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Table of Contents

1 Climate change-an introduction

Even though the terms are often used interchangeably, there are many differences between "climate" and "weather." Climate refers to the average pattern of weather in a specific place over several years, while weather encompasses the natural events happening in the atmosphere each day, including temperature and rainfall. Therefore, climate is defined as the average weather, or more precisely, as the statistical description in terms of the mean and variability of relevant quantities over a period ranging from months to thousands or millions of years. The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the climate system (IPCC, 2013).

The climate system is a highly complex system consisting of five major components: (i) the atmosphere (the gaseous envelope surrounding the Earth that consists almost entirely of nitrogen, oxygen and a number of trace gases), (ii) the hydrosphere (liquid surface and subterranean water, such as oceans, seas, rivers, freshwater lakes, underground water, etc.), (iii) the cryosphere (all regions on and beneath the surface of the Earth and ocean where water is in solid form, including sea ice, lake ice, river ice, snow cover, glaciers and ice sheets), (iv) the lithosphere (the upper layer of the solid Earth, both continental and oceanic, which comprises all crustal rocks and the cold, mainly elastic part of the uppermost mantle) and (v) the biosphere (comprising all ecosystems and living organisms, in the atmosphere, on land or in the oceans), and the interactions between them. The climate system evolves in time under the influence of its own internal dynamics and because of external forcings such as volcanic eruptions, solar variations and anthropogenic forcings (the changing composition of the atmosphere, land use change etc.).

Climate change refers to a variability in the state and properties of the climate system, that persists for an extended period. It refers to any change in climate over time, whether due to natural changes or as a result of human activity (IPCC, 2014). However, this usage differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), where climate change refers to a modification attributed to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods.

The climate system is influenced by many different factors, natural and anthropogenic, and it is the varying influence of these factors that lead to different parts of the Earth experiencing differing climates. The most important natural factors, external to climate system, are:

1. **Proximity to the ocean:** The sea affects significantly the climate of a place and in general coastal areas are cooler and wetter than inland areas. Clouds form when warm air from inland areas meets cool air from the sea and in the summer, temperatures in the inland areas can be very hot and dry as moisture from the sea evaporates before it reaches the center of the land mass.

2. **Ocean currents:** Ocean currents can increase or reduce temperatures, since they carry significant amounts of warm or cold air masses and moisture. For example, the Gulf Stream is a warm ocean current in the North Atlantic flowing from the Gulf of Mexico, northeast along the U.S coast, and from there to the British Isles. The Gulf of Mexico has higher air temperatures than Britain as it is closer to the equator.

This means that the air coming from the Gulf of Mexico to Britain is also warm. However, the air is also quite moist as it travels over the Atlantic Ocean. This is one reason why Britain often receives wet weather.

3. **Direction of prevailing winds:** Winds that blow from the sea often bring rain to the coast and dry weather to inland areas. Moreover, winds that blow from warm inland areas will be warm and dry while winds that blow from cold inland areas will be cold and dry in winter.

4. **Latitude:** The distance of a place from the equator (latitude) greatly affects the climate of an area. At the poles, energy from the sun reaches the Earth's surface at lower angles and passes through a thicker layer of atmosphere than at the equator. Therefore, near the equator, the climate will be warmer, while moving north or south from the equator brings a cooler climate.

5. **Altitude:** Altitude has a similar effect on climate like latitude. The higher someone is above sea level, the colder the climate. This happens because as altitude increases, air becomes thinner and is less able to absorb and retain heat. Moreover, mountains receive more rainfall than low lying areas because as air is forced over the higher ground it cools, causing moist air to condense and fall out as rainfall.

6. **Vegetation:** Just as climate determines the types of vegetation in a given region, to certain extent vegetation can contribute to a region's weather. Hot and wet climates in the tropics, for instance, develop rainforests; the more trees and plants there are, the more water vapor in the atmosphere and the moister and cooler the area. Along the same line, dry climates will often enable the growth of grasslands or savannas with little water vapor to contribute to the atmosphere, maintaining drier weather patterns.

The climate of the Mediterranean is mild and wet during the winter and hot and dry during the summer. Winter climate is mostly dominated by the westward movement of storms originating over the Atlantic and impinging upon the western European coasts. The winter Mediterranean climate, and most importantly precipitation, is thus affected by the North Atlantic Oscillation (NAO) over its western areas, the East Atlantic (EA) and other patterns over its northern and eastern areas (Trigo et al., 2006). In the summer, high pressure and descending motions dominate over the region, leading to dry conditions particularly over the southern Mediterranean. Summer Mediterranean climate variability has been found to relate to both the Asian and African monsoons (Alpert et al., 2006) and with strong geo potential blocking anomalies over central Europe (Trigo et al., 2006).

In addition to planetary scale processes, the climate of the Mediterranean is also affected by local processes induced by the complex physiography of the region and the presence of a large body of water (the Mediterranean Sea). For example, the Alpine chain is a strong factor in modifying traveling synoptic and mesoscale systems and the Mediterranean Sea is an important source of moisture and energy for storms (Lionello et al., 2006). The complex topography, coastline and vegetation cover of the region are well known to modulate the regional climate signal at small spatial scales. In addition, anthropogenic and natural aerosols of central European, African and Asian origin can reach the Mediterranean, possibly influencing its climate characteristics (Alpert et al., 2006).

Apart from the natural factors that affect the climate, there is also a significant anthropogenic effect. This effect was quite small early on in human history but as populations increased and mainly after the Industrial Revolution (which started at the end of the 19th Century), the human influence increased largely. Nowadays, there is broad scientific agreement that the climate conditions are being changed on a global scale by human activities such as burning of fossil fuels, deforestation, transport and a variety of agricultural practices and industrial processes (Walthall et al., 2012). All these activities are rapidly increasing the atmospheric concentrations of CO_2 and other greenhouse gases (GHGs): methane (CH_4), nitrous oxide (N_2O) and halocarbons (a gases group composed by fluorine, chlorine or bromine). In fact, they increased with 70% between 1970 and 2004 (IPCC, 2007). This increase happened when emissions concentration of the GHGs are larger than their removal processes. Global increases in CO_2 concentrations, the most important anthropogenic GHGs, are primarily due to fossil fuel use. The annual emissions have grown by approximately 80% between 1970 and 2004, representing 77% of total GHGs emissions in 2004 (IPCC, 2007). The increase in CH_4 concentration is predominantly due to agriculture and fossil fuel use. The increase in N_2O concentration is primarily due to agriculture.

GHGs differ in their warming influence or radiative forcing on the climate system, which is closely related to their different radiative properties and lifetimes in atmosphere. So, they are expressed through a standard and useful metric, based on the radiative forcing of CO_2 (CO_2 equivalent). These changes in atmospheric composition are increasing temperature, altering the timing and distribution of precipitation, and affecting terrestrial and marine ecosystems. Moreover, greenhouse gases and aerosols affect climate by altering incoming solar radiation and out-going infrared (thermal) radiation that are part of Earth's energy balance. The resulting negative or positive changes in the energy balance are expressed in radiative forcing (W/m^2), an influence factor used for comparing the warm or the cool influences on global climate. Therefore, climate change could be considered as a "force beyond borders". It is caused naturally or by human activity that increase air pollution and CO_2 equivalent concentrations mostly from the industrialized countries (China, USA, Europe and India) and it is irreversible.

The variety of natural and human mediated systems are expected to undergo changes because of climate change. Scientific evaluation of the effects of global climate change provides strong evidence of ongoing changes in the Earth climate system. Among the findings are included:

1. Global-average surface temperature has increased by about 0.74°C (0.56-0.92°C) over the 20th century (IPCC 2007, pg. 10). Each IPCC report is scaling up its projections for the next century. The 5th report of 2014 forecasts 4,8°C for 2100 for the scenario 4.8.

2. An average sea surface temperature rise of +0.75°C is expected at the scale of the Mediterranean Sea by 2040 and this trend is expected to continue, impacting directly and indirectly societies, economic activities and ecosystems.

3. The levels of CO_2 in atmosphere, has increased by about twice since ice ages. In 2013, CO_2 levels surpassed 400 ppm for the first time in recorded history (National Oceanic and Atmospheric Administration, 2017).

4. Long-term temperature records from ice sheets, glaciers, lake sediments, corals, tree rings, and historical documents demonstrate that every decade in the late 20th century has been warmer than the preceding decades (Hansen et al. 2012; Jones et al. 2012).

5. The most recent 50 years likely have been the warmest worldwide in at least the last 1,300 years (IPCC 2007), and 10 of the 11 warmest years on record have occurred since 2001 (Hansen et al. 2012).

6. Observations since 1961 show that at depths of at least 3,000 meters, the average temperature of the global ocean has increased; this deep storage of heat together with the higher heat capacity of water is causing the ocean surface to warm more slowly than the land surface (IPCC, 2007).

7. Global sea level has increased about 12-22 cm during the 20th century, but satellite records confirm that the rate of sea level rise has now almost doubled to about 3.4 mm per year (Allison et al., 2009).

8. Precipitation is highly variable, and trends are more difficult to isolate, but overall precipitation and heavy precipitation events have increased in most regions; at the same time the occurrence of drought has also been on the rise, particularly since 1970 (Allison et al., 2009). Floods frequency is also expected to increase.

9. Mountain glaciers and ice caps, as well as snow cover, are receding in most areas of the world. Both the Greenland and Antarctic ice sheets are now losing mass at increasing rates. The extent and thickness (volume) of Arctic sea ice is declining, and lakes and rivers freeze later in the fall and melt earlier in the spring (Allison et al., 2009).

10. Winter temperatures have increased more rapidly than summer temperatures, and nighttime minimum temperatures have warmed more than the daytime maxima. Across the United States (and elsewhere), the observed number of record high temperatures is about three times higher than the number of record cold events (Meehl et al., 2009). In Tunisia, the frequency of hot days and nights is increasing while that of cold days and nights is decreasing (Belghrissi, 2015).

The Mediterranean region is quite vulnerable to climate change since it lies in a transition zone between the arid climate of North Africa and the temperate and rainy climate of central Europe and it is affected by interactions between mid-latitude and tropical processes. Because of these features, even relatively minor modifications of the general circulation, e.g. shifts in the location of mid-latitude storm tracks or sub-tropical high-pressure cells, can lead to substantial changes in the Mediterranean climate. Indeed, the Mediterranean region has shown large climate shifts in the past (Luterbacher et al., 2006) and it has been identified as one of the most prominent "Hot-Spots" in future climate change projections (Giorgi, 2006).

The biggest problem in assessing the effects of climate change is uncertainty. The prognosis of the upcoming climate change is based on the use of complex global climate models, which consider the interactions between the atmosphere, the oceans, the biosphere and the cryosphere. The use of simulations based on data from the past and the modern era produces multi-dimensional chaotic systems, from which, at best, we can estimate a range of effects associated with high and low extremes of weather and calculate the respective odds distributions.

Climate models (General Circulation Models or GCMs), representing physical processes in the atmosphere, ocean, cryosphere and land surface, are the most advanced tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations. While simpler models have also been used to provide globally- or regionally-averaged estimates of the climate response, only GCMs, possibly in conjunction with nested regional models, have the potential to provide geographically and physically consistent estimates of regional climate change which are required in impact analysis.

Morrill et al. (2005) estimated the evolution of water quality of 43 rivers using the Hadley Centre Coupled Model, version 3 (HadCM3) GCM output directly. Efforts were also made by Rehana and Mujumdar (2011) to quantify the changes in water quality indicators namely BOD, temperature, pH, using the model QUAL2K under six hypothetical scenarios of increase and decrease of river flow water temperature. Smith et al. (2001) employed logistic regression to show that watersheds with large proportions of urban land cover or agriculture on steep slopes had a very high probability of being impaired by pathogens. Towler et al. (2010) developed a local logistic regression-based approach to estimate threshold exceedances of turbidity, conditioned on seasonal climate forecast of streamflow in the Pacific Northwest.

GCMs depict the climate using a three-dimensional grid over the globe, typically having a horizontal resolution of between 250 and 600 km, 10 to 20 vertical layers in the atmosphere and sometimes as many as 30 layers in the oceans. Their resolution is thus quite coarse relative to the scale of exposure units in most impact assessments. Moreover, many physical processes, such as those related to clouds, also occur at smaller scales and cannot be properly modeled. Instead, their known properties must be averaged over the larger scale in a technique known as parameterization. This is one source of uncertainty in GCM-based simulations of future climate. Others relate to the simulation of various feedback mechanisms in models concerning, for example, water vapor and warming, clouds and radiation, ocean circulation and ice and snow albedo. For this reason, GCMs may simulate quite different responses to the same forcing simply because of the way certain processes and feedbacks are modeled.

In a more regional way of speaking, regional or local climate change modeling studies currently require starting with a global climate model, then downscaling to the region of interest. In this process, it may be appealing to select global models based on the quality of their simulation in the region of interest. However, scientific studies have shown that this *does not result in systematically different conclusions than obtained by picking models randomly. This finding suggests there is little relationship between (i) the quality of the model-simulated physics that determines regional temperature and precipitation, and (ii) the quality of the physics that determines the anthropogenic climate change signal (Pierce et al., 2009).

The present simulations provide a quite clear picture of the climate changes that are expected in the Mediterranean region in the upcoming years. A substantial drying and warming is the main finding, especially in the warm season (precipitation decrease exceeding -25-30% and warming exceeding 4–5°C). The only exception to this picture is an increase of precipitation during the winter over some areas of the northern Mediterranean basin, most noticeably the Alps. Inter-annual variability is projected to generally increase as is the occurrence of extreme heat and drought events. These signals are robust in that they are present in most projections from both global and regional models and are consistent across emission scenarios and future time slices (Giorgi and Lionello, 2008). This, along with the potential of pronounced sea level rise under global warming, could have devastating effects on water resources, natural ecosystems (both terrestrial and marine), human activities (e.g. agriculture, recreation, tourism) and health.

2 Climate change impacts on agriculture and food supply

Agricultural systems are primarily defined by prevailing spatial and temporal distributions of climatic and edaphic (soil-related) conditions. As such, changes in key climate variables (e.g., seasonal temperatures or precipitation patterns) can result in changes – perhaps significant – in the mix of commodities produced and the systems and technologies that farmers employ to produce them. Climate change presents a novel challenge because of the sensitivity of agricultural system response to climatic variability and the complexity of interactions between agriculture and the global climate system. Interactions within the agricultural social-ecological system can result in synergistic effects that dampen or amplify the system response to climate change and complicate development of effective mitigation and adaptation options (Reidsma et al., 2010; Smith and Olesen, 2010).

While the agricultural systems usually have the ability to respond to changes or fluctuations in markets, technology, and the environment to a great degree, individual agricultural products differ in their ability to adapt to changing climate conditions. For example, crops have different critical temperature range for ideal lifecycle development. These vary by species and between vegetative and reproductive growth stages. In general, optimum temperatures are lower for the reproductive stage than the vegetative stage, i.e., plants are less able to tolerate high temperatures during the reproductive stage. Increasing temperature generally accelerates progression of a crop through its lifecycle phases, up to the species-dependent optimum, above which development (node and leaf appearance rate) slows.

However, increasing air temperature is only one factor to consider under current and future climate change scenarios; local management practices such as irrigation will also influence effects on agriculture. For example, amply irrigated plants growing under arid conditions create microenvironments that are 10°C cooler than ambient air temperature due to evapotranspiration cooling. Variables such as solar and reflected long-wave radiation, wind speed, air humidity, and plant stomatal conductance also affect to what degree temperature will influence crop growth and development.

Like temperature, precipitation has a direct influence on agriculture. In many areas of the world, precipitation is projected to increase but the incidence of drought is also expected to increase in some areas, and changes in timing and rain/snow mix may increase the management challenge of delivering water to crops at the right time through irrigation systems and practices. The intensity of precipitation events is also expected to increase. Excess precipitation, both in the form of short bursts or through increased amounts over longer episodes, can be just as damaging as too little precipitation, leading to increased erosion and decreased soil quality. Increased evapotranspiration due to warmer temperatures can result in less available water – even with increased precipitation – especially in soils with limited soil water holding capacity (Hatfield and Prueger, 2011).

In addition to their direct effects on plants, changes in temperature and precipitation also affect the amount of water in the atmosphere. With increases in water vapor, cloud cover is expected to increase, leading to a decrease in incoming solar radiation. This effect has already been observed in the solar radiation record around the world. Stanhill and Cohen (2001) observed a 2.7 % reduction per decade during the past 50 years, with the current solar radiation totals reduced by 20 W*m-2. Changes in solar radiation will directly affect crop water balance and evapotranspiration and have less effect on crop productivity due to other factors limiting productivity (e.g., water and temperature) (Hatfield et al., 2011).

Finally, changes in CO_2, temperature, precipitation, and radiation over the next century will be accompanied by other changes in atmospheric chemistry that have implications for agriculture. One of the most significant of these is expected changes in concentrations of ground level ozone. The number and complexity of these biophysical interactions demonstrates the necessity of systemic analyses of potential climate effects on agriculture.

In the Maghreb countries (Algeria, Morocco, Tunisia, Libya and Mauritania), agriculture plays an important economic and social role and has been identified as the most vulnerable sector to the climatic changes (Abou Hadid, 2006). Particularly in Tunisia, agriculture is mainly extensive in spite of efforts undertaken for its intensification, since such efforts have been limited by climatic conditions and lack of water resources (Lhomme et al., 2009). Rain-fed and irrigated agriculture represents, respectively, 88 and 10 % of the total agricultural area. The main rain-fed crops grown are cereals that represent about two-thirds of cultivated areas and 16 % of agricultural production as well as fruit and olive trees, covering more than 30 % of cultivated areas and representing 28 % of agricultural production and 60 % of exported foods. These crops are significant for the Tunisian national economy as they are important export goods and also secure almost all national consumer needs for wheat and barley. Nevertheless, agriculture remains by far the main water-consuming sector in the country and represents over 80 % of total water consumption. Thus, water availability is the major limiting factor in Tunisia and the annual variability in yields is mainly explained by rainfall variability (Louati et al., 1999).

