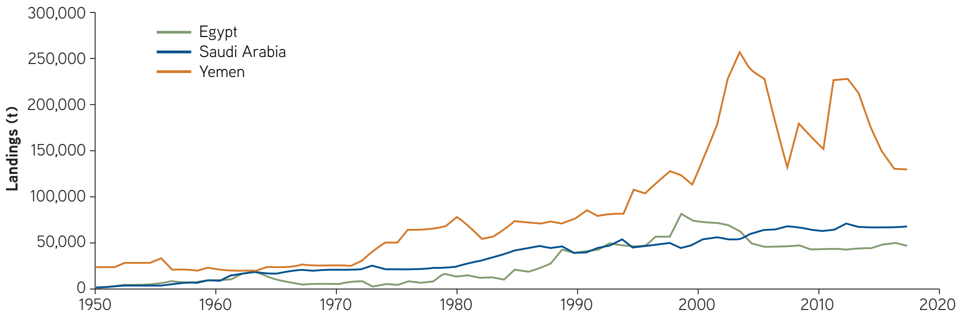


Source: FAO, 2020

patterns were rather uniform across the Mediterranean ecoregions, with low stock biomass and high fishing pressure being the common characteristics. According to a recent work on landings overall, central and eastern portions of the Mediterranean appear to be doing worse, with more overexploited and collapsed stocks and fewer developing ones – compared with the western Mediterranean [203]. Similarly, a study of four indicators (total landings, mean trophic level, fishing-in-balance index, stock status based on landings) suggests that the western and central Mediterranean are in better condition than the eastern portions [199]. The Levantine sea was recently evaluated as "intermediate" compared with all other Mediterranean subdivisions based on ecotrophic indicators and catch trends [196].

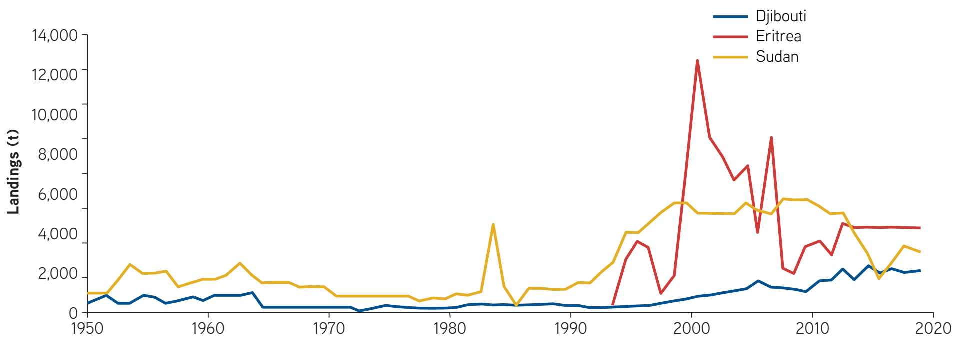
In the Red Sea, the two of the three main fishing countries (Saudi Arabia and Yemen) report landing more fish, but Egypt's catches have declined since 2000 (Figure 18). For the remaining countries, Djibouti landings have risen, while they have fallen for Eritrea and Sudan (Figure 19; data from FAO, 2020). Fisheries in the study area will be sustainable

FIGURE 18. Landings of fish in Egypt, Saudi Arabia, and Yemen (Red Sea), 1950-2020



Source: FAO, 2020

FIGURE 19. Landings of fish in Djibouti, Eritrea, and Sudan (Red Sea), 1950-2020



Source: FAO, 2020

only if the exploited marine populations are allowed to recover, i.e., if the fishing countries drastically reduce pressure on them [204, 205]. Ecosystem-based fisheries management aims to rebuild both higher and the lower trophic levels while protecting habitats and livelihoods. Marine-protected areas are a key management tool for rebuilding the biomass of marine populations, ensuring ecosystem health and resilience against sea warming and the encroachment of non-indigenous species.

The Mediterranean Sea is warming rapidly because of climate change, a trend that facilitates the encroachment of thermophilic non-indigenous species [206]. The Mediterranean Sea, especially its eastern part, is a hotspot for introduced, non-indigenous species [207, 208]arriving from the Indo-Pacific region. They accomplish this directly, by swimming or drifting, or indirectly, conveyed in ballast water through the Suez Canal (called "Lessepsian" migration, after the builder of the canal, [209]). The total known number of non-indigenous species has exceeded one thousand, most of them affecting local biodiversity as well as ecosystem functions and services [210].