Projected climatic conditions will have a direct impact on the agriculture sector and could endanger the socioeconomic development and social stability in Tunisia. Indeed, the rural population, which accounts for over 32 % of the total population (http://dataportal.ins.tn), is strictly dependent on the cultivated land which is usually equal or less than 5 ha. Additionally, the expected population increase of about 13 million by 2025, the urbanization process and industrial development, will contribute to an intensified water demand and competition among water users. A further increase in instability of agricultural production and food supplies is therefore likely.

2.1 Impacts on water resources

2.1.1 Water availability

Scientists within IPCC expect that the present increase in greenhouse gas concentrations will have direct first-order effects on the global hydrological cycle. In fact, for one-degree Celsius global warming, 7% of the population around the world would lost, at least, 20% of their renewable water resources (IPCC, 2014). The components of the surface hydrologic cycle affected by climate change include atmospheric water vapor content, precipitation and evapotranspiration patterns, snow cover and melting of ice and glaciers, soil water content (SWC) and temperature, and surface runoff and stream flow (Bates et al., 2008). More specifically, consecutively to the temperature increase, the air will get warmer and can hold more water vapor; more intense rainstorms may occur, and the risks of flooding will become very high. Such changes of the atmospheric and surface components of the global hydrologic cycle will likely result in changes in the subsurface hydrologic cycle within the soil, vadose zone, and aquifers of the world (Van Dijck et al., 2006).

The relation between climate change and hydrological cycle was deeply discussed by Trenberth (2011); in his review, Trenberth elucidate the role of water in the climate system and climate change. Kusangen et al. (2014) were analyzed the effect of greenhouse gases and were stated that the "increase of greenhouse gases will result in climate change which will increased frequency of extreme climatic events including intense storms, heavy rainfall events and droughts". Kundzewics (2008) was confirmed that "every change in the climate system induces a change in the water system". Arnell et al. (2013) studied the impacts of climate change on river flow regimes at the global scale. Regarding the groundwater impacts, Moseki (2017) presented a pure review article on climatic change impacts on groundwater; the aims are to collate and depict work done in this field as well as to serve as prelude to a research study in what and how appropriate response measure should be taken.

The infiltration of water into the soils and the recharge rate to the aquifers will be deeply reduced and thus the risk of depletion of water stocks in soils (green water) and groundwater resources (blue waters) will be very high. Furthermore, because of the atmospheric global movements, the dry areas will lose more water and will get more and more dry. At the opposite, the crop water needs will be increased direct consequence of global warming.

As the agricultural sector in the world consume 70% of the available water (green water and blue water), it is obvious that the global change in the hydrological cycle will affect directly the agricultural sector and food production. Indeed, Ingram (2014) was clearly argued that the climate change is the most significant threat to agriculture, therefore, to food security, worldwide, as consequence of drought. Also, Melkonyan (2015) was evaluated the climate change impact on water resources and crop production in Armenia and was stipulated that the agricultural sector of small mountainous Country in Armenia is very vulnerable towards climate change due to frequent drought episodes, enhanced air temperature, reduced precipitation, increased evaporation rate and water scarcity.

In addition, there may be other associated impacts, such as seawater intrusion, water quality deterioration, potable water shortage, etc. The effects include changes in water supply and quality (Kundzewicz, 2007) for domestic, irrigation, recreational, commercial, and industrial uses; in instream flows that support aquatic ecosystems, recreation uses, hydropower, navigation, and wastewater assimilation; in wetland extent and productivity that support fish, wildlife, and wastewater assimilation; and in the frequency and severity of floods. Watersheds where water resources are stressed under current climate are most likely to be vulnerable to changes in mean climate and extreme events (USGCRP, 2014).

Wurbs et al. (2005) provided a water availability modeling (WAM) system to assess the water supply capabilities and explore the climate impacts on hydrology and water availability for water users who depend on water supplies by the Brazos River Basin in Texas, and the key result is that future climate may decrease the mean stream flow, and its effects on water availability are various in different regions of the river basin. Alcamoa et al. (2007) evaluated climate impacts on water resources in Russia considering the changing frequency of extreme climate events and they concluded that average water availability will increase, and high runoff events will occur frequently, which can be a threat to food production in Russia. Mirza (2007) reported that climate change will increase the frequency of floods and droughts in South Africa while Cuculeanu et al. (2002), who discussed climate vulnerability impacts on water resources in 2075 in Romania, concluded that water requirements in the reference basin will exceed water availability.

Climate impacts on water resources are varied in different river basins. The frequency of droughts and floods will increase under future climate conditions. Runoff and streamflow are more sensitive to rainfall than to evapotranspiration. Efficient water use, and integrated management will be increasingly important for reducing the impacts on water scarcity and droughts.

Groundwater resources are related to climate change through the direct interaction with surface water resources, such as lakes and rivers, and indirectly through the recharge process. The direct effect of climate change on groundwater resources depends upon the change in the volume and distribution of groundwater recharge. Therefore, quantifying the impact of climate change on groundwater resources requires not only reliable forecasting of changes in the major climatic variables, but also accurate estimation of groundwater recharge.

According to Jorgensen and Yasin al-Tikiriti (2003) the effect of historical climate change on groundwater resources, which once supported irrigation and economic development in parts of the Middle East, is likely the primary cause of declining cultures there during the Stone Age. Climate change may account for approximately 20% of projected increases in water scarcity globally (Sophocleous 2004). Integrated groundwater management and planning into the future requires careful evaluation and understanding of climatic variability over periods of decades to centuries, while considering the increasing stresses on those groundwater resources from population growth and industrial, agricultural, and ecological needs (Warner, 2007).

Tunisia is highly vulnerable to water scarcity and water quality (Mougou et al., 2011). Most of the water resources have medium to poor quality, and the salinity is often high. Water deficits and droughts are ongoing risks for the agricultural sector that provides approximately 13 % of the national annual GDP (2004). Indeed, at the beginning of the 20th century, the country experienced one drought every 10 years, in contrast with the current state of five or six years of drought per 10 years. Tunisia is therefore particularly vulnerable to climatic changes also due to poor soils, limited ground and surface water, low rainfall and recurrent droughts. Projected climate change impacts, e.g., rising temperatures and decreasing precipitation, impose high risks for farmer's subsistence basis of nourishment and for the national economy.

It is expected that climate change will alter hydrologic watershed regimes, increase pick discharge in some regions and decrease runoff in other context. For example, as mentioned by Sellami et al. (2014), impact assessments of climate change on water resources in Tunisia might be more important droughts, despite the high uncertainty, which will strongly affect agricultural water shortages. The warming trend and changes in precipitation patterns could affect the composition and functioning of runoff and dam resilience. It is expected that crop water requirements are very likely to increase in case studied and thus adapted management practices might be required.

Because of world population growth, climatic changes and intensive agricultural activities, per capita arable land has decreased over the years, from a worldwide average of 0,38 ha in 1970 to 0,28 ha in 1990, and some analysts project a further decrease to 0,15 ha in 2050 (Ghassemi et al., 1995). Tunisia is one of the most seriously concerned country by insufficient water use efficiency (Ec ≤ 65 %) and the more significant climate changes' impacts. In fact, by 2050, the average temperature increase reaches 1.6 °C(in the northeast) up to 2.7 °C (in the extreme south). Consequently, crops' water requirement are increasing. Whereas the average annual rainfall is to be reduced by 11% (in the northeast) up to 27%(in the southernovest) as compared to the reference (1961-1990) period (Mitchell, 2003; Mitchell and Jones, 2005). Therefore, more rational agricultural water management became necessary for Tunisia. Such rational irrigation water management is to be insured at the academic, at the institutional and at the field level.

Actually, in Tunisia where 83% of mobilized water resources are used for irrigation, a serious water shortage exacerbated by the declining quality of water and soil resources is becoming a critical constraint on agricultural development. Water saving is needed so, firstly to deal with competition between sectors of potable and industrial water and also to ensure the sustainability of irrigation schemes.

2.1.2 Water quality

Among other factors like land use evolution, deforestation, urban spreading and area waterproofing, climate change could affect surface water quality as summarized by Depta et al. (2009). Water quality parameters can be classified into three clusters: (i) physico-chemical basic parameters (Temperature, pH, dissolved oxygen, dissolved organic matter, etc.) and nutrients, (ii) biological parameters namely pathogens microorganisms, cyanobacteria and water quality proxies and (iii) micropollutants (inorganic and organic) including metals, pharmaceuticals and pesticides.

Climate change impact on water quality is attributed to changing air temperature and hydrology. In fact, air temperature increase strongly influences water chemistry, biochemical reactions and growth or death of biota. Global warming and water temperature increase govern physico-chemical equilibriums in rivers and thus influence contaminant's concentration and transport (Hrdinka et al., 2015; Zhang et al., 2015). Moreover, more intense rainfall and flooding could result in increased loads of suspended solids and contaminant fluxes associated with soil erosion and fine sediment transport from the land. Consequent increased water turbidity may occur with potential health impacts from water-borne pathogens, as large volumes of water can transport contaminants into water bodies (Whitehead et al., 2009). In addition, lower minimum flows imply smaller volume for dilution and higher nutrients and organic pollutants concentrations. Lower flows, reduced velocities, higher water residence times in rivers and reduced dissolved oxygen levels cause more frequent algal blooms and can cause fish kills and do significant harm to ecosystems (Jun et al., 2010). The following water quality parameters are directly impacted by climate change patterns.

Temperature: Since 1960, North America, Europe and Asia are facing a rise in surface water temperatures, ranging between 0.2 and 2°C. This rise was mainly due to atmospheric warming, a consequence to the solar radiation increase (Bates et al., 2008). After the severe drought of 2003, Zwolsman and van Bokhoven (2007) and VanVliet and Zwolsman (2008) observed in Rhine and Meuse rivers, an average increase in water temperature of around 2°C, with a pH increase (reflecting a decrease in CO_2 concentration), and a decrease in dissolved oxygen (DO) solubility reflecting a lower DO solubility under higher water temperatures. This DO decrease could also be associated to an increase in DO assimilation of biodegradable organic matter by microorganisms (Prathumratana et al., 2008).

The rise in water temperatures could also affect the stratified period. In fact, in several lakes in Europe and Northern America, this period has lengthened by 2–3 weeks, which could affect the thermal stratification (Komatsu et al., 2007) and lakes hydrodynamics (Bates et al., 2008). Water temperatures have an impact on internal lake processes like diffusion, mineralization and vertical mixing (Malmaeus et al., 2006). Deepest lakes are most sensitive to climate warming on a long period of time due to their greater heat storage capacity (George et al., 2007).

Turbidity of the water column increases after intense precipitation and with soil erosion. High turbidity is usually related to reduction of light availability, higher growth rate of phytoplankton, higher mineralization and increased nutrient availability and loading. Thus, extreme climate events impact turbidity which reduces the light availability in the water column and negatively influences aquatic organisms, phytoplankton and macrophytes (Samal et al., 2013).

The rates of nitrification and denitrification are influenced by global warming as they increase with temperature. On one hand, the rates of the aerobic process of nitrification control the processing of nitrate in water system as ammonium is transformed into nitrate. On the other hand, denitrification and the presence of nitrogen in excess can lead to eutrophic conditions and water quality degradation. Nitrate concentration in water may also increase due to mineralization of organic matter by microorganisms while anthropogenic activities mainly fertilization has been increasing ammonium concentrations in the environment (Admiraal and Botermans, 1989).

Heavy rainfall induces the leaching of nutrients and contaminants into surface and groundwaters due to flooded landfills. Extreme droughts can also lead to an accumulation of nutrients such as nitrogen and phosphates due to interruption of microbial activity. In the hot summer, nutrients concentrations, except nitrate, increased as a result of lower dilution because of decreased discharges. The bioavailability of heavy metals depends on pH, concentration of organic matter, minerals and redox potentials. Nutrient availability is associated with eutrophication depending on light conditions, temperature, residence time and flow conditions (Whitehead et al., 2009; Zhang et al., 2015; Hosseini et al., 2017).

Toxic substances including persistent organic compounds and trace metals are flushed and remobilized due to the increase of soil and sediment erosion in storm events and flooding. In fact, temperature change influences the accumulation of persistent organic pollutants (POPs) which either enter food chains or can be taken up by aquatic biota. For instance, Polybromodiphenyl ethers (PBDEs) and polychlorinated biphenyls PCBs concentrations in fish show significant temperature correlations. Pesticide release and transport are also impacted by changes in temperature, rainfall intensity and seasonality (Bloomfield et al., 2006).

Global warming affects the concentration of oxygen in water systems as higher water temperatures lead to decreased concentrations of dissolved oxygen. In fact, increases in water temperature result in reduced oxygen solubility thus reducing dissolved oxygen (DO) concentrations and increases the biological oxygen demand. Reduced DO concentrations will have an impact on the duration and intensity of algal blooms. Aquatic organisms exposed to an increase in water temperature can face a decreased supply of oxygen which alter biotic assemblages and biochemistry, reduce biodiversity and the overall productivity of lakes and streams (Whitehead et al., 2009; Hosseini et al., 2017).

The salinization of freshwater can occur either through the increase of evaporite rock dissolution in surface water and the seawater intrusion in the coastal aquifers. Sea-level rise, extreme weather events, coastal erosion, changing precipitation patterns, warmer temperatures, and the potential for increased freshwater demand could all increase the risks of seawater intrusion (Trabelsi et al., 2013), which have a major impact on drinking water quality, crop irrigation and freshwater aquatic life (Rajaveni et al., 2016).

Global warming results in an increase of the water temperature in the epilimnion (top layer of water of lower density) and the duration of stratification, which lead to higher risk of oxygen depletion below the thermocline (transition zone between epilimnion and hypolimnion: bottom layer). These anaerobic conditions might increase the risk of internal nutrient release (Verweij et al., 2010).

Waterborne pathogens could be spread within the freshwater after a contamination by animal or human waste due to heavy rainfall discharge in sewer systems. When the flow exceeds the sewer system capacity, there is an overflow directly into surface water (Charron et al., 2004). A tidal embayment was found contaminated by coliforms, which were mainly from of the storm water coming from the surrounding watershed (Pednekar et al.,2005).

Although there is still no clear evidence, Hunter (2003) stated that higher water temperatures will probably lead to a pathogen survival increase. In fact, an increase in temperature threats water quality with regard to waterborne diseases especially cholera disease in Asia and South America (Hunter, 2003). Moreover, it was shown that with increased UV radiation due to ozone layer depletion, bioavailable organic compounds, minerals and micro-nutrients will be break. All these processes could stimulate bacterial activity in aquatic ecosystems (Soh et al., 2008).

Floods often led to a contamination of groundwater and additional disease outbreaks like Acanthamoeba keratitis in Iowa (USA) in 1994 (Hunter, 2003). According to Curriero et al. (2001), half of the waterborne disease outbreaks in the US during the last half century followed a period of extreme rainfall. Even though the risk of diseases outbreaks linked to mains drinking waters is low in developed countries, private supplies would be at risk (Hunter, 2003).

Competition between phytoplankton and cyanobacteria could be switch in favor of cyanobacteria in a warmer climate (Arheimer et al., 2005) and could also increase their dominance. Increase in water temperatures, nutrient concentration and summer heatwaves causes massive cyanobacteria bloom in many waterbodies through reducing vertical turbulent mixing and increasing growth rates (Hunter, 2003; Jöhnk et al., 2008).

Moreover, new cyanobacterium species as Cylindrospermopsis raciborskii have colonized northern habitats due to effects of rising temperatures. This tropical cyanobacterium, known to produce Cylindrospermopsin, is now detected in South and Western Europe freshwaters (Italy, Spain and France) (Brient et al., 2008) and has been detected in German lakes (Wiedner et al., 2007). Other cyanobacteria, like Microcystis which can produce microcystin, could become invasive with climate warming (Jöhnk et al., 2008).

Fishes, green algae and diatoms are often used as water quality indicators. Daufresne and Boët (2007) observed an increase related to global warming in total abundance and in proportions of warm-water species and size-structures changes in fish communities in French rivers. Southern thermophilic fish species progressively replaced northern cold-water species in the upper Rhône River (Daufresne et al., 2003). Furthermore, high temperature and low turbulent diffusivities in lakes could suppress the population abundances of green algae and diatoms (Jöhnk et al., 2008). High temperatures seem to favor the cyanotoxins dominance, as Microcystis, over diatoms and green algae (Jöhnk et al., 2008).

2.2 Impacts on soils

The increase in temperature, the changes in precipitations patterns, floods, droughts and sea level rise related to climate change are all factors that will affect directly or indirectly the natural environment and notably soils. Soils are important because human and ecological systems rely on them for the provision of water and nutrients for crop growth, the regulation of water cycle and the storage of carbon. Thus, soils are paramount to food security (Pimentel, 2006) and climate change has the potential to threaten food security through its effects on soil properties and processes (Brevik, 2013). Besides, when managed sustainably, soils can play an important role in climate change mitigation through carbon sequestration and decreasing greenhouse gas emissions in the atmosphere (FAO, 2015).

Soil Organic Matter (SOM) is considered as the main component that governs soil physical, chemical and biological properties. Moreover, Organic Carbon incorporated into SOM may play a major role in controlling soil behavior as a sink or source for atmospheric CO_2 (Ghee et al., 2013). Thus, the effect of climate change on SOM has received growing attention. Indeed, because of the variability of soils, the complex nature of SOM and the difficulty to measure carbon content changes, different trends were observed. Due to the CO_2 fertilization effect, it is expected that plant productivity would increase which will lead to higher Carbon inputs in soil thus helping to offset increasing atmospheric CO_2 levels (Coughenour and Chen, 1997; Hättenschwiler et al., 2002). Nevertheless, increased plant growth in a CO_2-enriched atmosphere may rapidly deplete soil nutrients. Consequently, the positive effects of CO_2 increase may not persist as soil fertility decreases (Bhattacharya and Geyer, 1993). On the other hand, increased temperature is likely to have a negative effect on C sequestration by soils as it will be responsible for accelerating SOM decomposition and increasing CO_2 release from soils to the atmosphere.

Erosion is a major environmental threat to the productivity of soils and the sustainability of agriculture. These adverse impacts may become more serious under the impacts of future climate change, ranging from direct changes in precipitation characteristics to the more indirect effects of temperature and solar radiation in governing plant biomass, plant residue decomposition rates, soil microbial activity, evapo-transpiration rates and shifts in land use to accommodate the new climatic regime (Mullan, 2013). For instance, during their study of a semi-arid Mediterranean ecosystem in Spain, García-Fayos and Bochet (2009) found strong correlations between climate change and soil erosion and negative impacts on aggregate stability, bulk density, water holding capacity, pH, organic matter content, total N, and soluble P in the soil, all properties important for good crop growth. Therefore, it can be stated that if climate change increases soil erosion, it will also damage soil properties that are important in the production of food needed by humans (Nearing et al., 2004; Brevik, 2013). Besides, according to simulations performed by Feddema and Freire (2001) in the African continent, soil degradation could reduce water holding capacities which will result in increased water runoff and reduced recharge rates to groundwater.

Climate change projections indicate increase of the extreme events such heavy rains and floods as well as droughts intensity and frequency (IPCC, 2014). It is expected that the rainfall erosivity will be at least as that in the past (Shiono et al., 2013) or will be increased (Panagos et al., 2017). However, the soil degradation will increase as land use will be changed and vegetation will decrease (Panagos et al., 2017). The GCM indicates an increase of extreme events in Mediterranean basin (IPCC, 2014) which could influence the rainfall erosivity. The future soil erosion dynamics will depend on latitude and projections horizon. In the Mediterranean region, the erosion will increase mainly due landcover shifting.

In addition to erosion, soil salinization is a degradation process that will be further exacerbated by climate change, especially in irrigated areas. Indeed, the changes in precipitation patterns, the increase in temperatures accompanied by higher evapotranspiration rates will favor salt concentration and accumulation in soils. Climate change also will increase salinity along coastal regions, through the influence of sea-level rise (Nicholls, 2000). The negative impacts of salinity on soil and on crops are well documented. Lavee et al. (1998) showed relatively small changes in climate may push many Mediterranean areas into a more arid and eroded landscape featuring decreases in organic matter content, aggregate size, and stability and increases in sodium adsorption ratio and runoff coefficient.

Soil biodiversity refers to all organisms living in the soil. In particular, soil microorganisms (bacteria, fungi) are responsible for up to 80% of soil biological activity related to nutrient cycling (carbon, Nitrogen, Sulphur) and organic matter decomposition. There is strong evidence to support the idea that changes in soil temperature, moisture and carbon content induced by climate change will affect growth, activity and composition of soil microbial communities (Mandal and Neenu, 2012). Nevertheless, there is great uncertainty surrounding the response of soil community function to climate change and the potential effects of these responses at the ecosystem level (Smith et al., 1998).

In general, temperature increase means a rise in microbial activity and SOM decomposition rates, which can release more carbon dioxide and even methane from soils. The magnitude of increased microbial activity varies due to differences in microbial communities, availability of carbon, and plant growth rates (Mandal and Neenu, 2012). Soil moisture may influence bacteria directly by limiting their capacity to decompose various types of organic compounds or indirectly through the modification of the quality and the quantity of plant litter production (Prado, 1999).

Nematodes, microarthropods and earthworms are equally sensitive to temperature and moisture changes. For these communities, high temperatures and drought significantly affect abundance, physiology and reproduction rates with important impacts on population growth (Booth et al., 2000; Choi and Ryoo, 2003; Strong et al., 2004). Furthermore, the distribution of individual species of soil biota will be affected by climate change where species are associated with specific vegetation and are unable to adapt at the rate of land-cover change (Kirschbaum et al., 1996).

The sea level rise predicted by climatic projections will lead to the flooding of the deeper located areas and the loss of coastal soils. The higher situated soils will periodically be flooded by saltwater, which will also have a negative influence on their productivity (Blume, 2011). In Tunisia, for a 50 cm seal level rise projected in 2100, potentially submerged areas are estimated to 18 000 ha. Besides, 10% of irrigated areas will be lost through salinization and submersion processes (MET, 2011).

In the permafrost regions of the lower latitudes (Alaska, Siberia), soils are covered by a permanently frozen layer. In these regions, global warming will be responsible for the melting of the upper permafrost. Thus, 50% and 90% of permafrost is expected to melt by 2050 and 2100 respectively. As a consequence, huge amounts of carbon (methane CH_4) that were sequestered in these soils will be released in the atmosphere (Tarnocai, 2006; Shuur et al., 2008).

Peats are highly organic soils where Organic Matter is accumulated in soils due to low temperatures and hydromorphic conditions. This type of soils represents only about 3% of emerged lands (400 Mha) but sequesters almost third of the total amount of carbon sequestrated by soils in the world. Under climate change, the increase in temperature, the eventual decrease in precipitations and droughts are expected to induce accelerated OM mineralization and considerable CO_2 and CH_4 emissions by soils. These emissions will create a positive-feedback in the global C cycle, i.e. increased temperatures lead to increased GHG release from soils to the atmosphere, which in turn leads to more increase in temperature (Tarnocai, 2006; Dieleman et al., 2016).

2.3 Impacts on crops

2.3.1 Effects of atmospheric composition

Most plant life on Earth can be broken into two categories based on the way they assimilate carbon dioxide (CO_2) from the atmosphere into different physiological components, C3 and C4 plants; CAM species are less cropped. More than 95 % of the world's plant species fall into the C3 category.

C3 plants are called temperate or cool season plants. They reduce CO_2 directly by the enzyme ribulose bi-phosphate carboxylase in the chloroplast. The reaction between CO_2 and ribulose bi-phosphate forms two molecules of a 3-carbon acid. This 3-carbon acid is called 3-phosphoglyceric acid and explains why the plants using this reaction are called C3 plants. C3 plants have an optimum temperate range of 18-24oC. Growth begins when the soil temperature reaches 4oC. C3 plants become less efficient as the temperature increases. However, they provide a higher percentage of crude protein than C4 plants. Cool-season grasses are productive in the spring and fall because of the cooler temperatures during the day and night, shorter photoperiods, and higher soil moisture. During the summer, growth is reduced, and dormancy is induced by high temperatures and low precipitation. C3 plants include wheat, rye, rice, barley, soybean, potato, spinach and oats, among others.

C4 plants are often called tropical or warm season plants. They reduce carbon dioxide captured during photosynthesis to use able components by first converting carbon dioxide to oxaloacetate, a 4-carbon acid. This is the reason these plants are referred to as C4 plants. This type of photosynthesis in highly efficient and little fixed CO_2 is lost through photorespiration. C4 plants are more efficient at gathering carbon dioxide and utilizing nitrogen from the atmosphere and in the soil. C4 plants grow best at 32-35oC. They begin to grow when the soil temperature is 15-18oC. Forage of C4 species is generally lower in protein than C3 plants. C4 plants can be annual or perennial. C4 plants include corn, sugar cane and sorghum, among others.

One of the most important differences between C3 and C4 species for rising CO_2 levels is that C3 species continue to increase photosynthesis with rising CO_2, while C4 species do not. Another important difference between C3 and C4 plants is evident in stomatal conductance and water use by plants. There is a decrease in the stomatal conductance of the leaves (Ainsworth et al., 2002) as the atmospheric concentration of CO_2 increases. The result of this decrease in conductance is a reduction in the rate of water use and an increase in water use efficiency (amount of biomass produced per unit of water transpired).

Over the past 200 years, the CO_2 concentration in the atmosphere has increased by 30%, from 280 to 360 ppm (Keeling and Whorf, 1997). Though the exact prediction is impossible, its concentration levels could reach 600-800 ppm in the future (Walker and Kasting, 1992). Because enhanced atmospheric CO_2 concentrations stimulate photosynthesis and plant growth, much work has been focused on determining the responses of crops and weeds to elevated CO_2. Although higher CO_2 levels typically increase growth, the response varies by species. Part of this variability is related to photosynthetic biochemistry. For example, plants with the C_3 photosynthetic pathway (about 95% of all plant species) are likely to respond more strongly than plants possessing the C_4 photosynthetic pathway (for which photosynthetic rates are saturated at current, ambient CO_2).

Most experiments have used one or two elevated CO_2 concentrations, most often near 550 to 700 ppm. Yields of wheat, rice, and soybeans under field conditions increased approximately 12% to 15% under 550 ppm compared with 370 ppm CO_2 concentrations, with the percentage increases about 1.6 times those for elevated CO_2 concentrations of approximately 700 ppm. As compared with most other annual crop species, cotton had an exceptional 43% yield increase under increased CO_2 concentrations, but it should be noted that some varieties of rice and soybean also had yield increases as large as cotton. Corn had negligible yield increases (Long et al., 2005; Long et al., 2006; Ziska and Bunce, 2007). Of course, it should be considered that significant variation in response among varieties within species exist and that response differences may exist between annual and perennial species because the stimulation of growth by perennial species grown with little competition may be cumulative over years.

Elevated atmospheric CO_2 can modify responses of crops to environmental stresses. Some modifications tend to reduce effects of stress, such as elevated CO_2 causing partial stomatal closure and reducing penetration of ozone into leaves, which in turn lowers yield losses due to ozone (Booker and Fiscus, 2005). Partial stomatal closure at elevated CO_2 also reduces crop water loss (Bunce, 2004). However, elevated CO_2 increases crop tissue temperatures, which may exacerbate damage to reproductive processes caused by high air temperatures.

Rising atmospheric CO_2 concentrations over the last 150 years have likely increased productivity of pastures (Polley et al., 2003; Izaurralde et al., 2011). Based on simulation studies, it is expected that the productivity of native grasslands will continue to increase over the next 30 years as air temperature and atmospheric CO_2 concentrations increase (Parton et al., 2007). Rangeland species encompass a wide variety of types of plants and include both C_3 and C_4 species; elevated CO_2 can increase the proportion of C_3 relative to C_4 species (Owensby et al., 1999). Rangeland species' responses to increased temperature and CO_2 are similar to those of the major crops, though interactions among species are more important as rangelands consist of a mixture of species. As is the case for rangelands, the mixed nature of pasture crops has important implications for the response to water and nutrients under elevated temperatures and CO_2. Rangeland species will grow faster with higher temperatures and experience a longer growing season.

In addition to production quantity, the quality of agricultural products may be altered by elevated CO_2. For example, some non-nitrogen-fixing plants grown at elevated CO_2 have reduced nitrogen (N) content (Ainsworth and Long, 2005). Nitrogen is a critical agricultural crop nutrient. The mechanism for this is unclear. One implication may be that changes of N application-practices may be useful in dealing with climate change effects, both for the economic gains by producers, and to reduce the environmental effects of elevated residual soil N. For instance, non N-fixing cereal and forage crops grown at elevated CO_2 often have lower protein contents (Erbs et al., 2010), which will affect human and animal nutrition, and could also affect the behavior of pests. More subtle product quality responses, especially to temperature and water stress, may also be very important economically.

2.3.2 Effects of temperature increase

Global warming is the current increase in temperature of the Earth's surface (both land and water) as well as its atmosphere. Average temperatures around the world have risen by 0.75°C over the last 100 years, while about two thirds of this increase has occurred since 1975 (Hansen et al., 2010). Such temperature increase will almost inevitably affect agricultural products, as all plants have minimum, maximum, and optimum temperatures that define their response to temperature. The minimum and maximum temperatures are the boundaries for growth; between these extremes is an optimum temperature that allows greatest growth. Beyond a certain point, higher air temperatures adversely affect plant growth, pollination, and reproductive processes (Sacks and Kucharik, 2011). However, as air temperatures rise beyond the optimum crop yield losses accelerate, instead of falling at a rate commensurate with the temperature increase. An analysis by Schlenker and Roberts (2009) has shown that yield growth for corn, soybean, and cotton gradually increases with temperatures up to 290C to 320C and then decreases sharply as temperature increases beyond this point.

Hatfield et al. (2011) have reported the min and max temperatures for a number of different species, providing thresholds to use when assessing the potential effects of increasing temperature on crop growth. Based on this information, crop simulation models have shown that continued increases of temperature will lead to yield declines between 2.5 and 10 % across a number of agronomic species throughout the 21st century. Other evaluations of temperature on crop yield have had varying outcomes: Lobell et al. (2011) showed estimates of yield decline between 3.8 and 5 %; Schlenker and Roberts (2009) used a statistical approach to produce estimates of wheat, corn, and cotton yield declines of 36 to 40 % under a low-emissions scenario and declines between 63 to 70 % for a higher emissions scenario. These simulation exercises, though, did not incorporate effects of rising atmospheric CO_2 on crop growth, yield reductions due to pests, crop genetic variability, or management innovations such as new fertilizers, rotations, tillage, or irrigation.

Even as climate warms and minimum average temperatures increase, years with low maximum temperatures may more frequently be closer to achieving the temperature optimum, which will result in higher yields than is the case today during years when average temperatures are below the optimum. Welch et al. (2010) found this to be the case for a historical analysis of rice in Asia – higher minimum temperatures reduced yields, while higher maximum temperature raised yields; notably, the maximum temperature seldom reached the critical optimum temperature for rice. As future temperatures increase, the authors found that the maximum temperatures could decrease yields if they rise substantially above the critical zone.

Increasing air temperature can enable earlier planting during the spring if suitable moisture and soil temperature conditions exist, resulting in a longer growing season. A longer growing season creates more time to accumulate photosynthetic products for greater biomass and harvestable yields as long as the temperatures do not exceed optimum values. However, increasing temperatures will also increase crop water demand and larger plants will use more soil water as part of the growth process (Betts et al., 2007). The positive effects of temperature could be offset by increased variation of precipitation and soil water availability to the crop. At the same time, a longer growing season can affect water availability (Betts et al., 2007), as well as weed and insect interactions with crops.

With a closer approach to European conditions, at middle and higher latitudes of Europe, global warming will extend the length of the potential growing season, allowing earlier planting of crops in the spring and earlier maturation and harvesting. Less severe winters will also allow more productive cultivars of winter annual and perennial crops to be grown. Cropping areas may expand northwards in regions such as Scandinavia and Russia. The shifts will be most pronounced along the current margins for production of specific crops. In warmer, lower latitude regions of Europe, increased temperatures increase respiration, resulting in less than optimal conditions for net growth.

2.3.3 Effects of water availability

Climate change is one of the greatest pressures on the hydrological cycle along with population growth, pollution, land use changes and other factors (Aerts and Droogers, 2004). Agriculture of any kind is strongly influenced by the availability of water. Climate change will modify rainfall, evaporation, runoff, and soil moisture storage. Changes of the timing, intensity, and amount of rain/snow mix for a location are expected to increase the management challenge of delivering water to crops at the right time through irrigation systems and practices. Excess precipitation can be as damaging as receipt of too little precipitation due to the increase in flooding events, greater erosion, and decreased soil quality. Increases in evapotranspiration can result in less available water even in cases when precipitation amounts increase, particularly in soils with limited soil water holding capacity.

The expected climate changes are, especially the increasing temperatures, the increased variability of the early growing season and its shortening, etc. These changes affect agricultural water requirement, water's availability and quality; moreover, these effects are expected to be intensified particularly in regions where water scarcity is already a concern. The demand for water for irrigation is projected to rise in a warmer climate, increasing the competition between agriculture and urban as well as industrial users of water (Arnell, 1999). More water will be required per unit area under drier conditions, and peak irrigation demands are also predicted to rise due to more severe heat waves (Parry, 2000). Many studies have considered climate change impacts on stream flow as well as spatial distribution of water availability under different climate conditions across the world. Guo et al. (2002) studied the climate change impacts on the runoff and water resources in China and pointed out that runoff is more sensitive to precipitation variation than to temperature increase, and integrated water resources management can help mitigate climate change.

A major component of hydrological cycle and crop growth estimation, and crop water requirement is the potential evapotranspiration (Zuo et al. 2012). Its spatio-temporal variation is related to climate change and its effect on water resources, crop water requirement and agricultural production. In this regard, during analyzes of the trends of the different climatic parameters in the Tunisian Sahel (Chott Meriem), Mansour

(2017) showed that the evolution of reference evapotranspiration depends on the method of calculation used and the evolution of the dependent climatic parameters. There is no particular trend of evapotranspiration when using Penmann Monteith method (Allen et al., 1998), methods based mainly on the temperature used by Hargreaves and Samani (1985) and those based on the radiation tested byTurc (1961) and Priestley and Taylor (1972) showed an upward trend.

Ma et al. (2008) discussed climate variability impacts on annual stream flow in the Shiyang River northwest of China and the results present that climate change can reduce 64 % of mean annual streamflow owing to the decreased precipitation; meanwhile, precipitation is more sensitive for the catchment streamflow than potential evapotranspiration. Fujihara et al. (2008) analyzed the water resources under present and future climate scenarios in the Seyhan River Basin and the conclusion is that water scarcity will occur when water requirements increase, e.g. due to the expansion of irrigation; therefore, efficient water resources use is important in managing future water resource conditions.

2.3.4 Effects of extreme events

Extreme weather events include spells of very high temperature, torrential rains, floods and droughts. Under an enhanced greenhouse effect, change can occur in both mean climate parameters and the frequency of extreme meteorological events. Relatively small changes in mean temperature can result in disproportionately large changes in the frequency of extreme events. Sequential extremes can affect yields and diseases. Droughts, followed by intense rains, for example, can reduce soil water absorption and increase the potential for flooding, thereby creating conditions favoring fungal infestations of leaf, root and tuber crops in runoff areas. Prolonged anomalous periods can have destabilizing effects on agriculture. Sequential extremes, along with altered timing of seasons, can decouple long evolved relationships among species (e.g. predator/prey) essential for controlling pests, pathogens and populations of plant pollinators.

Drought stress and heat stress frequently occur simultaneously, exacerbating one another. They are often accompanied by high solar irradiance and high winds. Under drought stress, the crop's stomata close, reducing transpiration and, consequently, raising plant temperatures. Flowering, pollination and grain-filling of most grain crops are especially sensitive to water stress. Moreover, excessively wet years may cause yield declines due to waterlogging and increased pest infestations. High soil moisture in humid areas can also hinder field operations. Intense bursts of rainfall may damage younger plants, promote ripening grain lodging in standing crops, and cause soil erosion. Nevertheless, the extent of crop damage depends on the duration of stress and crop developmental stage. Crop yields are most likely to suffer if the adverse weather conditions, especially high temperature and excess or deficit precipitation, occur during critical developmental stages such as the early stages of plant reproduction.