Climate change (and variability) has led to parallel changes in Mediterranean marine ecosystems and resources, with implications for species diversity and catch composition. Examples of this changing environment are, among others, the decline of Posidonia meadows, the Neptune grass that carpets seafloors [211], the increase in the frequency of red tides and jellyfish outbreaks [212], the "tropicalisation" of marine fauna in favour of thermophilic species [213], and the spread of microbial pathogens seen with sea warming [214]. Apart from fish distribution shifts and biomass declines in local stocks, future projections suggest that marine populations and biodiversity will suffer increasing stress if temperatures exceed 2°C above preindustrial levels [215]. Sea warming and deoxygenation combined with intense fishing pressure and other anthropogenic and environmental stresses could affect somatic growth, spawning and mortality as well as distribution of fish populations, resulting in changes in the potential catch of exploited marine species and economic losses [216] as fisheries yields are expected to decline [217].

The mean temperature of the catch, an indicator for the effect of global warming on marine populations [218], has been increasing across the Mediterranean and locally, showing that the ratio of warm-water (thermophilus) to cold-water (psychrophilus) marine species is changing in favour of the former. This indicates either a rise in the relative proportion of thermophilus species in the catches or a drop in the relative proportion of the psychrophilus ones, both driven by sea warming [219].

A newly developed theory (Gill-Oxygen Limitation Theory) predicts that the somatic size of fish will shrink when their gill surface area cannot compensate for the increased metabolic rates required by higher water temperatures. To survive temperature increases, individuals are likely to shrink [220]. The theory may also explain the poleward shift of marine organisms [218] and their move into deeper waters [221]. Both these trends are seen in the Mediterranean [219] and may affect fisheries (in effort, catch, and revenue) across the study area. The Mediterranean Sea is among the semi-enclosed marine areas where extinctions and range shifts of local species are predicted to be most common [222].

At the end of 1980s and especially during the mid-1990s, the region underwent regime shifts [212, 223] that inflicted major atmospheric, hydrological and ecosystem changes; marine resources and fisheries were affected. Various studies link ocean-atmospheric processes—such as the Atlantic Multidecadal Oscillation (AMO) and the North Atlantic Oscillation (NAO)—that have identified indices for alterations in the distribution and biomass of pelagic fish, as well as their catch composition across the Mediterranean, especially to pelagic species [223] During mid-1990s, sea surface temperature and AMO index show a temperature spike in the Mediterranean [224, 225], and the dynamics of many pelagic fish species showed a conspicuous change around that time. The late 1990s was determined as the turning point for the northward expansion of warm-water species in the Mediterranean [226], as confirmed by stark upturns of non-indigenous species in the eastern Mediterranean Sea in 1998 [227]. A recent study reports that the pelagic fishes of the eastern Mediterranean respond most strongly to AMO variability, while the effect of the NAO on pelagic fishes of the eastern Mediterranean is negligible [228]. It is not yet clear, however, how these climatic changes affect pelagic fish population dynamics when they combine with anthropogenic pressures.

3.5. Gaps in knowledge

This section highlights the gaps in knowledge regarding agriculture and the region's adaptation to climate change. It is also essential that a main objective of the study is to highlight the most critical focus for the coming years. Global warming will require a paradigm shift for the practice of agriculture generally and specifically for the role of livestock within farming systems.

Regarding animal husbandry, science and technology need to identify the most pressing themes of climatic adaptation. For example, the dissemination of recent findings on rangeland ecology, in particular matching stocking rates with pasture; adjusting herds and water points; altered seasonal and spatial patterns of forage; diet quality and the use of silage; pasture seeding and rotation; fire management of woody shrubs; and shifting to more suitable livestock breeds or species. In addition, the holistic approach to pastoral management can encourage greater knowledge about migratory pastoralism and biosecurity measures to monitor and manage the spread of pests, weeds, and diseases. Grain crops integrated with pasture plants and livestock could produce a diversified system more resilient to higher temperatures, elevated carbon dioxide levels, uncertain precipitation, and other untoward effects of climate change. The integration of new technologies into research and technology transfer systems could offer many opportunities to further develop climate change adaptation and mitigation strategies.

The following thematic areas have been identified; strategies should be designed and implemented to close the relevant gaps. Detailed research and policy actions are highlighted below.

3.5.1. Food systems

In general, farmers possess limited knowledge about the:

- adverse effects of climate change on the yield and quality of crops, animals and aquaculture

- importance of agriculture for other sectors
- effect of invasive species on agricultural ecosystems
- urban and peri-urban agricultural ecosystems and their food-growing potential
- overlooked risks of climate change on people in the EMME region; rising food prices, scarce non-agricultural income and food safety
- early warning systems for pests and diseases arising from multi-trophic interactions and climatic data analysis and modelling

3.5.2. Water resources

Farmers also have limited access to or knowledge about:

- available data on water quantity and quality
- the status of their water resources
- technologies and best-performing practices regarding water resources to adapt to climate change

3.5.3. Land degradation

Farmers also have limited access to or knowledge about:

- the interconnection of desertification and socio-economic development
- available solutions and best practices to combat desertification
- the role of greenhouse gas emissions under climate change conditions
- how microbial communities help to fix CO_2 in soils; the regional diversity and abundance of autotrophs.
- soil biodiversity and functioning

3.5.4. Aquaculture

Farmed fisheries and their workers lack:

- information about disease baselines and time-series monitoring
- baseline setting and monitoring of wild populations as they relate to farmed species via standardised methodologies
- knowledge about climate parameters related to disease outbreaks and the effects on each of farmed species. Field data along with experimental manipulation in the laboratory.