Weeds compete with crops for soil nutrients, light, and space. Drought conditions increase the competition for soil moisture; humid conditions increase the proliferation of weeds; and warmer temperatures increase the maximum biomass of grass weeds. Temperature, precipitation, humidity, dew, radiation, wind speed, and circulation patterns influence the growth, spread, and survival of crop pathogens. Increased temperature and humidity result in the spread of diseases as wet vegetation promotes the germination of spores and the proliferation of fungi and bacteria. Enhanced soil moisture encourages the spread of nematodes, roundworms that inhabit water films or water-filled pore spaces in soils. Some pathogens (e.g., powdery mildews) thrive in hot, dry conditions as long as there is dew formation at night.

2.3.5 Effects on agricultural pests

Climate also affects agricultural pests. The spatial and temporal distribution and proliferation of insects, weeds, and pathogens is determined, to a large extent, by climate, because temperature, light, and water are major factors controlling their growth and development. As a result, climate also affects the pesticides used to control and/or prevent pest outbreaks: the intensity and timing of rainfall influence pesticide persistence and efficiency; temperature and light affect pesticide persistence through chemical alteration. Most analyses show that in a warmer climate, pests may become more active than currently and may expand their geographical range, resulting in increased use of agricultural chemicals with accompanying health, ecological and economic costs (Stinner et al., 1989; Sutherst, 1990; Coakley et al., 1999).

Because of the great variation of pest species' responses to meteorological conditions, the relationships between pests and weather are not susceptible to overall characterization. Crop damage by pests is a consequence of complex ecological dynamics between two or more organisms, and therefore, is difficult to predict. For example, dry conditions are unfavorable for sporulation of fungi, but are also unfavorable for the crop; during a drought, a weak crop is more likely to become infected by fungi than when it is not stressed.

Climate change includes an increased weather variability and higher incidence of extreme events such as droughts, heat waves and cold waves which are expected more frequently (Easterling et al., 1997, 2000; Walther et al., 2002). In any given ecosystem, the multi-trophic interactions, between the different trophic levels, result from a long co-evolutionary process specific to a particular environment and relatively stable climatic conditions. These multi-trophic interactions are particularly affected by climatic changes as exemplified from several studies that showed a change in the temperature influenced the biology of each component species of a system differently. This might lead a destabilization in the population dynamics that may lead to the extinction of part of the system (Hance et al., 2007; Parmesan et al., 2013).

The impacts of above mentioned changes are particularly relevant in agrosystems of economic importance. Indeed, many models estimate that the negative impact of climate change on multi-trophic interactions will increase the severity and timing of pest outbreaks in addition to ecosystem functioning (Hance et al., 2007). Altogether, the need for improved control of agricultural pests and diseases and the necessity to reduce the use of chemicals require a change in the paradigm of crop protection, especially in the context of climate change.

In agrosystems, the tri-trophic interactions between plant-pest and pest-natural enemies are relatively well known, but a part of the system remains a black box, in a context of a minimization of the use of pesticides, and how this evolution will impact the relation of the pests with their natural enemies under climate change will evolve. Altogether, the need for improved control of agricultural pests and diseases and the necessity to reduce the use of chemicals require a change in the paradigm of crop protection, especially in the context of climate change.

The main key will be to know the changes in food web structure and function resulting from invasion of some of the representative of lower trophic levels and of their natural enemies, from their origin center to invaded regions. The scale insects is quite diverse in terms of major evolutionary lineages, species richness, reproductive biology and morphological traits (Hodgson & Hardy 2013).

Insect pests have been spreading very fast in recent decades due to the increase of agricultural trades, human mobility and climatic change. In Tunisia, 68 scale insect species belonging to 9 families have been recorded up to now (Garcia et al., 2017). Recently Ben Halima et al. (2015) reported the presence of 2 invasive species of mealybug: Phenacoccus madeirensis Green and Maconellicoccus hirsutus Green with a risk to vineyards and citrus crops (OEPP, 2005).

Some studies on Scales Insect were conducted in Tunisia and Mediterranean Basin (Mansour et al., 2012) on crops with highly economic importance such us olive (Mansour et al., 2011) vineyards and Citrus plantations (Mansour et al., 2009, 2010). Other laboratory studies assessing the degree of suitability of Planococcus ficus and P. citri towards the Sicilian ecotype of the encyrtid parasitoid Anagyrus sp. were carried out (Mansour et al., 2011b).

Because of their cryptic habit, pests such as the palm weevil Rhynchophorus ferrugineus, the brown citrus aphid Toxoptera citricida, the cannabis aphid Phorodon cannabis can escape detection during quarantine plant inspection and are increasingly being introduced and became invasive in new regions in Tunisia (Boukhris-Bouhachem, 2017). Moreover, The Russian wheat aphid Diuraphis noxia, introduced in Tunisia in 2010 cause a considerable loss of 15,000 ha of barley fields in the Kef region (Boukhris-Bouhachem, 2017).

Cherif et al. (2017) showed that the invasive pest Tuta absoluta tunisian strain can develop over different ranges of temperature and humidity. This pest is adapted to high temperature values related to our warm climate. Tunisian study showed that populations of T. absoluta are particularly affected by climatic changes as exemplified from several studies that showed a change in the temperature altered the population dynamics and may lead to the extinction of part of the system. Indeed Hance et al. (2007) estimate that the negative impact of climate changes on multitrophic interactions will increase the severity and timing of pest outbreaks in addition to ecosystem functioning. It is then of tremendous importance to explore new ways to decrease pest effects by biological control.

Invasive species constitute a major threat to biodiversity and agricultural ecosystems and may have a significant ecological and economic impact (Pimentel et al., 2001). Phytophagous mites also are typical invasive pests; due to their small size and cryptic behavior, they often remain undetected during quarantine inspections.

Migration of a given herbivore species may release it from predation pressure as stated in the enemy release hypothesis. This represents a major disturbance in the trophic web, potentially altering its functioning. For agricultural pests, such enemy release could result in major pest outbreaks (Guillemaud et al., 2011).

Although biological invasions represent major threats to biodiversity, human health and agriculture, the critical demographic and genetic parameters responsible for their success are poorly known because of methodological and experimental limitations. While a posteriori characterization of population genetics allows inference of the historical and demographical parameters of invasions; these approaches remain insufficient to powerfully investigate the factors affecting the process of establishment and the demo-genetic dynamics of invasive organisms. At early stages of the invasion process, population sizes are generally small and often undetectable. As a consequence, the dynamics of invasive species during the first generations following introduction are in most cases unknown, and the picture drawn from the characterization of already expanding populations is the result of interactions between several factors (environmental, demographic and genetic) that are difficult to distinguish.

Climate change will impact population dynamics of endemic pest. Some pests such as aphids will reproduce more rapidly at the elevated carbon dioxide levels forecast for 2050, and temperature increases will accelerate the rate of multiplication even further, allowing more generations per season and earlier infestation of crops in the spring and autumn. Increases in the rate of reproduction and the number of generations a season will also increase the risk of certain pests becoming resistant to insecticides.

Aphids are also vectors of diseases that are obviously linked to emerging diseases and evolving virus strains. Almost all aphids that were screened in Tunisia had a facultative symbiont infection. However, infection by more than one facultative symbiont in the same aphid was rare. Although these secondary bacteria are not essential for survival, they play an important role in the ecology and evolution of aphids by affecting important traits such as insecticide resistance, natural enemy resistance, thermal resistance, viral transmission, reproduction and development (Morin et al., 1999; Gottlieb et al., 2010). Some studies showed that the prevalence of facultative bacteria such as Serratia symbiotica, Hamiltonella defensa and Regiella insecticola varies considerably across pea aphid host plant races and geographic areas (Russell & Moran 2006) possibly influenced by the selective advantage of carrying different symbionts in different habitats, along the season and in habitats with different cultural practices (organic or conventional agriculture) (Oliver et al., 2008; Oliver, 2010). These pests of a wide range of agricultural plants and may cause serious problems if they become established in new environments lacking natural enemies.

Ectomyelois ceratoniae is a considerable agricultural pest, recognized as the most economically damaging pest of the date in Tunisia. Recently, it attacks pomegranate and citrus by seriously affecting the fruit quality (Boukhris-Bouhachem, 2017). Climatic change may explain the great invasiveness of these pests for different host plants and consequently for Tunisian regions. Migration of a given herbivore species may release it from predation pressure. This presents a major disturbance in the trophic web, potentially altering its functioning. For agricultural pests, such enemy release could result in major pest outbreaks. Conversely, increased natural enemy pressure could occur if pest enemies are 'freed' from the restraints imposed by upper trophic levels after migration, e.g. fewer or no hyperparasitoids. Other fundamental ecological questions to be addressed include invasion ecology and the relationship between ecosystem function and biodiversity.

2.3.6 Effects on post-harvest activities

Climate change exerts its influence not only on crop production, but also on post-harvest activities. Indeed, it is necessary to increase yields to ensure food security for continuously growing human populations. However, under climate change, the post-harvest losses and the costs of not reducing these losses are expected to increase. Furthermore, where extra food has to be produced to compensate for losses due to ineffective post-harvest management, this is a waste of valuable resources (Stathers et al., 2013) (Table 1).

Table 1: Examples of possible effects of a general increase in temperature on selected aspects of post-harvest activities (Stathers et al., 2013).

Post-harvest activity	Impacts
Harvesting and drying	▪ **Increased rate of crop drying, in field and at homestead**

Post-harvest activity	Impacts
	▪ **Increased fire risk of the mature crop**
Pest & disease management	▪ **Faster reproduction of insect pests and diseases (shorter life cycles due to higher temperatures) leading to more rapid build-up of insects and fungi in stored produce** ▪ **Increased risk of fungal rot and mycotoxin contamination of stored products n Pest and disease territories expand e.g. to higher altitudes or previously cooler areas** ▪ **Efficacy of some grain protectant active ingredients decrease, and others increase**
Storing	▪ Higher pest incidence and carry-over during 'cold season' increases the need for thorough storage structure hygiene and management of residual infestation prior to storing new crop ▪ Increased pest reproduction and mobility leading to need to re-winnow, sort and re-treat grain midway through storage period ▪ Increased moisture migration and condensation resulting in rotting zones in grain bulks with excess free moisture ▪ Increased risk of reduced seed viability especially for some legumes, e.g. groundnuts

The increase in temperature and CO2 atmospheric concentrations, the change in precipitations patterns as well as the frequency of storms, floods and droughts are the main factors affecting post-harvest activities. For instance, rise in atmospheric carbon dioxide levels may affect post-harvest quality causing sugar content reduction in potatoes and tuber malformation incidence of common scab (Mattos et al., 2014). Besides, a general increase in temperature would affect different aspects of post-harvest activities (Table 1).

In Tunisia, cereals are one of the main strategic crops They have always occupied large areas (one third of the cultivable areas in the country) and are still the main food source for Tunisian people. Nevertheless, as much as 10–15% cereal grains can be lost during the storage stage due only to the lack of technical inefficiency (FAO, 2014). The projected climate changes related to air humidity and temperature will undoubtedly affect cereal storing and may result in more important losses. In fact, when grain is placed in a storage cell, physical events caused by climate change can lead to an increase in moisture content and grain temperature. At present, the foreseeable consequences of climate change go beyond simple weather disturbances to more decisive impacts for the quality of the product stored (Kurukulasuriya et al ., 2003).

2.4 Impacts on Livestock

2.4.1 Direct effects of heat stress

All animals have a ***thermal comfort zone***, which is a range of ambient environmental temperatures that are beneficial to physiological functions. Within that range of ambient temperature and besides unvarying feed and nutrient intake the total heat production of the animal remains constant. During the day, livestock keep a body temperature within a range of ± 0.5°C (Henry et al., 2012). When temperature increases more than the upper critical temperature of the range (varies by species type), the animals begin to suffer heat stress. Heat stress on livestock is dependent on temperature, humidity, species, genetic potential, life stage and nutritional status. Livestock in higher latitudes will be more affected by the increase of temperatures than livestock located in lower latitudes, because livestock in lower latitudes are usually better adapted to high temperatures and droughts (Thornton et al., 2009). Moreover, more intensive livestock production systems that have more control over climate exposure will be less affected by heat stress (Rotter and van de Geijn, 1999). Dairy breeds are typically more sensitive to heat stress than meat breeds, and higher producing animals are, furthermore, susceptible since they generates more metabolic heat (Ramendra et al., 2016).

Animals have developed a ***phenotypic response*** to a single source of stress such as heat called acclimation. Acclimation results in reduced feed intake, increased water intake, and altered physiological functions such as reproductive and productive efficiency and a change in respiration rate (Nardone et al., 2010).

2.4.1.1 Effects on livestock production

Livestock have several ***nutrient requirements*** including energy, protein, minerals and vitamins, which are dependent on the region and type of animal (Thornton et al., 2009). Animals exposed to heat stress reduce feed intake and increase water intake, and there are changes in the endocrine status which in turn increase the maintenance requirements leading to reduced performance (Gaughan and Cawsell-Smith, 2015).

Heat stress is one of the major causes of ***decreased production*** in the dairy and beef industry (Nardone et al., 2010) and significant economic losses have been related to this. The United States livestock industry has an annual economic loss between 1.69 and 2.36 billion US dollars due to heat stress, of which 50 % occurs in the dairy industry (St-Pierre et al., 2003). An average decrease of about 28% of daily milk production was reported by Bouraoui et al. (2013) for Holstein cows exposed to heat stress in the center region of Tunisia.

High-producing dairy cows generate more metabolic heat than low-producing dairy cows. Therefore, high-producing dairy cows are more sensitive to heat stress. Consequently, when metabolic heat production increases in conjunction with heat stress, milk production declines (Berman, 2005). Moreover, milk quality is also affected: reduced fat content, lower-chain fatty acids, solid-non-fat, and lactose contents; and increased palmitic and stearic acid contents are observed (Sejian et al., 2016). Smith et al. (2013) mentioned that during heat stress, milk yield, fat content and somatic cell score decrease significantly for Holstein cows.

Heat stress also affects ***ewe, goat, and buffalo milk production***. In general, ewes are more sensitive to the combined temperature and relative humidity affect (the temperature humidity index) than actual temperature or relative humidity. However, the index values that trigger heat stress on ewes varies by breed type (Finocchiaro et al., 2005). Goats have been considered to be more tolerant to heat stress due to their higher capacity in water conservation and related metabolic size (Silanikove, 2000). Heat stress also impacts goat milk composition and amount. For example, in lactating goats, a water loss reduction mechanism is activated during hot seasons. This mechanism reduces water loss in urine in favor of milk production during seasons with limited water resources (Olsson and Dahlborn, 1989). Buffalo exposure to high temperatures also reduces milk production because it affects the animal physiological functions, such as pulse, respiration rate and rectal temperature (Seerapu et al., 2015). However, less attention has been given to these animals because of their adaptability to warm conditions and lower demand for their milk (Nardone et al., 2010).

In the case of ***meat production***, beef cattle with high weights, thick coats and darker colors are more vulnerable to warming (Nardone et al., 2010). Global warming may reduce body size, carcass weight and fat thickness in ruminants (Nardone, 2000). The same is true in pig production, where larger pigs will have more reduction in growth, carcass weight, and feed intake (Nardone et al., 2010). Piglets' survival may be reduced because of a reduction of sows feed intake during suckling periods with temperatures greater than 25°C, which reduces the milk yield of the sow (Lucas et al., 2000).

The ***poultry industry*** may also be compromised by low production at temperatures higher than 30°C. Heat stress on birds will reduce body weight gain, feed intake and carcass weight, and protein and muscle calorie content (Tankson et al., 2001). Heat stress on hens will reduce reproduction efficiency and consequently egg production because of reduced feed intake and interruption of ovulation (Nardone et al., 2010). Egg quality, such as egg weight and shell weight and thickness may also be negatively affected under hotter conditions (Mashaly et al., 2004).

2.4.1.2 Effects on livestock reproduction

Reproduction efficiency of both livestock sexes may be affected by heat stress. In cows and pigs, it affects oocyte growth and quality (Barati et al., 2008), impairment of embryo development, and pregnancy rate (Nardone et al., 2010). In cows, reproductive inefficiency due to heat stress involves changes in ovarian function and embryonic development by reducing the competence of oocyte to be fertilized and the resulting embryo (Naqvi et al., 2012). Heat stress can affect plasma progesterone levels and generally the metabolic state of dairy cows. These endocrine changes reduce follicular activity and alter the ovulatory mechanism, leading to a decrease in oocyte and embryo quality (Rensis and Scaramuzzi, 2003). The conception rate of lactating dairy cows was negatively affected by heat stress both before and after the day of breeding (Schuller et al., 2014). Heat stress, shortly before or after breeding, severely compromises the breeding success of high yielding Holstein cows (Smith et al., 2013). Heat stress has also been associated with lower sperm concentration and quality in bulls, pigs, and poultry (Karaca et al., 2002; Kunavongkrit et al., 2005).

2.4.1.3 Effects on livestock health

Variations in temperature and rainfall are the most significant climatic variables affecting ***livestock disease outbreaks***. Warmer and wetter weather (particularly warmer winters) will increase the risk and occurrence of animal diseases, because certain species that serve as disease vectors, such as biting flies and ticks, are more likely to survive year-round. The movement of disease vectors into new areas in Europe has been documented. Certain existing parasitic diseases may also become more prevalent or their geographical range may spread, if rainfall increases. This may contribute to an increase in disease spread for livestock such as ovine chlamydiosis, caprine arthritis (CAE), equine infectious anemia (EIA), equine influenza, Marek's disease (MD), and bovine viral diarrhea (Sejian et al., 2016).

Nardone et al. (2010) presented several ***livestock health problems*** related to climate change. Prolonged high temperature may affect metabolic rate, endocrine status, oxidative status (Bernabucci et al., 2002), glucose, protein and lipid metabolism, liver functionality (reduced cholesterol and albumin) (Bernabucci et al., 2006), non-esterified fatty acids (NEFA) (Ronchi et al., 1999), saliva production, and salivary HCO_3 - content. In addition, greater energy deficits affect cow fitness and longevity (King et al., 2006). Heat stress suppresses the immune and endocrine system thereby enhances susceptibility of an animal to various diseases (Ramendra et al 2016).

Warm and humid conditions that cause heat stress can affect ***livestock mortality***. Howden et al. (2008) reported that increases in temperature between 1 and 5°C might induce high mortality in grazing cattle. Sirohi and Michaelowa (2007) linked livestock mortality to several heat waves between 1994 and 2006 in the United States and northern Europe.

2.4.1.4 Livestock adaptations

Heat stressed animals, in order to maintain body temperature within physiological limits, initiate ***compensatory and adaptive mechanisms*** to re-establish homeothermy and homeostasis, but this may result in the downgrade of the productive potential. There are various physiological responses, i.e. respiration rate, pulse rate and rectal temperature, and their relative changes give an indication of the stress that is imposed on livestock. The thermal stress primary affects the hypothalamic–pituitary–adrenal axis, and the corticotropin-releasing hormone stimulates somatostatin, possibly a key mechanism by which heat-stressed animals reduce growth hormone and thyroxin levels.

The animals that have been adapted in hot climates have acquired some 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 can lead to the identification of animals that are genetically superior for coping with stress and to the creation of therapeutic drugs and treatments that target affected genes (Collier et al., 2012). Studies evaluating genes identified as participating in the cellular acclimation response from microarray analyses or genome-wide association studies have indicated that heat shock proteins are playing a major role in adaptation to thermal stress.

Genetic selection for heat tolerance may be possible, but continued selection for greater performance in the absence of consideration for heat tolerance will result in greater susceptibility to heat stress (West, 2003). Genetic selection for heat tolerance may be possible, but continued selection for greater performance in the absence of consideration for heat tolerance will result in greater susceptibility to heat stress (West, 2003). Although the theoretical framework for developing breeding strategies for harsh environments is well known from years; there is still a lot to do to develop efficient and sustainable breeding programs including adaptive traits in the breeding goal for production under harsh environment (Phocas, 2015). The issue of whether to directly select for adaptive traits is highly debatable because physiological adaptability is expressed in performance (e.g. survival, reproduction, growth and production). Special attention should be paid of the true interest of crossbreeding strategies *versus* straight breeding strategies promoting well adapted local breeds. Efficient exploitation of genetic diversity among and within breeds of different species bred in relevant production systems with using indigenous purebred animal and improving production traits of local breeds that are well adapted to their environment (Phocas, 2015). The key for sustainability of small ruminant farming systems is to search for a balance between the environment and the animal (Mandonnet et al, 2014).

2.4.2 Indirect effects

2.4.2.1 Impacts on feeds and forage

Quantity and quality of ***feed and forage*** will be affected by the climate change, mainly due to an increase in atmospheric CO_2 levels and temperature as well as the altered precipitation. The effects of climate change on quantity and quality of feeds and forage are dependent on location, livestock system, and species. However, the complexity of the above-mentioned factors, coupled with others such as inter-plant competition, seasonal development as well as annual and perennial species make it difficult to study the effects of climate change. Nevertheless, some of the impacts on feed crops and forage are:

- ***Increase of CO_2 concentration*** will result in herbage growth changes, with greater effect on C_3 species and less on grain yields (Chapman et al., 2012). The effects of CO_2 will be positive due to inducing partial closure of stomata, reducing transpiration, and improving some plants' water-use efficiency (Wand et al., 1999).

- ***Changes in temperature and CO_2*** levels will affect the composition of pastures by altering the species competition dynamics due to changes in optimal growth rates (Thornton et al., 2015). Primary productivity in pastures may be increased due to changes in species composition if temperature, precipitation, and concurrent nitrogen deposition increase.

- ***Extreme climate events*** such as flood, may affect form and structure of roots, change leaf growth rate, and decrease total yield (Baruch and Mérida, 1995).

- ***Quality of feed crops and forage*** may be affected by increased temperatures and dry conditions due to variations in concentrations of water-soluble carbohydrates and nitrogen. Temperature increases may increase lignin and cell wall components in plants, which reduce digestibility and degradation rates (Polley et al., 2013), leading to a decrease in nutrient availability for livestock (Thornton et al., 2009). However, as CO_2 concentration rises forage quality will improve more in C_3 plants than C_4 plants.

- ***An increase of 2°C*** will produce negative impacts on pasture and livestock production in arid and semiarid regions and positive impacts in humid temperate regions. The length of growing season is also an important factor for forage quality and quantity because it determines the duration and periods of available forage. A decrease in forage quality can increase methane emissions per unit of gross energy consumed (Benchaar et al., 2001). Therefore, if forage quality declines, it may need to be offset by decreasing forage intake and replacing it with grain to prevent elevated methane emissions by livestock (Polley et al., 2013).

- ***Nutritional needs of livestock change*** during heat stress, and ration reformulation is required to compensate reduced dry matter intake, by increasing nutrient density, changing nutrient requirements, avoiding nutrient excess and maintaining normal rumen function (West, 2003).

2.4.2.2 Impacts on livestock water allocation

There is a lack of research related to implications of ***reduced water availability*** for land-based livestock systems due to climate change (Thornton et al., 2009). Therefore, it is important to consider water availability and appropriate mitigation strategies in the context of sustainable livestock production. Global agriculture uses 70% of fresh water resources, making it the world's largest consumer (Thornton et al., 2009). However, global water demand is moving towards increased competition due to water scarcity and depletion, where 64% of the world's population may live under water-stressful conditions by 2025 (Rosegrant et al., 2002).

Water availability issues will influence the livestock sector, which uses water for animal drinking, feed crops, and product processes (Thornton et al., 2009). The livestock sector accounts for about 8 % of global human water use and an increase in temperature may increase animal water consumption by a factor of two to three (Nardone et al., 2010). For example, the goats under thermal stress environment increased by 112% the daily water intake in relation to the goats under thermo-neutral environment (Araujo et al.,2000). To address this issue, there is a need to produce crops and raise animals in livestock systems that demand less water (Nardone et al., 2010) or in locations with water abundance.

As sea level rises, more saltwater will be introduced into coastal freshwater aquifers. Salination adds to chemical and biological contaminants and high concentrations of heavy metals already found in waterbodies worldwide and may influence livestock production (Nardone et al., 2010). Water salination could affect animal metabolism, fertility and digestion. Chemical contaminants and heavy metals could impair cardiovascular, excretory, skeletal, nervous and respiratory systems, and impair hygienic quality of production (Nardone et al., 2010).

2.4.2.3 Impacts on livestock risk diseases

The effects of climate change on ***livestock diseases*** depend on the geographical region, land use type, disease characteristics and animal susceptibility (Thornton et al., 2009). There could be a significant effect on the microbial communities (pathogens or parasites), spreading of vector-borne diseases, food-borne diseases, host resistance, and feed and water scarcity (Thornton et al., 2009; Nardone et al., 2010). Nevertheless, it is very difficult to estimate the actual disease risk because of the dependence of diseases on animal exposure and interactions factors.

Temperature increases could accelerate ***the growth of pathogens*** and/or parasites or it may induce shifts in disease spreading, outbreaks of severe disease or even introduce new diseases, which may affect livestock that are not usually exposed to these type of diseases (Thornton et al., 2009). Evaluating disease dynamics and livestock adaptation will be important to maintain their resilience. Global warming and changes in precipitation affect the quantity and spread of vector-borne pests such as flies, ticks and mosquitoes (Thornton et al., 2009). In addition, disease transmission between hosts will be more likely to happen in warmer conditions (Thornton et al., 2009). For example, White et al. (2003) found that livestock lost about 18% of their weight due to increased tick infestations. Wittmann et al. (2001) also used a model to simulate the response of *Culicoides imicola* in Iberia, which is the main vector of the bluetongue virus that affects mainly sheep and sometimes cattle, goat and deer. They reported that the vector would spread extensively with a 2°C increase in global mean temperature. However, these predicted spreads may be prevented by disease surveillance and technologies, such as DNA fingerprinting, genome sequencing, tests for understanding resistance, antiviral medications, cross-breeding, and more (Thornton and Herrero, 2010).

2.4.2.4 Impacts on livestock welfare in transport

Animal transportation (by road, sea and air) constitutes one of the most important "acute" threats to animal welfare and productivity in commercial animal production. Good work over many weeks or months, in terms of animal housing and husbandry, can be undone in a matter of hours or days if transportation stress is excessive. In addition to the risks associated with animal handling, loading and unloading and the vibrations and accelerations experienced by animals in transit, the "on-board" thermal microenvironment represents a major source of transport stress and is the cause of increased mortalities, poor welfare, reduced production efficiency and product quality and decreased performance in livestock after completion of the journeys. As external conditions become warmer or cooler, then the risks of the transported animals being subject to heats tress or cold stress increases. For example in broiler chickens it is known that at ambient temperatures greater than 24°C, heat stress may occur and mortalities in transit will increase and product quality will decline (Mitchell and Kettlewell 1998). In young calves, temperature greater than 28°C and less than 5°C will cause transport stress and may compromise welfare.

Very little information (limited data – scientific, statistical or economic) is currently available upon the actual costs to the industry of the effects of transport mortalities, compromised welfare, product quality changes, and compliance with existing legislation. For example, an increase in mortality during transport could impose serious costs on the livestock sector. The full range of impacts of climate change scenarios upon the various components of the animal transport process and the consequent welfare and production issues must be considered for all the livestock species of central significance. The major impacts are:

- Increased mortality in transit or "dead on arrivals".
- Reduced welfare status (fear, stress, injury, pathology) and product quality in slaughter animals.
- Imposition of thermal and extreme physiological stress involving tissue damage and over patho-physiology.
- Detrimental effects of physiological adaptive responses e.g. blood gas and acid base disturbance associated with thermoregulatory responses.
- Increased risk of dehydration, detrimental weight loss and transport associated pathology or disease (shipping fever in cattle and calves).
- Impaired immunological responses and physiological function in relocated animals rendering them more vulnerable to subsequent infection and disease as well as reducing post transport performance and reproductive function.

2.5 Impacts on marine ecosystems, resources and fisheries

Although uncertainties remain with regard to the magnitude of expected ecological changes, the projections based on IPCC scenarios all confirm that climate change is a serious threat for the biodiversity and the sustainable exploitation of fishing resources in the Mediterranean Sea. This calls for the reinforcement of innovative and integrated research and assessment capacities to support an ecosystem-based management at the scale of the Mediterranean basin (Menut, 2017). The fishing activities in North African coasts are considered one of the most vulnerable to climate change (Allison et al., 2009).

Previous studies highlight the winners and losers in fisheries under climate change based on shifts in biomass, species composition and potential catches (Lam et al, 2015). Understanding how climate change is likely to alter the fisheries revenues of maritime countries is a crucial next step towards the development of effective socio-economic policy and food sustainability strategies to mitigate and adapt to climate change. Particularly, fish prices and cross-oceans connections through distant water fishing operations may largely modify the projected climate change impacts on fisheries revenues. However, these factors have not formally been considered in global studies. Lam et al. (2016) by using climate-living marine resources simulation models, showed **that global fisheries revenues could drop by 35% more than the projected decrease in catches by the 2050 s under high CO_2 emission scenarios**. Regionally, the projected increases in fish catch in high latitudes may not translate into increases in revenues because of the increasing dominance of low value fish, and the decrease in catches by these countries' vessels operating in more severely impacted distant waters. Lam et al. (2015) highlighted that developing countries with high fisheries dependency are negatively impacted. They suggest the need to conduct full-fledged economic analyses of the potential economic effects of climate change on global marine fisheries.

Fish provide essential nutrition and income to an ever-growing number of people around the world, especially where other food and employment are limited (FAO, 2015). Many fishers and aqua culturists are poor and not prepared to adapt to change, making them vulnerable to impacts on fish resources.

2.5.1 Effect on marine water circulation

Change in climate means there is a change in precipitation and evaporation rates, constituents of the ***hydrologic cycle***, which affect surface runoff, and groundwater and ocean levels. A rise in global temperature, generally, would increase regional evaporation in the lower latitudes and increase regional precipitation in the higher latitudes (Palmer and Räisänen, 2002). Shifts in the evaporation/precipitation regime could have significant consequences to the continents, including worsening conditions for flood control and water storage (Milly et al., 2002). Approximately 6% of the total water influx to the oceans and seas comes from direct groundwater discharge. An increase in the amount of groundwater entering the ocean would lead to a net gain in oceanic volume. In addition to increased groundwater discharge, meltwater from glaciers may contribute to increasing ocean volume (Stevenson et al., 2002). Finally, as water temperatures rise, the volume of the oceans will also increase due to thermal expansion (Stevenson et al., 2002).

Increased oceanic volume and concomitant sea level rise have tremendous implications for ***coastal environments***. Depending on model factors, sea level predicted increases range from 0.3 to 5.0 m, possibly inundating almost 1 million km^2 of coastal land (Liu, 2000). This rise is occurring at a faster rate than plants can colonize and establish wetland habitat (Stevenson et al., 2002). Therefore, many tidal wetlands, estuaries, mangroves, and other shallow-water habitats may be lost if climate change continues at the predicted rates. An increasing water column depth affects the complex interactions of the hydrodynamic processes that take place in the coastal environment. Tides and tidal currents, distribution of turbulent energy, shoreline configuration, near-shore depth distribution, sedimentation patterns, and estuarine-river interactions will be affected (Liu, 2000).

Another major consequence of a changing climate is the likely perturbation of ***oceanic circulations***. Currents are driven directly by winds (upper layer of ocean), fluxes of heat and freshwater (thermohaline circulation), or by the gravitational pull of the sun and moon (tides). Thermohaline circulation is the deep ocean water (> 200 m) that is conveyed in slow large-scale circulations, driven by water density, which is dependent on heat and salinity (Garrison, 1996). Although there is much debate on the predicted future of this circulation, many global climate change models suggest weakening, and possibly complete breakdown, of the thermohaline circulation, particularly in the Atlantic Ocean (Vellinga and Wood, 2002). Furthermore, suggestions that a rise in sea level may also decrease the formation of North Atlantic deep water (NADW) will directly impact massive ocean water circulations (Mikolajewicz et al., 1990).

2.5.2 Effects on ocean acidification

The oceans act as an ***immense carbon sink***. The amount of carbon stored in the oceans is regulated by atmosphere-sea gas exchange, carbonate equilibria, ocean circulation, and marine organisms (Sabine et al., 2004). Increasing water temperature decreases the solubility of CO_2, resulting in the slowed uptake of atmospheric CO_2 (Plattner et al., 2001). There has already been an 8-10 % decrease in CO_2 uptake during the 20th Century, attributed to increasing surface water temperatures (Joos et al., 1999). Reduced oceanic uptake, along with deforestation, decreases the effectiveness of natural CO_2 buffering systems, which exacerbates the accumulation of anthropogenic CO_2 emissions in the atmosphere (Chambers et al., 2001).

The CO_2 that is introduced to ocean waters and hydrated, ***produces hydrogen ions***. When the CO_2 concentration increases, more carbonic acid (H_2CO_3) is formed, which partially dissociates into bicarbonate (HCO_3^-) and hydrogen ($H^{+)}$ ions, lowering water pH. Bicarbonate may further dissociate so that 2 H^+ are created for one molecule of CO_2. The pH is a measure of H^+ activity, and is an important water quality indicator because fish and other organisms are sensitive to pH. Ocean surface pH has already decreased by 0.1 pH units in colder waters and almost 0.09 pH units in warmer waters (Haugen, 1997). If atmospheric CO_2 concentrations continue to increase, another 0.3 pH unit decrease of oceanic surface waters may occur (Haugen, 1997). Furthermore, as temperature increases, an increased proportion of the water molecules dissociate to H^+ and OH^-, decreasing water pH.

Recent studies (Orr, in press) showed a large increase in surface acidity in the Mediterranean Sea by the end of the century (0.5 pH unit) and a surface waters unfriendly to corals and pteropods by mid-century. So, an urgent need to understand how unique Mediterranean ecosystems are likely to respond to ocean acidification in case of better manage Mediterranean natural resources and ecological services. Mediterranean ecosystems are likely experience dramatic change in ocean acidification. Drastic reduction in calcification rates of red coral (*Corallium rubrum*) is expected under low pH.

2.5.3 Effects on marine water salinity

Salinity is another important factor that is greatly affected by climate. Because the oceans contain such a massive amount of water, net changes in salinity have not been much of an issue to this point. However, it may be a significant issue in the future, considering that although groundwater discharge to the ocean floors contributes only 6 % of total water influx, it's salt load is 50 % that of rivers, and groundwater discharge is expected to increase with increasing precipitation (Zestser and Loaiciga, 1993). Therefore, oceanic salinity could rise if the salt load introduced by groundwater discharge is not offset by water volume increases (Zestser and Loaiciga, 1993). It is also likely that the upper oceanic layers near the higher latitudes may become more dilute due to increased precipitation (Manabe et al., 1994) and river discharge (Peterson et al., 2002). A slight decrease in salinity has been observed in the northern Pacific, although a definite causal link has not been established (Freeland and Whitney, 2000). Changes in salinity have important implications on thermohaline circulation and on the formation of dense water (Peterson et al., 2002).

2.5.4 Effect on ocean water temperature

In the Mediterranean Sea, the increase in water temperature has already modified marine resources and biodiversity such as jellyfish population dynamics (Coll et al., 2010). For several decades, the extent and intensity of jellyfish outbreaks have increased, in particular blooms of *Pelagia noctiluca*, a planktonic predator of fish larvae and their zooplankton prey (Licandro et al, 2010). The increasing frequency of jellyfish blooms can be explained by the alteration of the trophic structure of ecosystems due to overfishing, eutrophication and sea warming.