3.5.5. Fisheries

Fishery workers have limited knowledge about:

- monitoring fish stocks and how fisheries affect marine populations (stock assessments)
- non-indigenous species in marine ecosystems and their interactions with and effect on native species
- how climate and fisheries interact to affect on marine populations
- assessing climate change risks on the social and economic components of fisheries, especially small-scale coastal activities
- the effect of climate on western and central Mediterranean fisheries

4. The policy landscape

This section catalogues those policies relevant to the task force's scientific focus, specifying, where applicable, their types – e.g. regulatory approaches (including economic instruments), information and dissemination programmes, investments and R&D in technologies, etc. The policies are also classified as national, regional, or international; distinctions are drawn between adaptation and mitigation measures. Policy gaps are also identified.

4.1. United Nations Climate Policy and Governance: Synopsis and guidance

Developed and developing countries came to a common cause, undertaking ambitious efforts to mitigate climate change and adapt to its effects by adopting the Paris Agreement. The central objective of the agreement is to limit global average temperature increases to well below 2°C above pre-industrial levels. Under the agreement, countries arranged to present their Nationally Determined Contributions (NDCs), meaning each country would propose its national plan to reduce greenhouse gas emissions. To stay beneath the 2ºC ceiling, global GHG emissions must decline by 25% until 2030. Meanwhile, the opportunity to bridge the emission gap by 2030 is quickly closing. Indeed, the UN Environment (UNEP) 2018 Emissions Gap Report shows that the goals spelled out in the NDCs need to be tripled to keep global temperatures from rising 2ºC. Further actions need to be identified, and any gaps financed, so that the ambitious NDCs can be implemented.

The agriculture sector holds a central position in the Paris Climate Change Agreement: of the 194 countries submitting NDCs, 96% of them included measures to address the role of agriculture and/or land use, in addition to land use change and forestry (LULUCF), in their mitigation and adaptation contributions. For the EMME region (comprising 17 countries), 15 countries (94%) submitted NDCs that named agriculture as a sector in their adaptation and/or mitigation actions. A case study of NDCs could highlight the importance of specific measures and guide policy makers through the constraints affecting climate change in the region.

4.2. Climate change and the EU's Common Agricultural Policy

The European Union policy framework for climate change was fashioned in response to the development of international commitments made since 1991, after the International Panel on Climate Change (IPCC) was first convened. The European Union proposes to achieve climate-neutral targets by 2050 and an intermediate target of at least a 55%

BOX 5. The Arab Centre for Climate Change Policies

The Arab region has been actively addressing climate change impacts, having established the Arab Centre for Climate Change Policies (ACCCP). The centre aims at strengthening the capacity of Arab states to understand and address climate change with the goal of sustainable development in the Arab region.

ACCCP was established at the 30th session (28 June 2018) of the UN Economic and Social Council for Western Asia (ESCWA) by high-level representatives of member countries and was the culmination of work that ESCWA and partner organisations have been undertaking on behalf of Arab states in climate change assessment, adaptation, mitigation and negotiations for over a decade in response to requests for assistance from member states. In fact, ESCWA and the League of Arab States, in partnership with UNEP and UNESCO, have to date co-organised 13 technical workshops on issues of concern to the region in negotiations under the UNFCCC and Paris Agreement processes. Topics covered include finance, technology, and scientific knowledge.

According to the resolution, ACCCP supports member states through technical assistance and advisory services, capacity building to strengthen institutional frameworks and support regional platforms; promoting climate-related responses; and providing access to knowledge and data using the Regional Knowledge Hub.

reduction in greenhouse gas emissions by 2030. The Commission is revising the regulation on the inclusion of GHG and removals from land use and land use change and forestry (LULUCF). This action lies within the EU leaders' agreement, that all sectors should contribute to the EUs emission reduction target, including the land use sector. Moreover, this effort is in line with the Paris Agreement, which stresses the role of land use sector in meeting the mitigation challenges. According to the new Regulation (EU) 2018/841, each Member State shall ensure that emissions do not exceed removals, including those accounted for any land use, including wetlands.