Climate change and especially global warming drives also commercial fish production in the Mediterranean Sea, a significant relationship was found between round sardinella (*Sardinella aurita*) landings and water temperature anomalies (Sabates et al., 2006). An overall increase in landings of this fish species has been observed over the last 30 years. This increase is linked to the successful reproduction of the species, marked by an increase in larval abundance. At the same time, in the Mediterranean Sea, landings of two other pelagic fish species, sardine (*Sardina pilchardus*) and anchovy (*Engraulis encrasicolus*) have declined in recent decades. Sprat (*Sprattus sprattus*), a cold water small pelagic species, has virtually disappeared from commercial catches.

Global warming affects already functional traits of fishes. Several studies have shown that changes in temperature affect the growth, reproduction and physiology of marine organisms (Sumaila et al., 2011). It was recently shown that fish body size may be reduced due to climate change, especially in response to warming, reduction in oxygen and resource availability (Cheung et al., 2013). According to the IPCC (2014), oceans are projected to become warmer and less oxygenated. As a consequence, in the Mediterranean Sea, the average maximum body weight of fish is expected to shrink by 4 to 49% from 2000 to 2050.

It is also the case for fish distribution and associated assemblages. In the Mediterranean Sea, the increasing abundance of thermophilic species can be described by two major processes of change involving both indigenous and exotic species (meridionalization and tropicatization) (Boero et al., 2008). Climate change play a key role in the dispersal success of exotic species. The Mediterranean Sea is experiencing some increasing southern invasions. The last update of alien fauna in Tunisian marine waters highlights 136 species (Ounifi-Ben Amor et al., 2016). Nearly half of the first sightings in Tunisian waters took place in the Gulf of Gabès. The dominant taxa are Crustacea (24%), Mollusca (23%) Fishes (19%). 21 species previously reported as alien, were, upon consideration reclassified as range-expanding Atlantic species. This update highlights the dual origin of biological invasion in Tunisian waters (Red Sea and Atlantic Ocean).

With the notable exceptions of partial endothermy in some pelagic tunas (Scombridae), sharks (Lamnidae), and billfish (Block et al., 1993), **fish are ectotherms** meaning that they cannot regulate their body temperature through physiological means and that their body temperatures are virtually identical to their environmental temperatures. Every species has its temperature tolerance range, and, typically, energy allocation towards growth and reproduction declines at temperatures near the range extremes (Sogard and Olla, 2002; Roessig et al., 2004). These fishes may thermoregulate behaviorally, by selecting thermally heterogeneous microhabitats (Brio, 1998), but they are constrained by the range of temperatures available in the environment. Because biochemical reaction rates vary as a function of body temperature, all aspects of an individual fish's physiology, including growth, reproduction and activity are directly influenced by changes in temperature (Franklin et al., 1995). Therefore, increasing global temperatures can affect individual fish by altering physiological functions such as thermal tolerance, growth, metabolism, food consumption, reproductive success and the ability to maintain internal homeostasis in the face of a variable external environment (Fry, 1971). Temperature tolerance ranges are species-specific and include both stenothermal (narrow thermal range) and eurythermal (wide tolerance range) species. Fish populations that are faced with changing thermal regimes may increase or decrease in abundance, experience range expansions or contractions, or face extinction.

2.5.5 Effects on dissolved oxygen

Biologically available (dissolved) oxygen (DO) is much less concentrated in water than in air. Oxygen enters the water column through diffusion from the atmosphere (this is potentially facilitated via turbulence and mixing) and by photosynthetic production (Stickney, 2000). Plant, animal and microbial aerobic respiration may decrease DO in the water column, especially at night when photosynthesis stops. Dissolved oxygen concentrations of 5 mg/l or more are acceptable for most aquatic organisms; on the other hand concentrations below 2–3 mg/l are considered hypoxic. Oxygen solubility in water has an inverse relationship with water temperature. For example, water at 0°C holds about 14.6 mg/l, but water at 25°C can only hold about 8.3 mg/l (Kalff, 2000). Because the aerobic metabolic rates of most cold-blooded aquatic organisms increase with temperature, an increase in temperature both decreases the DO supply (through reduced saturation concentrations relative to air) and increases the biological oxygen demand (BOD) (Kalff, 2000). Fishes exposed to elevated water temperatures (from climate change) can face an ''oxygen squeeze'' where the decreased supply of oxygen cannot meet the increased demand. Changes in dissolved oxygen levels will depend on a multitude of factors such as ambient temperatures, biological oxygen demand, and local climate (e.g., wind mixing). Whether or not the incidence of hypoxia or anoxia increases in individual systems remains to be seen. Given the probability of higher temperatures and increased biological oxygen demand, it is possible that levels of dissolved oxygen will decrease in at least some systems.

2.5.6 Effects on toxicity of pollutants

The effects of temperature on ***toxicity*** have been tested in the laboratory with myriad chemical compounds and a diverse array of fish species, but many experiments have used short exposure times and concentrations higher than those found in ecosystems. In addition, the temperature related toxicity effects often decrease with time (Nussey et al., 1996). Despite these complications, there are general trends that can be identified with respect to toxicity, especially when considering the effect of temperature on poikilotherm metabolism.

The toxicity of ***common pollutants*** (e.g., organophosphates and heavy metals) to fish generally increases at higher temperatures (Murty, 1986b). These increases in toxicity may result from the increased production of bioactivated free radicals that are more toxic than the parent compound or from the increased uptake of the original toxin (Murty, 1986a). Studies on bioaccumulation have shown a positive correlation between temperature and the uptake of anthropogenic (e.g., mercury), and natural (e.g., nitrite) pollutants. This increased uptake is thought to result from increased gill ventilation rates at warmer temperatures (Kock et al., 1996). An increase in fish metabolism also facilitates a faster depuration of toxicants (Huey et al., 1984). Despite their increased ability to metabolize pollutants at warmer temperatures, fishes may still experience increased negative, toxicant-specific effects at higher temperatures. Kock et al. (1996) suggested that non-essential metals such as cadmium and lead are difficult for fish to depurate because no specific metabolic pathway exists to process them. Therefore, fish accumulate these toxins more quickly at higher temperatures.

An ***increase in toxicant uptake rates*** has the potential to affect the quality of fish populations worldwide. Even when fish can physiologically process toxicants present in the water or their food, the processes used to depurate these compounds are energetically expensive and increase the cost of maintenance metabolism (Jeney and Nemcsok, 1992). Therefore, elevated toxicant concentrations in fish tissues can have sublethal effects, including the reduction of reproductive output.

Increased uptake of ***exogenous toxicants*** and the synergy existing between high temperatures, poor environmental conditions, and the presence of ammonia suggest that an increase in global temperatures has the potential to lower productivity in wild fish populations and in intensive aquaculture systems worldwide. Continued atmospheric deposition and natural production of mercury in combination with increased water temperatures could exacerbate existing conditions in industrialized countries or create new problems in unaffected areas.

2.6 Socio-economic responses

Agricultural production is chronically vulnerable to stress factors like dry spells, weed competition, and insect damage. Local farm production patterns and practices have evolved in response to weather conditions and stress factors that have historically prevailed for that region. As growing conditions and stress factors change, so too will farm production decisions. Adaptation behaviors such as changing crops and crop varieties, adjusting planting and harvest dates, and modifying input use and tillage practices can lessen yield losses from climate change in some regions and potentially increase yields in others where climate change creates expanded opportunities for production (Adams et al., 1998).

An assessment of the ***economic impacts of climate change*** on agriculture begins with a set of assumptions or projections about future climate conditions, generally including some combination of information on patterns and magnitude of temperature and precipitation change (Tol, 2009). Local climate conditions must be then translated into local yield and production cost impacts based on a subset of stressors and simultaneously into a set of economic indicators through representation of a portion of the potential production, price, consumption, technology development, and trade responses to those productivity effects.

Fischer et al. (2005) estimated that under a range of climate scenarios evaluated in 2080, agricultural gross domestic product (GDP) increases in most developed countries and decreases in most developing countries (with the exception of Latin America). In North America, gains to agricultural GDP range from 3 to 13 %, depending on the climate scenario, however the effects of climate change are generally projected to be more severe in poor developing countries (Hertel et al., 2010). Productivity may be more negatively affected because many developing countries are already at the upper end of their temperature ranges, and precipitation is not expected to increase as it is in many temperate regions (Mertz et al., 2009). Overall economic impacts may be more severe because developing countries rely on agriculture for a much greater proportion of their national income and employment than do developed countries (Mertz et al., 2009). In North Africa, for example, a 1°C rise in temperature in a given year would probably reduce the economic growth in that year by about 1.1 points (Radhouane,2013). ***Economic impacts of climate change*** can occur at ***many levels*** and to different stakeholders.

At farm level, **farmers** (producers) are affected by initial yield and production cost effects, which they respond to through adaptive strategies and, subsequently, by the price effects that emerge from the market adjustments responding to widespread influences on productivity and adaptive behaviors.

The impacts of the climate and socioeconomic changes cause variable impacts according to the biophysical, institutional, and socioeconomic context. Otherwise, predicting the response of farming systems to climate change means forecasting the change in the farm's environment (water and soil resources, market and institutional changes, etc.) and assessing the responses of the cropping systems to water and heat stress which would probably become more frequent as the climate changes (Souissi et al., 2013). More particularly, the variability of cropping system responses to the irregular precipitation and temperatures would almost lead to a disparity in the farmers' responses (Reidsma et al., 2010). The heterogeneity of farmers' responses can be explained by both the structure of the farm (size, technical-economic orientation, etc.) and the related performance indicators (net margin, intensification rate, etc.) (Reidsma et al., 2009; Souissi et al., 2013; Reidsma et al., 2010). The interactions between farm characteristics and the impacts of climate change on cropping systems would lead to different behavior of farming systems in different regions. Based on the economic and agronomic performances and the diversity of agricultural activities, farms that appeared to be least vulnerable to external shocks do not necessarily enjoy greater adaptability to climatic conditions (Challinor and Wheeler, 2008; Reidsma et al., 2010). Small-scale traditional farms, for example, whose flexibility, robustness, and adaptability to climate change have proved superior to large-scale intensive farms (Reidsma et al., 2010; Souissi et al., 2017). In France, small-scale farms demonstrate a greater capacity for adapting to climate, whereas this does not hold for either Spain or Greece, where the impacts of temperature on production are positively correlated with the economic scale of the farm (Reidsma et al., 2010). In northern Tunisia, the farms, which would be able to maintain their viability, are those characterized by diversified cropping systems based essentially on arable and forage crops with a significant livestock activity. Large-scale farms specializing in tree crops, however, are the most sensitive to climate change due to a lack of flexibility at farm level (Souissi et al., 2017).

Consumers would be also affected by market price changes and also have adaptation options including changing consumption patterns to substitute relatively low-priced yields for products that have become higher priced due to the effects of climate (Adams et al., 1998). According to Nelson et al. (2009), climate change would probably cause a slight reduce in meat consumption and more substantial fall in the consumption of cereals. By 2050, the meat consumption will decline about 10% over the world; while, cereal consumption decrease from climate change will be 25% in developed countries and 21% in developing countries. These results indicate the negative effects on the welfare in a climate change context.

Furthermore, relative capacity for ***adaptation*** varies by region, country, sector, and crop, and is therefore itself a factor in determining how the economic impacts of climate change will be distributed across and within agricultural sectors worldwide. Tol (2009) suggests that "low-income countries are typically less able to adapt to climate change both because of a lack of resources and less capable institutions." Such differences in relative adaptive capacity, together with differential climate change effects on yields, may entrench and exacerbate existing production and consumption discrepancies between developed and developing countries

(Fischer et al., 2005). Even future climate scenarios with mild to inconsequential aggregate global effects on food production may result in severe implications for the food security of the world's poorest and most vulnerable populations.

Concerns about whether future food supply can meet the demands of a ***growing population*** have been raised independently of climate change issues, often citing issues related to increasing meat consumption and increasing use of grain for biofuel production (Funk and Brown, 2009). Questions about the evolution of agriculture under changing climate conditions, however has added several new levels of risk and uncertainty to those analyses.

The ***food security*** implications of climate change vary significantly according to the assumptions made about level of development and population growth into the future that underlie emissions trajectories used in the climate scenarios, for instance (Fischer et al., 2005). As with economic impacts, the food security implications of climate change are also significantly different across regions (Funk and Brown, 2009).

Regional differences in yields and adaptation capacity are expected to result in regional differences in vulnerability to effects of ***hunger and poverty***, with particularly severe implications for tropical semi-arid developing countries (Fischer et al., 2005). Almost 90 % of world hunger is concentrated in Asia, the Pacific, and Sub-Saharan Africa (Acevedo, 2011). These regions are particularly vulnerable to climate change; by the end of the 21st century, there is a high probability (>90 %) that normal growing season temperatures in the tropics and the subtropics will exceed the hottest temperatures on record for those regions from 1900 to 2006 (Battisti and Naylor, 2009).

It is unequivocal that to meet food demand in the future, ***multiple strategies*** will be involved, such as intensification of production on existing land, expansion of agricultural land, and reduction of waste along the food supply chain (Pfister et al., 2011). Reliance on specific adaptation mechanisms will depend on regional patterns of climate change; however, intensification and expansion of agriculture can have significant ***environmental implications***. A multitude of concerns are linked with climate change, including increased water stress and competition with downstream aquatic systems, increased GHG emissions associated with land clearing, increased pesticide use, increased nutrient loading, and loss of natural systems and the ecosystem services they provide (Pfister et al., 2011; Tilman et al., 2011).

3 Adaptation Strategies

Vulnerability and ***adaptive capacity*** are characteristics of human and natural systems, are dynamic and multi-dimensional, and are influenced by complex interactions among social, economic and environmental factors. The vulnerability of a system is a function of the exposure and the sensitivity of the system to hazardous conditions mediated by the ability of the system to cope, adapt or recover from the effects of those conditions. Because agricultural systems are human-dominated ecosystems, the vulnerability of agriculture to climatic change is strongly dependent not just on the biophysical effects of climate change but also on the responses taken by humans to moderate those effects. As climate change intensifies, "climate risk" is likely to be added to the production, finance and marketing risks already commonly managed by producers.

3.1 Management of water resources

Water shortage, high runoff variability and drought should be considered to cope with climate change. The adaptation strategies include water supply and demand effects in specific river basins, the institutional context and the ability of adaptation to mitigate those impacts (Olmstead, 2014). To deal with its scarcity, water management issues might consider multiple decision criteria and large numbers of possible alternatives, considering their uncertainty and conflicting interests (Giupponi and Gain, 2017). Therefore, adaptation strategy of water resources management might be implemented considering the sustainable development goal – SDG 6 including societal participation to the decision making, transboundary cooperation and exchange (Fehri et al., 2017). In addition to traditional practices, water managers must cope with severe droughts, intense and frequent floods, water risks and vulnerability and hydraulic structures should be designed and adapted to these constraints.

Water productivity can be improved through several water-saving irrigation strategies; being used in recent years such as supplemental irrigation and deficit irrigation. Indeed, currently, traditional irrigation practice (full irrigation) is considered as luxury water consumption for crop production within the context of limited irrigation water resources. Deficit (or regulated deficit) irrigation increases crop water use efficiency by reducing the amount of water applied (Kirda, 2002). The adoption of deficit (or regulated deficit) irrigation strategies for which plants are exposed to certain levels of water stress during either a particular growth period or throughout the whole growth season, will allow saving water without significant reduction in yields (English and Raja, 1996; Pereira et al., 2002). Yield reduction will be insignificant compared to the benefits gained through diverting the saved water to irrigate other crops (Eck et al., 1987). These approaches have already been applied to a wide variety of crops (relatively resistant to water stress, or they can avoid stress by deep rooting, allowing access to soil moisture lower in the soil profile) and have shown their potential in conserving scarce water resources, increasing farm profitability and enhancing environmental protection. However, these strategies require prior and precise knowledge of crop responses to water deficit as drought tolerance varies considerably by species, cultivar and stage of growth.

Furthermore, water-saving irrigation technologies, as drip and sprinkler irrigation methods are preferable to less efficient traditional surface methods. Another water-saving irrigation strategy is being tested in many crop species is "Partial Root-zone Drying" (PRD); concept primary used by Grimes et al. (1968) in the USA. This technique involves applying irrigation to one half of the root-zone whilst the remaining half is allowed to dry. The principle of PRD is that by allowing the soil on one half of a root zone to dry, those roots will send drought signals to the shoot to reduce vegetative growth and stomatal conductance leading to reduced water transpiration and hence clearly improved water use efficiency respect to conventional irrigation using higher rates of irrigation (Davies et al., 2002; Morison et al., 2008).

Several practices such as contour farming and terrace's effect will have the same performance under different climatic scenarios as their actual impact (Woznicki et al., 2011). Soil and water conservation practices and water harvesting techniques are considered as one of the main adaptation practices especially in drylands (Azari et al., 2017). These authors indicate that practices will be more effective at reducing sediment yields under future climate changes. Previous studies indicate that soil conservation practice and water harvesting techniques can improve crop yields, and may actually help farmers in semi-arid regions adapt to climate change (Molden et al., 2010). In Tunisia context, contour bench terraces, check dams, mini –catchments, runoff widespread, water harvesting techniques (jessour, meskat, tabia,…) allow runoff decrease, water infiltration increase, soil fertility improvement, crop production and adaptation to drought conditions.

For climate change adaptations through wastewater management, literature showed that each country possesses its own strategy. In fact, there are studies that focused on the wastewater infrastructure and others on the effluents reuse as measures of climate change adaptation. As climate change are affecting the current wastewater infrastructures, Campos and Darch (2015) recommended, for the United Kingdom, that their adaptation could be settled by the assessment of indicators, the assessment of the vulnerability, the use of risk-based approaches and, where appropriate, integrated catchment and sewer system models.

In Jordan, a country characterized by a severe water scarcity, Salahat et al. (2017) demonstrated that the reuse of the treated wastewater effluents in the agriculture sector can be a feasible adaptive option when managed properly. Trinh et al. (2013) in Vietnam assessed this adaptation through indicators selected to define the strategies for wastewater management and reuse as a means of the improvement of the resilience to climate change. These indices were namely: (i) rice production from wastewater during winter-spring crop, (ii) irrigation water and nutrient demand (%) satisfied by treated wastewater, (iii) remaining flow downstream (%) of the considered river, (iv) the environmental benefits and (v) the total investment cost for wastewater treatment. They concluded that the climate change adaptation can be assessed by the selected indicators, which contribute, through effective actions, to the definition of the implementation of adequate measures and policies adaptation and to the vulnerability reduction.

In Tunisia, the reuse of treated waste water (TWW) is considered an efficient tool for managing water resources and is an integral part of national water resources strategy (Bahri, 1998). The total volume of TWW of 238 million m3 (5% of the total mobilized water resources), is expected to reach 480 million m3 (10% of total mobilized water resources) at the horizon 2030. TWW can be used for fruit trees, cereals, fodder crops and industrial crops, or golf courses. The used portion ranging between 20 and 30% is going to increase in the coming decade.

3.2 Sustainable soil management

Depletion of the Soil Organic Carbon (SOC) can be considered as the most adverse consequence of climate change on soils. Thus, as far as agricultural soils are concerned, adaptation strategy consists in managing agroecosystems in order to enhance SOC storage. Thus, land use change, degraded soils restoration along with adoption of sustainable management practices, can be important instruments of SOC sequestration (Post and Kwon, 2000; Lal, 2013). The table 2 shows a comparison between traditional and recommended management practices in relation to SOC sequestration.

Furthermore, conservation agriculture or agroecology, such as agroforestry, minimum till, no till, contouring, mulching is a mitigation practice to climate change, by carbon sequestration. Such practices will improve the farming system resilience, spatially for rain fed crops. Annual carbon sequestration rates are improved for practices that rely tillage and residue management, agroforestry and restoration of degraded land (Sommer and Bossio, 2014). It is known that these practices improve soil organic matter which is beneficial for biological activity and

Table 2: comparison between traditional and recommended management practices in relation to SOC sequestration (Lal, 2013).

Traditional methods	Recommended management practices
Biomass burning and residue removal	Residue returned as surface mulch
Conventional tillage and clean cultivation	Conservation tillage, no till and mulch farming
Bare/idle fallow	Growing cover crops during the off-season
Continuous monoculture	Crop rotations with high diversity
Low input subsistence farming and soil fertility mining	Judicious use of off-farm input
Intensive use of chemical fertilizers	Integrated nutrient management with compost, biosolids and nutrient cycling, precision farming
Intensive cropping	Integrating trees and livestock with crop production
Surface flood irrigation	Drip, furrow or sub-irrigation
Indiscriminate use of pesticides	Integrated pest management
Cultivating marginal soils	Conservation reserve program, restoration of degraded soils through land use change

physical and chemical characteristics of the soil. In fact, stable aggregates enhance soil resistance to water erosion (Magdoff and Weil 2004). Diversified farming systems, such as agroecology system, provide a variety of examples on how they may be adapted and resilient to climate change effects through carbon sequestration (Altieri et al., 2015; Azari et al., 2017; Soleimani et al., 2017). The combined benefits of water regulation, favorable microclimate, biodiversity, and carbon stocks in the above-described diversified farming systems not only provide environmental goods and services for producers but also a higher resilience to climate change. Agroecology practices improve soil's water holding capacity thus enhancing the drought tolerance by crops, increase infiltration, reduce runoff and soil erosion and sediment transport (Magdoff and Weil 2004; Altieri et al., 2015).

Recent studies indicated the positive effect of soil amendment with biochar - a highly carbonaceous and porous material obtained through organic matter pyrolysis for agriculture to improve water productivity (Akhtar et al., 2014). Biochar has a potential to enhance water holding capacity of soil. This infers that biochar soil amendment improve crop productivity by retaining more water from rainfall in arid regions and reduce the frequency or amount of irrigation water in irrigated regions. According to Sohi et al. (2010), biochar, is being used increasingly in agriculture with an intention to mitigate climate change by sequestering carbon, improving soil properties and functions and enhancing crop yield.

3.3 Farming adaptation

To avoid or at least reduce negative effects and exploit possible positive effects, several agronomic ***adaptation strategies*** for agriculture have been suggested. Economic considerations are very important in this context. Results of farm level analyses on the impact and adaptation to climate change have generally shown a large reduction in adverse impacts when adaptation is fully implemented (Mendelsohn and Dinar, 1999). This often implies land use changes (Parry et al., 1999). Indeed, the possibility exists for a global increase in agricultural productivity, if adaptation is at least partially effective in lower latitude countries, and the productivity increase in mid and higher-latitude agriculture is exploited. However, this may have negative effects on farm income through decreases in prices (Reilly, 1999). The agronomic strategies available include both short-term adjustments and long-term adaptations.

3.3.1 Short-term adjustments

Short-term adjustments to climate change include efforts to optimize production without major system changes. They are autonomous in the sense that no other sectors (e.g. policy, research, etc.) are needed in their development and implementation.

For spring crops climate warming will allow ***earlier planting or sowing*** than at present. Earlier planting in spring increases the length of the growing season; thus, earlier planting using long season cultivars will increase yield potential, provided moisture is adequate and the risk of heat stress is low. Otherwise earlier planting combined with a short-season cultivar would give the best assurance of avoiding heat and water stresses (Tubiello et al., 2000). Winter cereals are required to have reached a specific growth stage before the onset of winter to ensure winter survival, and they are often sown when temperatures approach the time when vernalization is most effective (Harrison and Butterfield, 1996). This may mean later sowings in northern Europe under a climatic warming (Olesen et al., 2000).

The use of ***fertilizers*** is generally adjusted to the removal of nutrients by the crop and any losses of nutrients that may occur during or between growing seasons. The projected increases in atmospheric CO_2 concentration will increase crop growth and nitrogen uptake by the crop, and thus increase the need for fertilizer applications. On the other hand, climatic constraints on yields may lead to less demand for fertilizers. Changes in climate may also cause larger (or smaller) losses of nitrogen through leaching and gaseous losses. This may also lead to changes in the demand for fertilizer (Porter et al., 1995).

The use of ***pesticides*** reflects the occurrence of weeds, pests and diseases. Global warming will, in many areas, lead to a higher incidence of these problems and thus to a potentially larger use of pesticides. The use of pesticides can, however, be kept low through the adoption of integrated pest management systems, which targets the control measures to the observed problem.

Several ***water-conserving practices*** are commonly used to combat drought. These may also be used for reducing climate change impacts (Easterling, 1996). Such practices include conservation tillage and irrigation management. Conservation tillage is the practice of leaving some or all the previous season's crop residues on the soil surface. This may protect the soil from wind and water erosion and retain moisture by reducing evaporation and increasing the infiltration of rainfall into the soil. Irrigation management can be used to improve considerably the utilization of applied water through proper timing of the amount of water distributed.

3.3.2 Long-term adjustments

Long-term adaptations refer to major structural changes to overcome adversity caused by climate change. ***Changes of land use*** result from the farmer's response to the differential response of crops to climate change. Studies reported by Parry et al. (1988) for central Europe showed an 'optimal land use' in which the area cultivated with winter wheat, maize and vegetables increased, while the allocation to spring-wheat, barley and potato decreased. Changes in land allocation may be used also to stabilize production. In this case, crops with high inter-annual variability in production (e.g. wheat) may be substituted by crops with lower productivity but more stable yields (e.g. pasture). ***Crop substitution*** may be useful also for the conservation of soil moisture.

Crop breeding may be considered as another adaptive response to climate change using both traditional and biotechnological techniques that allow the introduction of heat and drought resistant crop varieties. Collections of genetic resources in germ–plasm banks may be screened to find sources of resistance to changing diseases and insects, as well as tolerances to heat and water stress and better compatibility to new agricultural technologies. Genetic manipulation may offer possibilities for more rapid adaptation to stresses aggravated by climate change (Goodman et al., 1987).

New land management techniques (minimum tillage, stubble mulching, etc.) or ***management strategies*** (e.g. irrigation scheduling) may be used to improve irrigation efficiency in agriculture (Kromm and White, 1990). Moreover, a wide array of techniques (such as intercropping, multicropping, relay cropping etc.) can be also useful to improve water use efficiency. Restrictions in the availability of good-quality irrigation water may increase the need for such techniques.

Nutrient management will need to be adapted to changes in the turnover of nutrients in soils, including losses. It may thus be necessary to revise standards of soil nitrogen mineralization and the efficiency of use of animal manure and other organic fertilizers. There is a range of management options that will affect the utilization of fertilizers and manure, including fertilizer placement and timing, changed crop rotations and use of cover crops.

Changes in farming systems may be necessary in some areas for farming to remain viable and competitive. In many regions of Europe, farms have become specialized in either specific livestock or arable farming. This specialization is often linked to the local soil and climate conditions. Dairy farming is thus often located in conditions which ensure a proper water supply to the grass and forage crops during summer, as continuity of feed supply is essential. Specialized pig or poultry production on the other hand only requires access to cereals and protein feeds, which are easier and cheaper to transport. These farms are therefore less reliant on local feed supply, but often have restrictions on the disposal of urine and manure from production. Specialized arable farms with production of vegetables, cereals, seed crops, fruits etc. often have only a few species on the farm, depending on soil and climate conditions. These specialized farms, especially dairy farms and arable farms, will probably respond more to climate change than mixed farms. On mixed farms with both livestock and arable production there are more options for change, and thus a larger resilience to change in the environment (Olesen and Bindi, 2002). Thus, when dealing with farmer's behavior to cope with changes, several studies suggest adaptation strategies (exploit longer growing season and planting crop earlier (Mall et al., 2004; Matthews et al., 1997; Trnka et al., 2004); variety selection for stress tolerance and resistance (Ortiz et al., 2008; Southworth et al., 2000), adjusting timing irrigation (Reynauds, 2008), diversification of cropping system (Iglesias et al., 1997), socio-economical adaptations (diversification of farmers revenues...) (Kelkar et al., 2008), and political (the implementation of management measures of the resource by government, improving means of predicting dry periods (Reynauds, 2008) factors that improve system resistance and resilience to stresses. Farmers' strategies must be accompanied by appropriate policy measures to improve the management of water and soil resources. These measures must be implemented in consultation with farmers as well as local stakeholders.

3.4 Livestock adaptations

The livestock sector is an important contributor to the global food and agricultural economy and to human nutrition and culture, accounting for 40% of the value of world agricultural output and providing 10%–15% of total food calories and one quarter of dietary protein. In most of the developing country regions, it is the fastest growing segment of the agricultural sector. The livestock sector is expected to provide safe and plentiful food for growing urban populations and livelihoods for almost 1 billion poor producers, while at the same time it enables the exploitation of non-arable lands, provides food security against crop failure for subsistence farmers, utilizes food wastes and field losses or residues, and even provides fuels and concentrates and recirculates farm nutrients, as well as global public goods related to food security, environmental sustainability and public health (Geers and Madec, 2006; Steinfeld et al., 2010).

Adaptation measures involve production and management system modifications, breeding strategies, science and technology advances, changing farmers' perception and adaptive capacity and institutional and policy changes. According to some Authors, future policies should shift from maximizing agricultural output to stabilizing it (Schilling et al., 2012). Research is needed on assessments for implementing these adaptation measures and tailoring them based on location and livestock system. Some attempts of mapping and quantifying climatic data in combination with the spatial information on livestock production systems, livestock numbers and people to identify hotspots of change and vulnerability have been already done (Tibbo & van de Steeg, 2013).

3.4.1 Livestock management

An adaptation such as the ***modification of production and management systems*** involves diversification of livestock animals and crops, integration of livestock systems with forestry and crop production, and changing the timing and locations of farm operations.

Diversification of livestock and crop varieties can increase drought and heat wave tolerance and may increase livestock production when animals are exposed to temperature and precipitation stresses. In addition, this diversity of crops and livestock animals is effective in fighting against climate change-related diseases and pest outbreaks (Batima et al., 2005).

Changes in ***mixed crop-livestock systems*** are an adaptation measure that could improve food security. This type of agricultural system is already in practice in two-thirds of world, producing more than half of the milk, meat, and crops such as cereal, rice and sorghum (Herrero et al., 2012). Changes in mixed crop-livestock systems can improve efficiency by producing more food on less land using fewer resources, such as water (Herrero et al., 2012).

Improving ***feeding practices*** as an adaptation measure could indirectly improve the efficiency of livestock production. The European Nitrogen Assessment has estimated that 85% of harvested N goes to feed livestock, while only 15% feeds people directly (Sutton et al., 2011). Some of the suggested feeding practices include, modification of diets composition, changing feeding time and/or frequency and training producers in production and conservation of feed for different agro-ecological zones. These practices can reduce the risk from climate change by promoting higher intake or compensating low feed consumption, reducing excessive heat load (Renaudeau et al., 2012), decreasing the feed insecurity during dry seasons (Thornton and Herrero, 2010), and reducing animal malnutrition and mortality.

Shifting locations of livestock and crop production could reduce soil erosion and improve moisture and nutrient retention (Kurukulasuriya and Rosenthal, 2003). Another adaptive measure could be adjusting crop rotations and changing timing of management operations (e.g. grazing, planting, spraying, irrigating). This measure can be adapted to changes in duration of growing seasons, heat waves and precipitation variability (Batima et al., 2005).

3.4.2 Breeding

It is known that different breeds exhibit different reactions and ***resistance to high temperatures***. Animals that have dark or black skin or coat colors, with a weak immune system, with more subcutaneous fat and more irritability are more susceptible to high temperatures (Brown - Brandl et al., 2006). Bovine breeds such as Boran, Brahman, Africander, etc. that have been created in tropical or subtropical climates and originate or carry a significant percentage of genes from *Bos indicus*, can dispense larger amounts of heat resulting in better adaptation to warm climates than the European breeds that originate from *Bos taurus.*

Adapted local livestock breeds produce under conditions where other breeds cannot survive, resist or tolerate diseases, drought, water scarcity, stress from strong heat and solar radiation. They are also integral parts of their environment that help sustain biodiversity, as highlighted in FAO's *Global Plan of Action for Animal Genetic Resources* (FAO, 2007). Most of the adapted breeds, however, are largely uncharacterized and their loss as a result of droughts and floods, or disease epidemics related to climate change may increase.

These breeds have ***lower meat and milk production capacity***. For this reason, it is sometimes difficult to use purebred animals or their crosses to meet the nutritional needs of the developed world. Genetic improvement can help towards the creation of animals more resistant to high temperatures. Significant genetic variation has been observed regarding features such as body temperature and heat dispersion (Turner, 1982). In addition, the color is related to the ability of the animal to deal with high temperatures, since it is related to the absorption of solar radiation. Improving European breeds as well as different cross-breeding patterns can help in the long run.

Herd diversity by using multi-species and multi-breed, and herd splitting into smaller manageable groups and moving them into different areas would buffer against climatic adversities, prevent over-grazing and maintain the long-term productivity of rangelands (Hoffman, 2010).

3.4.3 Microclimate adjustments

Shading systems, natural or artificial ventilation, cooling and air conditioning have been proposed. Shading is the simplest and less cost-effective way of protecting animals from sunlight. It is estimated that shading reduces the heat load received by a cow by 30 - 50 % (Bond & Kelly, 1955). Cows under shade had lower body temperature (38.9°C vs. 39.4°C), lower breathing rate (54 breaths / min vs. 82 breaths / min) and 10 kg higher milk production than cows directly receiving sunlight (Roman-Ponce et al., 1978). For shading, natural tree vegetation or shelters of various materials have been used. The type of material used is of great importance, since with the rise in temperature, heat radiation from the shading material to the animal increases. Using insulating materials can reduce the internal temperature up to 10°C.

Although shading reduces the ***accumulation of heat*** from solar radiation, it affects the temperature or relative humidity if there is a combination of high temperature and high humidity. In this case, dynamic ventilation, cooling, animal spray systems or a combination of the above are used. It has been reported that with the application of such systems, milk production was 10 - 20 % higher daily during hot days (Strickland et al., 1988).

3.5 Fisheries adaptation

Adaptation can be planned or be autonomous (i.e. spontaneous reaction to environmental change or planned action based on climate-induced changes). Autonomous adaptation in fisheries may be changing the timing or locations of fishing as species arrive earlier/later or shift to new areas. Planned adaptation in fisheries may be research funding for finding species resistant to salinity and temperature fluctuations for aquaculture. A "no regrets" approach relies on building general resilience without a heavy reliance on specific climate impact projections, which is useful in areas with high impact uncertainty, which include many equatorial areas and developing countries without long-term historical climate data sets.

Adaptation in fisheries and aquaculture may be addressing short- or long-term impacts and can include a variety of policy and governance actions, specific technical support or community capacity building activities that address multiple sectors, not just capture fisheries or aquaculture farmers, such as:

- Investments in safer harbors and landings and measures to improve safety at sea due to increased storm severity as well as improved early warning and forecasting systems for severe weather events. Adequate onshore storage facilities for boats and gear can prevent loss or damage from storms and extreme events.

- Promote disaster risk management in general (including disaster preparedness) and protective infrastructure (e.g. "hard" options such as seawalls and flood reservoirs, or "soft" options such as buffer zones).

- Mainstreaming Integrate fisheries and aquaculture sectors fully into climate change adaptation and food security policies at the national level (draft and enact where non-existent) to ensure incorporation into broader development planning. This will also involve trade-offs, compromises, and planning with other industries affecting fisheries and aquaculture (e.g. irrigation infrastructure, dams, and urban and agricultural runoff).

- Capacity building: Civil society, non-governmental organizations (NGOs), and government organizations need to be included in climate change planning, not just technically focused departments such as fisheries/interior agencies or science and meteorology departments. Partnerships between private, public, civil society and NGO sectors are vital for holistic climate change adaptation planning.

- Financial mechanisms: In addition to building capacity, the potential of new financial mechanisms as tools needs to be investigated. This can include insurance at national and international levels and other innovative instruments to create effective incentives and disincentives. These approaches are new and overall untested and there is an opportunity to test new approaches in the public sector, as the private sector will be controlled and integrated to some extent by the public sector via market mechanisms.

- Recognition of opportunities: New opportunities may become available, for example, the promotion of aquaculture-based livelihoods where delta areas have been inundated and agriculture is no longer possible.

- Learning from the past: What have people done and how have decision-making processes worked under highly variable and extreme events? How have people addressed a similar issue in the past?

- Identification of useful information and where to obtain it (e.g. future fish production projections, decision-making tools under uncertainty).