At the 2013 meeting, the EU Commission adopted an EU strategy on adaptation to climate change. The overarching objectives of this strategy are to make the EU more climate resilient and through preparedness and capacity building address the challenges of climate change. Although the strategy has been set, it does not include binding targets or requirements for the Member States but provides supporting documents and guidance. This was expected to assist Member States in their efforts to develop and integrate adaptation strategies on climate change as well as initiatives to face the related challenges. In particular, the EU Commission set out principles and recommendations on integrating adaptations into the National Rural Development Plans within the programming period 2014-2020. The current Rural Development Regulation (1305/2013) requires that at least 30% of funding for each rural development programme must be dedicated to measures relevant for the environment and climate change adaptation. The current CAP contains no legally binding or concrete, quantified objectives for climate adaptation. The Directorate General for Agriculture funded a study to evaluate the impact of the CAP on climate change and GHG emissions, and the findings showed that several CAP measures are either fully or partially relevant to the EU's rural mitigation and adaptation needs. The study also revealed that some of the most relevant measures included in CAP are constrained by the lack of compulsory implementation. There are no mandatory measures in Pillar I, for example, targeting emissions from livestock or crop farming.

In the legislative proposals for CAP after 2020, the European Commission has set ambitious environmental and climate change objectives, knowing agriculture is responsible for around 10% of the EU's GHG emissions. The European Green Deal aims to make Europe the world's first climate-neutral continent by 2050. The new CAP aims to provide strong institutional support and substantial contributions to the European Green Deal. Special attention has been given to support farm-to-fork and biodiversity initiatives. In its proposals, the Commission suggests the following measures related to climate change:

- An obligatory nutrient management tool that helps farmers reduce ammonia and N_2O emissions
- The adoption of eco-schemes as a funding stream within CAP's direct payment modes

Although a major effort is being made to introduce measures to face the challenges for climate change adaptation and mitigation, there is an urgent need for more coherent objectives linked to the United Nations Sustainable Development Goals (SDGs) and associated with measurable targets [229].

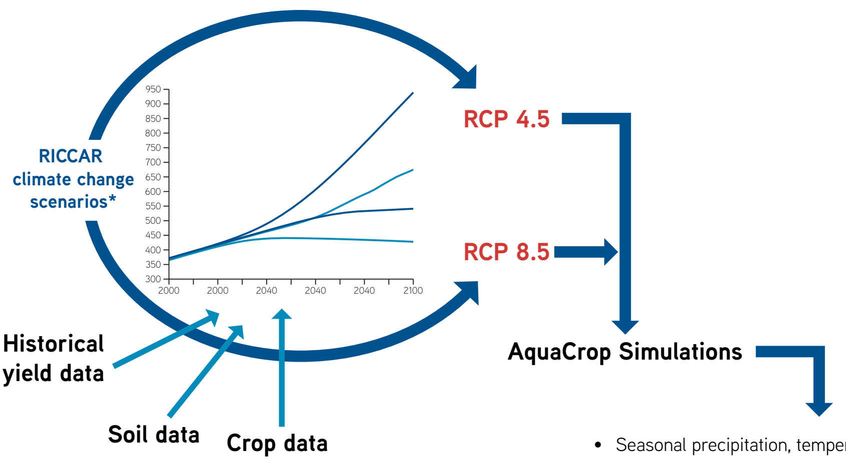
4.3. Climate change and crop production in the Arab region

The AquaCrop simulation programme, developed by the UN Food and Agriculture Organization, and the climate-variables projections of the RICCAR Initiative on Climate Change in the Arab Region, led by the UN Economic and Social Council for Western Asia, were utilised to identify the impacts of climate change on agricultural production in the Arab region. A technical country team was established and trained by ESCWA, FAO and ACSAD to conduct assessments for nine Arab countries (Egypt, Jordan, Iraq, Palestine, Lebanon, Morocco, Sudan, Tunisia, and Yemen) in 2017 and 2018. The assessments occurred within the framework of ESCWA's regional project, "Promoting Food and Water Security through Cooperation and Capacity Development in the Arab Region."

Climate models were used on selected areas in each country, representing both rainfed and irrigated agricultural areas. The climate change projections correspond to GHG concentration trajectories adopted by the Intergovernmental Panel on Climate Change. Called Representative Concentration Pathways (RCP), these trajectories track two emissions scenarios. The first is RCP 4.5 (a moderate-emissions scenario), while the second is RCP 8.5 (a scenario involving higher emissions, or "business as usual"). In a way, RCP 4.5 and RCP 8.5 correspond to more optimistic and more pessimistic scenarios, respectively. The time horizons for the two RCPs consider the periods 2020-2030 (represented by 2025) and 2040-2050 (represented by 2045). Further, to analyse the effect of elevated CO_2 on crop yield loss, two sets of projected CO_2 concentration changes, for each of the RCP scenarios, were simulated: one that considered the effects of increasing CO_2 concentrations; and another that kept CO_2 concentrations at baseline. Figure 20, below, presents a schematic diagram of the methodology used.

A summary of findings for five Arab countries (Jordan, Iraq, Egypt, Lebanon and the State of Palestine) is presented in Box 6, using RCP 4.5 and 8.5 scenarios for both periods (2025 and 2045) and under stable and changing CO_2 concentrations. In general, simulations showed that climate change altered crop productivity and growth cycle; decrease in productivity is accompanied by a shortage in the length of crop cycle, which could be a result of rising temperatures. The change in CO_2 concentration increased productivity as

FIGURE 20. Identifying the impact of climate change on agricultural production in the Arab region



- Seasonal precipitation, temperature changes and evapotranspiration
- Changes in crop yield, crop water productivity, length of growth cycle
- Irrigation scheduling and deficit irrigation

*EC-Earth, CNRM-CMS, and GFDL-ESM2M

BOX 6. Main findings of the AquaCrop/RICCAR simulation for five Arab countries

Jordan: Irrigated tomatoes in Mafraq and rainfed wheat in Madaba

- Crop growth cycle decreases by 2-4 days for tomatoes, and 3-5 days for wheat under RCP 4.5
- Productivity of tomatoes decreases by less than 3.1% in case of stable CO_2 for both scenarios. In case of changing CO_2, productivity increases by 21.3 % for 2045 period under RCP 8.5.
- Productivity of wheat increases by about 32.1% and 36.5% for 2025 and 2045 periods, respectively in cased of stable CO_2. In case of changing CO_2, productivity increases by 42.4% and 73.9%, for both periods under RCP 8.5.
- Application of 17% deficit irrigation for tomato crops results in significant yield reductions of around 8% under RCP 4.5, and around 6% under RCP 8.5 for both periods.

Iraq: Irrigated tomatoes and wheat in Al Suwaira region

- Crop growth cycle decreases by 1-2 days for tomatoes and by 4-9 days for wheat under RCP 4.5.
- Productivity of tomatoes decreases by less than 7% for both periods and scenarios under stable CO_2. In case of changing CO_2, productivity increases by around 12% for 2045 period under both scenarios.
- Productivity of wheat decreases by less than 4% for both periods and scenarios under stable CO_2. In case of changing CO_2, productivity increases by 15% for 2045 period under RCP 8.5.
- Application of 40% deficit irrigation on tomatoes results in yield reduction reaching 34% for both scenarios under stable CO_2 conditions.
- Application of 40% deficit irrigation for wheat crop results in yield reductions of around 9.34% in case of stable CO_2 and increased yields by 9.4 % in case of altered CO_2 under RCP 8.5.

Egypt: Irrigated wheat and maize in the Sakha area and irrigated tomatoes in Nubaria region

- Crop growth cycle decreases by 3-6 days for wheat, 2-3 days for maize and 3-4 days for tomatoes under RCP 4.5
- Wheat productivity decreases by less than 6% for both periods and scenarios under stable CO_2. In case of changing CO_2, productivity increases by around 13% for 2045 period under both scenarios.
- Productivity of maize decreases by less than 3% for both periods in case of stable CO_2 and increases by about 1% for both periods under changing CO_2 and for both scenarios.

(Continued next page)

BOX 6 (continued)

- Productivity of tomatoes decreases by less than 1% for both periods under RCP 4.5 in case of stable CO_2. In case of changing CO_2, productivity increases by 25.7 and 32.6 under RCP 4.5 and 8.5, respectively for 2045 period.
- Application of 40% deficit irrigation increases productivity of wheat by less than 1% and does not impact maize yield, whereas tomato yields drop by around 44% for all periods and scenarios.

Lebanon: Irrigated wheat in Bekaa

- Crop growth cycle decreases 3-7 days under RCP 4.5.
- Productivity of wheat increases by 17.4% in case of stable CO_2 and increases by 42% in case of changing CO_2 for 2045 period under RCP 8.5.

State of Palestine: Rainfed wheat and Irrigated potatoes, Marj Ibn Amer

- Crop growth cycle increases by 1 day for wheat and decreases by 2 days for potatoes under RCP 4.5.
- Productivity of wheat increases by 30% in case of stable CO_2, and 56% in case of altered CO_2 for 2045 period under RCP 4.5.
- Productivity of potatoes decreases by less than 4 % for both periods and scenarios with stable CO_2 and increases in case of altered CO_2 by 11.6% and 23.8% for both periods under RCP 8.5.
- Application of 25% deficit irrigation for potato crop decreases yields by up to 28% for 2025 period under RCP 4.5.

it enhances the photosynthetic rate of plants while reducing transpiration. Deficit irrigation simulations were carried out as an adaptation measure towards water shortages to identify changes in yield and obtain a better understanding of different management strategies. Application of deficit irrigation on tomato and potato crops registered significant changes, whereas no changes were observed with maize crops. The wheat crop showed increased productivity with deficit irrigation under altered CO_2 concentrations.

ESCWA translated the assessment results into country-specific policy alternatives to make the agriculture sector more resilient to climate change and to help tailor more precise agricultural strategies. These include:

Institutional and financial arrangements

- Adopt and scale up conservation practices in rainfed agriculture.
- Mobilise resources for investment in agriculture value chains.
- Promote investments to modernise irrigation systems.

- Enhance water accounting systems to monitor water availability and water allocations.
- Promote research and assessments on use of crop varieties suited to new climate conditions.
- Ensure cross-sectoral coordination among, for example, water and agriculture ministries.

Technical arrangements

- Adjust sowing dates according to temperature and rainfall patterns.
- Modify irrigation depth and application time.
- Apply conservation agriculture such as minimum tillage and crop rotation.
- Promote rainwater harvesting, and application of supplementary irrigation.
- Use innovative and improved agricultural technologies and digital solutions.

Evidence generation

- Improve research to compare yields and develop soil properties and plant-growth phases.
- Produce interactive maps based on geographic-information systems to visualise and analyse the effects of climate change on agricultural lands.
- Improve data collection, reporting, and sharing; promote unified and reliable databases for agriculture and water authorities.
- Perform periodic risk-assessments that evaluate decision making (short, medium and long-term).

Another important initiative, implemented from 2014 to 2019, focused on a coordinated policy of Arab countries on water use in agriculture (Box 7).

BOX 7. Coordinated policy development on food and water security in the Arab region

The Arab Ministerial Council (AMWC) and the Arab Organization for Agricultural Development (AOAD) of the League of Arab States have strived to coordinate policy on water use in the agriculture sector. The initiative on food and water security in the Arab region (2014-2019) has been funded by the Swedish International Development Cooperation Agency, the UN Economic and Social Council for Western Asia (ESCWA) NS FAO-RNE (Regional Office for Near East and North Africa).

In that respect, a technical advisory working group was formed to coordinate water and agriculture ministries, ESCWA, FAO-RNE, AMWC and AOAD, and all the councils responsible for

(Continued next page)

BOX 7 (continued)

water and agriculture in the Arab states. The initiative and objectives became part of the League of Arab States' regional initiative on the water-energy-food nexus as a permanent agenda item of the AMWC, anchoring it to the regional intergovernmental processes for water resources (Resolution #174). The outcomes of this initiative directly address the objectives of Arab Water Security Strategy covering sustainable agricultural development in the region from 2005 to 2025 and the Emergency Program for Arab Food Security and its action plan. A similar modality was followed to include activities for this initiative in the reporting for the political setting of AOAD, covering the regional intergovernmental processes for agriculture (Resolution #15/49).

In April 2019 the first joint meeting of Arab ministers of agriculture and water was organised at the League of Arab States in Cairo. It resulted in the adoption of terms of reference for the Joint Ministerial Committee, a high-level technical committee assisted by a Joint Secretariat comprising AOAD and AMWC that are assisted by regional and international organisations. This ministerial meeting concluded with a call to integrate water and food security issues into the national sustainable development strategies. It further called for the adoption of the Cairo Declaration urging regional coordination to harmonise policies across water and food sectors so they can face impacts of climate change and water scarcity.

On October 23-24, 2019, the Joint High-Level Committee on Agriculture and Water held its first meeting, on the side-lines of Cairo Water Week. There, it sought to inform discussions in the technical meeting and presented a background paper (entitled "Towards a Paradigm Change" on water allocation for agriculture in the Arab region. There were recommendations that the water allocation mechanism was made more sustainable in the face of mounting water scarcity. The meeting resulted in the adoption of five priority areas for work of the Joint High-level Committee on Agriculture and Water.

The second meeting of the Joint High-Level Committee on Agriculture and Water was organised virtually on October 19, 2020, again on the side-lines of the Cairo Water Week. The meeting followed up on the progress made in implementing the recommendations of the first meeting and discussed the themes and contents of a proposed action plan for 2021-2025 to activate the Cairo Declaration of 2019.

FIGURE 21. Key elements of the Cairo Declaration (April 2019)

Activation of regional coordination mechanisms for effective implementation of new policies and investments	Ensuring harmonisation and integration of policies across the agriculture and water sectors	Increase of investments in agricultural water management	Use of innovations, data management and analysis, and exchange of expertise

(Continued next page)

BOX 7 (continued)

FIGURE 22. Cross-sectoral work in the Joint Secretariat: Five priority areas

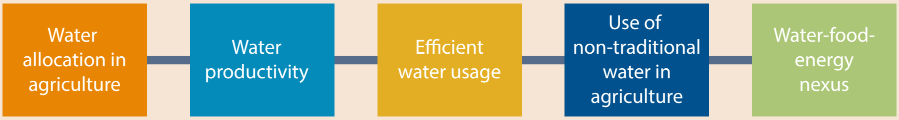


FIGURE 23. The 2019 Cairo Declaration: Proposed framework for implementing the action plan

In addition, preparations of the Arab Region Guidelines on Water allocation in the Agriculture sector are underway and will be presented for discussion to the Joint High-Level Committee on Agriculture and Water in their upcoming meeting in 2020 prior to adoption by the Second Joint Ministerial Meeting for Agriculture and Water planned for mid-2021.

5. Proposed policy and research initiatives

This section provides policy proposals classified, where applicable, by type – e.g. economic instruments, regulatory approaches, information and dissemination programmes, investments and R&D in technologies, etc. The impact of regionally implemented policies will also be explained here. The "toolkit" will be presented in this section, where it will receive extra attention.

The section also proposes new research projects/directions based on the gaps identified in Section 4. See Box 7 for more about the importance of regional cooperation on joint research programmes and projects.

5.1. Policy proposals

- Creating strong and direct links between Science and Administration: capacity building of a novel structure facilitating the communication between scientists and politicians.
- Creating joint research programmes – establishing a funding tool or a cooperative fund [funding schemes like the Joint Programming Initiative on Agriculture, Food Security, and Climate Change (FACCEJPI) and the EMME-Climate and Atmosphere Research Centre (EMME-CARE)].
- Prioritising climate change actions and including relevant joint research projects in the national research policies of the participating countries.
- Ensuring cross-sectoral coordination among ministries targeting to agriculture, water, and environment.
- Creating public awareness around the initiative and the potential benefits for national economies and societies. Forming efficient mechanisms for disseminating the joint research outcomes to all stakeholders.
- Preparing a package of strong incentives to farmers in order to facilitate the adoption and broad implementation of the appropriate management practices: Linking national subsidies with climate performance (e.g. sustainable agriculture practices with emphasis on rainfed agriculture, soil and water conservation, integrated livestock-crop production systems etc.).

- Promoting low-input agricultural ecosystems.
- Attracting investments for building infrastructures to face extreme events (flood-prevention, drainage and novel irrigation networks, water reservoirs, reforestations, etc.).
- Establishing/extending existing insurance policies for agricultural production against hazards from extreme events (floods, droughts, heat waves).
- Developing and implementing a set of best practices for agriculture and natural ecosystems that are maintaining or increasing the productivity of sustainable ecosystems.

5.2. Research proposals

A research agenda would provide EMME region governments with science-based information about climate change so they can develop policy strategies and economic tools that facilitate adaptations in rural and urban communities.

The following general actions are considered necessary for the guidance and implementation of the adopted adaptation and mitigation strategies.

- Establishing control over all task forces and creating a database encompassing all the task force reports (existing and new) supported by a special website on the initiative.
- Monitoring the implementation efficacy of already-established adaptation and mitigation policies and measures.
- Developing reliable indicators as policy tools to assess adaptation/mitigation frameworks and measures.

5.2.1. Research directions on adaptation: Recommendations

- Taking a regional approach in assessing climatic changes on a mid- (2050) and long-term (2100) basis under different emissions scenarios. Adopting the most suitable regional meteorological models to be used by the participating EMME countries (link to science task force necessary).
- Undertaking regional analyses of land degradation with well-established methodologies and indicators by all participating countries. Creating the relevant reliable databases in a comparable way.
- Predicting climate change impacts on agricultural production in the EMME countries, adopting the most suitable crop simulation models.

- Developing and scaling-up best practices of sustainable measures for agriculture and natural ecosystems, conservation practices in rainfed agriculture, and practices of integrated livestock-crop production systems.
- Establishing networks for monitoring risks from climate change: new pests, plant and animal diseases, invasive weeds, water resources and quality, vulnerable and threatened plant and animal species, and desertification.
- Exploiting local germplasms to breed new cultivars suited to the region's climatic conditions. Promoting research and assessments of new the cultivars in the new climatic conditions.
- Introducing innovative and improved agricultural technologies and digital solutions.
- Studying crop/ weed interactions under the new climatic conditions in the EMME region.
- Establishing and testing alternative crop husbandry (e.g. crop species and cultivar selection, planting dates, fertiliser application, weed control, integrated protection, etc.).
- Promoting and fine-tuning deficit irrigation as a strategic tool for crops sensitive to water shortage.
- Establishing on-farm irrigation efficiency programmes to increase farmers' knowledge about irrigation infrastructure or to modify inefficient irrigation practices.
- Assessing the effects of climate change on the quality of agricultural products.
- Developing appropriate genetic resources (plant, animal and microbes) suitable for the region.
- Examining alternative cropping systems to enhance the productivity of agricultural ecosystem.
- Improving and allocating resources to improve rearing environments in aquaculture.
- Developing tools and methodologies for aquaculture environments based on nature-mimicking conditions to increase ecological resilience of the system.
- Capacity-building to enable continuous and up-to-date learning about the impact of climate change on aquaculture.

5.2.2. Research directions on mitigation

The aim of the following research activities is to enhance the contribution of the managed and natural ecosystems to mitigate greenhouse gas emissions. Special attention should be paid on reducing C losses and increase its sequestration in ecosystems. Research efforts should also be focused on the reduction of non-CO_2 GHG emissions. The following research priorities have identified:

- Establishing a network for monitoring GHG-emissions and develop an emissions database for the agroecosystems in the EMME-region.
- Developing practices and technologies for increasing C-sequestration in natural and agricultural ecosystems.
- Novel management practices to reduce CH_4 and N_2O-emissions from rice fields, animal husbandry, and nitrogen fertilizer application.
- Reducing fuel consumption (e.g. by reducing soil cultivation intensity and agrochemicals).
- Enhancing the use of renewable energy resources in agriculture.
- Develop tools and technologies that are reducing external inputs in agroecosystems
- Develop and test practices that are improving crop quality and productivity without increasing GHG emissions
- Evaluate the impact of different management practices on N_2O and CH_4 - emissions and how C-N interactions are affecting the soil microbial communities.

6 Recommendations

Table 4 below contains the recommendations for policy actions in short, medium and long-term. In addition, it refers to the diligent party responsible for their implementation.

Institutions or platforms acting on these recommendations should take into account the impediments barring their adoption. These include ill-informed actions and practices, insufficient knowledge about climate-smart strategies, lack of resources, small farm size, high costs of implementation, and lack of awareness among policy makers, researchers and farmers. Based on the EU experience, adaptation to climate change at the farm level depends mainly on the farmer's willingness to implement specific practices and their ability to cover the costs of a specific technology or accept some loss of income when implementing an environmentally friendly technique. Climate change is not the main constraint on farmer income (crop, animal, fisheries and aquaculture) but part of several problems, all tied to the economic viability of food production systems.

At this point, it is essential to understand the importance of regionally driven policies and the development of locally adapted, participatory design of practices, approaches and strategies that engage farmers. Efficient funding tools and subsidies could be pivotal for mitigating or adapting to climate change. To develop novel approaches to adapting primary food production ecosystems to climate change, it is vital for the region to support the national research and innovation environment. Funding is the main bar against the development of such tools, while there are, in addition, dramatic declines in relevant specialists. The region overall is showing poor research coordination and collaboration on solving common problems.

The Task Force recommends the following policy actions to improve the primary food production systems in the EMME region as they relate to climate change (Table 4 below). The list is not exhaustive.

TABLE 4. Recommendations for policy actions in short, medium and long term

Policy	Measures implementing the Policy	Examples of actions	Mitigation	Adaptation	Beneficiaries	Implementation time
Creating strong and direct links between Science and Administration	• Capacity building of a novel structure facilitating the communication between scientists and politicians.				National/ Transnational	Short term
Production of new knowledge by research	• Prioritization of climate change and adaptation research in the National Research policies. • Establishment of a cooperative funding tool to support research activities in the Region.	• Understanding the physiology of crop and weed species of the region to climate change. • Surveys for predicting climate change impacts on agriculture and fisheries. • Utilizing local germplasm for producing new cultivars resilient in the new conditions (etc., see 7.2.1 of the TF Report)		+	National/ Transnational	Short term Medium term
Emphasis on Education/ Outreach	• Creating public awareness on the initiative and its potential benefits to national economies and societies. • Develop efficient dissemination mechanisms of the joint research outcomes to all stakeholders.		+	+	National	Medium term Long term
Developing policy tools for adaptation/mitigation measures	• Creating reliable indicators for assessing adaptation/mitigation frameworks and measures.	• Best practices of sustainable measures for agriculture and natural ecosystems. • Adopt and scale-up conservation practices in rainfed agriculture. • Best practices of integrated livestock-crop production systems.	+	+	National	Short term
Preparing a package of strong incentives for farmers	• Adopting sustainability measures for soil, water, biodiversity, energy. • Promoting low input agriculture.		+	+	National	Short term
Predicting and facing environmental degradation and crop losses by pests and diseases	• Establishing networks of observatories for monitoring water resources, soil degradation, new invasive pests and pathogens			+	National/ Transnational	Short term Medium term
Building appropriate infrastructures for facing extreme events	• Attracting investments from national/ international foundations	• Protection from floods. • Building reservoirs for water harvesting. • Reforestations, restorations. • Modernization of irrigations systems.		+	National	Medium term Long term
Protection of rural income	• Establishing or extending existing insurance policies for agricultural production from extreme events.	• Developing reliable crop loss assessment methods.		+	National	Medium term

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