- Link local, national and regional policies and programs: Links will be required across both spatial and sectoral frameworks, plans and programs. Climate change will affect poverty, food security, infrastructure and other sectors within and between countries. In addition, climate change will probably cause spatial displacement of both aquatic resources and people, requiring strong regional structures to address these changes and their implications. At the international level, climate change will affect international trade, competition and policies at the same time as current development.

- Monitoring: This information will feed into adaptive management as well as contribute to understanding what impacts are occurring. As climate change will introduce changes outside the scope of experience for many people and species, it is important to collect information on what and when these changes are. As more is learned and understanding becomes more refined, people will be better able to make decisions that result in benefits for both the aquatic environment and the people who depend on it.

Policy and management considerations: As some aquatic populations shift their range, probably poleward for many species, the fishery will follow. This may induce socio-economic changes as people migrate to follow populations, or as old fisheries become less profitable and new ones become available. Policies that are flexible and support easier entry and exit into new fisheries and out of those that are declining can ease both socio-economic impacts from changing fisheries and also prevent overfishing of the edges of stocks as they move away (Pinsky and Fogarty, 2012). Standard practice adoption for improved fisheries and aquaculture management (e.g. the FAO Code of Conduct for Responsible Fisheries, precautionary principles, adaptive and ecosystem management) and integrated coastal management for coastal and near shore fisheries can improve resilience and increase system adaptability. Overall, capacity reductions and the removal of incentives for overfishing are vital to ensuring sustainable fisheries.

Safety at sea: One potential to increase safety at sea could be to invest in larger vessels that are safer than smaller vessels in rough conditions. If these were capable of accessing seasonal pelagic species and small enough to also fish for demersal species in other seasons, safety during harvesting would be increased and year-round harvesting options made available. However, to prevent overcapacity, these vessels would have to replace smaller fishing vessels rather than add to the fleet.

Ghost fishing: As storm severity increases, it is likely that more gear, such as lobster traps, will be lost. Such lost gear can cause mortality and habitat damage. However, there are some measures that can reduce their impacts. In addition to gear retrieval programs, certain gear could be designed to minimize impacts if lost. For example, traps could have biodegradable escape panels (e.g. after a week) so trapped animals would be able to escape.

International trade: Some trade measures and barriers such as tariff escalation, sanitary and phytosanitary measures and rules of origin requirements in export markets can work against increasing economic diversification of production and exports of high-value-added processed products. Other barriers include fishery subsidies in developed countries constraining the competitive stance of developing countries, and rapid trade liberalization in developing countries. This liberalization has limited the policy space available for a wide range of policies that could enhance supply-side fishery capacities. To address these obstacles, developing countries can support the elimination of distorting fisheries subsidies in developed countries and reduced tariff escalation and other trade barriers (ITCSD, 2009). At the national level, policies that discourage economically unviable fisheries can lead to economic diversification, leading to increased economic resilience. Other ways to create value-added fishery products include ecolabelling. Although fish products in developing countries may be travelling far to developed country markets, emissions from capture and processing in developing countries may be lower, and if product is shipped in bulk or within the region and it could meet ecolabelling criteria.

3.6 Food supply chain wastes valorization

Food supply chain wastes imply an increasing environmental burden due to associated resource consumption and pollutant emission. E.g., it has been estimated that for each ton of FW there is an emission of about 2 tons of CO_2 (European Commission, 2010). Increasingly, industrial ecology concepts are considered leading principle for eco-innovation, aiming at "zero waste economy" in which waste are used as raw material for new products and applications. The large amount of waste produced by the agro-industry, in addition to being a great loss of valuable materials, also raises serious economic and environmental management problems. Many of these residues, however, have the potential to be reused into other production systems, trough e.g. biorefinery which is an emerging concept in the field of biomass waste management suggesting that all kinds of biomass-derived material can be converted into different types of biofuels and chemicals by various conversion processes. Different valorized molecules can be derived from food supply chain waste (Ravindran and Jaiswal, 2016).

In addition, agro-industry waste can be considered as a renewable resource for energy as it is mostly lignocellulosic in nature, with high cellulose and lignin content, except animal-derived food waste. In fact, several microorganisms can use apple residues as a substrate for growth. Many studies analyzed different uses of this by-product: fuel purposes, food products, pectin extraction, cattle feed, biotransformation, source of fibers (Kosseva, 2011; Van Dyk et al., 2013; Mirabella et al., 2014).

Furthermore, potatoes industry processing byproducts can be reused as cattle feed, in paper production and as a base for natural polymers. Potatoes waste is used also as a quantitatively important energy source in beef cattle diets and solved a potentially massive disposal problem (Nelson, 2010; Matharu et al., 2016).

Moreover, olive oil production, which is an agro-industrial activity of vital economic significance for many Mediterranean countries such as Tunisia, is associated with the generation of large quantities of wastes. These wastes are rich in phenolic compounds with a great biological and pharmaceutical interest, due their antioxidant properties. For example, an important by-product of the olive oil industry is the olive cake that could be used as a material for many processing industries (e.g. food and cosmetic) or animal feed leading to contribute in minimizing the environmental impacts of this agro-industrial waste. Olive cake can be used also to obtain phenolic extracts from its vegetative water and solid residue, to maximize the extraction of all phenolic compounds (Suárez et al., 2009). In another study, Delgado-Moreno et al. (2007) proposed to apply olive cake to soil as disposal strategy, due its high content in organic matter, increasing also sorption of all triazine herbicides tested and reducing desorption of the most hydrophobic ones, terbuthylazine and prometryn.

The huge quantity of annually agro-industrial food wastes poses serious environmental issues and contributes to the climate change. Hence, it’s important, as a short-term solution, to deal with the existing accumulated food waste by converting it in others valorized compounds and renewable energy, while preventive measures can be taken to reduce the generation of food waste and to establish a cleaner industry with “zero waste” as long term solution.

4 Impact of agriculture on climate change

By paying attention only on the effects of climate change on agriculture, we only see the one side of the coin. Agriculture, from its perspective, also ***contributes to climate change***. Management of agricultural land, land-use change, and forestry has a profound influence on atmospheric GHG concentration. The two broad anthropogenic sources of GHG emission from agriculture are the energy use in agriculture (manufacture and use of agricultural inputs and farm machinery) and the management of agricultural land. An understanding of GHG emissions by sources and removal by sinks in agriculture is important to take appropriate mitigation and adaptation strategies and to estimate and create inventory of GHGs.

The agriculture sector is increasing in size, but exactly how this is impacting on GHG emissions remains uncertain, as do the ***opportunities for mitigation***. Within the scientific community there is increasing recognition that agriculture, in general, and livestock production, in particular, contribute significantly to GHG emissions. As a result, the global agricultural community is committed to reducing emissions to safeguard the environment; however, it must simultaneously meet the demands of a growing human population and their increasing requirements for food high in quality and quantity. There is a need to improve the efficiency of agricultural production if we are to meet global food supply demands and decrease agriculture's impact on climate change. Quantification of the impacts of the agriculture on the environment is thus of major importance.

4.1 Effects of water resources

Natural hazards, mainly floods and droughts which are expected to increase in frequency and severity, might exacerbate climate change due to material discharged during extreme floods or the extension of bare lands as consequence of long period without rain affecting large area. Besides, the expected increase in evapotranspiration rates as affected by climate change, will release more water vapor in the atmosphere, especially for irrigated crops and in wetland. Water vapor being the most abundant GHG, a positive feedback is thus induced.

Hydraulic structures, such as dams which affect hydrological watershed functioning, release carbon dioxide due to eutrophication in their reservoirs. The organic matter in the sediments silted in their reservoir will be reduced, releasing CO_2 , instead of being stored in ocean. Dams also alter the ecosystem, menace species threatened with extinction, favor insect proliferation due to humidity increase in their vicinity.

The wastewater treatment systems, including plant equipment, pipelines, local collection system and finished-water storage facilities, provide similar effect on climate change as dams. Household, commercial, and industrial effluents and raw untreated sewage are often discharged into the open receiving environment, without any treatment, which can amplify climate change. The use of treated wastewater, as climate change forcing especially water shortage in arid regions, can have adverse effects on agricultural systems.

At the farm scale, the on-farm wells, on-farm surface reservoirs and off-farm surface reservoirs are the major sources of irrigation water. Fossil fuels are generally used to power pumps which distribute irrigation water. Thus, irrigation systems have energy and CO_2 costs.

4.2 Effects of crops

Direct and indirect emissions from ***agricultural soil*** are determined by a multitude of factors such as the rate of fertilizer and organic manure application, yield and area under cultivation. Direct emission sources include N fertilizers, crop residues and mineralization process of soil organic matter. Indirect sources comprise leaching, runoff and atmospheric deposition. N_2O emitted from the soil represents some 50 % of the total agricultural emissions. Even when it is not being cultivated, the soil naturally releases GHGs. N_2O is generated as a by-product of microbial activities that convert ammonium into nitrate or nitrate into nitrogen gas N_2. Both processes are influenced and controlled by environmental conditions. They are independent of the origin of N, whether from organic or mineral fertilizers or soil organic matter. Emissions increase with agricultural activity, partly because of N input from manure, mineral fertilizers, or from symbiotic N fixation in legumes (Lenka et al., 2015).

Globally, use of ***synthetic fertilizers*** in agriculture has increased more than agricultural production, and emissions from synthetic N fertilizers are increasing more than nine-fold, from 0.07 to 0.68 $GtCO_2$ eq/year from 1951 to 2010 (Tubiello et al., 2013). Considering current trends, synthetic fertilizers will become a larger source of emissions than manure deposited on pasture in less than 10 years and the second largest of all agricultural emission categories after enteric fermentation. Globally, agricultural sources contribute to 4–6 Tg N/year through N_2O, including both direct and indirect emissions. (Sharma et al., 2011).

The contribution of ***crop residue burning*** is the lowest 0.5 % of the total agricultural emissions among different sources of GHG emission in the agriculture sector. In developing countries agricultural wastes are burnt in the field to clear the remaining straw and stubble after harvest and to prepare the field for the next cropping cycle. Farmers prefer crop residue burning as a quick and labor-saving process to dispose of the crop residues of rice, wheat, maize, and sugarcane. Emissions of CO_2 during burning of crop residues are considered neutral, as it is reabsorbed during the next growing season. However, biomass burning is one of the significant sources of atmospheric aerosols and trace gas emissions, which has a major impact on human health.

Forestry and other land use encompasses anthropogenic emission from deforestation, cultivation of organic soils, peatland drainage for cultivation, forest fires, etc. Emissions from cultivation of organic soils have become important because when peatlands are drained and degraded there is change in absolute carbon stocks. The continued expansion of farmland has a major environmental impact. It decreases biodiversity through destruction of ecologically valuable natural environments, such as forests and natural grasslands. In addition, deforestation and depletion of the humus releases large quantities of CO_2 from the carbon bound in the trees and the soil organic matter (SOM). Furthermore, deforestation has an immediate impact on the natural water cycle, resulting in a greater likelihood of flooding or drought. Some 24 % of the total global GHG emissions can be currently attributed to agriculture. About 12 % of these are due to change in land use and, with extended agricultural production, this percentage would rise considerably.

Use of fossil fuels in agriculture results in CO_2 emissions, and there are additional emissions associated with production and delivery of fuels to the farm. Carbon emissions attributed to fossil fuels are estimated using existing C coefficients, higher heating values, fuel chemistry, and the energy consumed during production and transport of the fuels. The CO_2 emission attributed to electricity consumption is based on the fuels used in power generation. The production of fertilizers demands much energy and generates considerable GHG emissions. Kongshaug (1998) estimates that fertilizer production consumes approximately 1.2 % of the world's energy and is responsible for approximately 1.2 % of the total GHG emissions. Carbon dioxide emissions result from the energy required for production of fertilizers plus the energy required for their transport and application. Carbon emissions from fossil fuels used in the production of fertilizers include emissions from mineral extraction and fertilizer manufacture. Postproduction emissions can include those from packaging, transportation and field application of fertilizers. Energy is also used during fertilizer application using farm machinery, thus the greater the fertilizer use, the greater are the emissions.

Modern ***pesticides*** are almost entirely produced from crude petroleum or natural gas products. The total energy input is thus both the material used as feedstock and the direct energy inputs. Carbon dioxide emissions from production of pesticides consist of both these contributions to manufacture the active ingredient. Postproduction emissions include those from formulation of the active ingredients into emulsifiable oils, wettable powders, or granules and those from packaging, transportation and application of the pesticide formulation. Carbon dioxide emissions from pesticide use are estimated for specific pesticide classes by calculating average values of energy input for the production and application of individual pesticides.

4.3 Effects of livestock

The primary ***livestock GHG emissions*** are CO_2, CH_4, and N_2O. CH_4 contributes the most to anthropogenic GHG emissions (44 %), followed by N_2O (29 %) and CO_2 (27 %) (Gerber et al., 2013). Globally livestock contribute 44 % of anthropogenic CH_4, 53 % of anthropogenic N_2O and 5 % of anthropogenic CO_2 emissions. Direct emissions from animal sources include enteric fermentation, respiration, and excretions (Jungbluth et al., 2001). Indirect emissions refer to emissions derived from feed crops, manure application, farm operations, livestock products processing, transportation, and land use allocation for livestock production. Enteric fermentation is the largest contributor of the sector's emissions with 39.1 %, followed by manure management, application and direct deposit with 25.9 %, feed production with 21.1 %, land use change with 9.2 %, post-farmgate with 2.9 %, and direct and indirect energy with 1.8 % (Gerber et al., 2013). Livestock excreta in livestock housing, during manure storage, processing, treatment and application to land, and from excreta from animals at pasture are the main sources of NH3 emissions in most countries (Bittman et al., 2014). However, contribution to GHG emissions varies depending on the type of farming system and region. Cattle held in tied stalls emit less NH3 than in loose housing systems, because a smaller floor area is fouled with dung and urine. However, tied systems are not recommended in consideration of animal welfare unless daily exercise periods are applied. The tied housing system is the traditional reference system for maintaining continuity in emission inventories (Bittman et al., 2014). Straw-based systems producing solid manure for cattle are not likely to emit less NH3 in the animal houses than slurry-based systems. Further, N2O and di-nitrogen (N2) losses due to (de) nitrification tend to be larger in litter-based systems than slurry-based systems. While straw based solid manure can emit less NH3 than slurry after surface spreading on fields (Powell and others, 2008), slurry provides a greater opportunity for reduced emissions applications. The physical separation of faeces (which contains urease) and urine in the housing system reduces hydrolysis of urea, resulting in reduced emissions from both housing and manure spreading (Burton, 2007; Fangueiro and others, 2008a, 2008b; Møller and others, 2007). Verification of any NH3 emission reductions from using solid-manure versus slurry-based systems and from solid-liquid separation should consider all the stages of emission (housing, storage and land application).

The use of ***manure and synthetic fertilizers*** for forage and feed crop production, processing of feed, and transport of feed are the most important contributors of GHG emissions related to the livestock sector. These make up 45 % of global livestock anthropogenic GHG emissions, consisting primarily as CO_2, N_2O and NH_4 (Gerber et al., 2013). The livestock sector contributes significantly to GHG emissions through the production of nitrogenous fertilizers used to produce crops for animal feed (Steinfeld et al., 2006).

On-farm fossil fuel use in livestock production produces 50 % more CO_2 emissions than manufacturing N fertilizers for feed. The livestock sector includes direct and indirect (e.g. electricity) on-farm fossil fuel use, which is used for machinery operations, irrigation, heating, cooling, ventilation, production of herbicides and pesticides, and more. More than half of fossil-fuel use is attributed to feed production. By assuming CO_2 emissions from on-farm fossil fuel use are double that of manufacturing N fertilizers, and adding emissions related to livestock rearing, on-farm fossil fuels account for 90 million tons of CO_2 per year (Steinfeld et al., 2006).

In general, ***livestock respiration*** is not counted as a net source of CO_2 emissions because they are part of the global biological system cycle. The vegetation consumed by the animal originates from the conversion of atmospheric CO_2 to organic compounds or biomass. Conversely, the animal is a carbon sink because a fraction of the carbon consumed is absorbed in the live tissue of the animal and products such as milk. Animals that contribute the most to livestock GHG emissions are beef and dairy cattle, accounting for 65 % of the total livestock GHG emissions (Gerber et al., 2013). Pigs, poultry, buffaloes, and small ruminants contribute about 7 to 10 %. If GHG emissions are estimated based on commodities, beef cattle contribute the most with 41 % of the sector's emission, followed by dairy cattle (20 %), swine (9 %), buffalo (8 %), poultry (8 %), and small ruminant (6 %).

Livestock manure releases CH_4 and N_2O gas. Manure methane emissions are a function of air temperature, moisture, pH, storage time, and animal diet. Steinfeld et al. (2006) estimated global methane emissions from manure decomposition of 17.5 million tons of CH_4 per year. Pig manure comprises almost half of global manure-related methane emissions. N_2O emissions from manure storage are dependent on environmental conditions, handling systems, and duration of waste management. Manure must be handled aerobically and then anaerobically to release N_2O emissions, which is more likely to occur in dry waste-handling systems. Steinfeld et al. (2006) reported that N_2O emissions from stored manure are equivalent to 10 million tons N per year. Nitrous oxide soil emissions from manure application are the largest source of global N2O emissions (Steinfeld et al., 2006).

Energy costs of ***processing animals and their products*** combined with global livestock production from "market-oriented intensive systems" can be used to obtain global processing emissions. However, the source of the energy and its variation in the world is uncertain. Energy use depends on the type of livestock system and if they are small or large scale. More than half of the energy used in confinement systems is for feed production, including seed, herbicides, pesticides and machinery. Substantial energy is also used for heating, cooling and ventilation systems. Steinfeld et al. (2006) estimated that the United States produces a "few million" tons of CO_2 emissions related to total animal product and feeding processing. Following the same trend, they estimated that the world produces "several tens of millions" tons CO_2 emissions in animal-product processing. Transportation of livestock products to retailers and transport of feed to livestock farms contribute to GHG emissions. Long distance shipping is the most significant GHG emitter in this category. For example, high volumes of soybean are transported long distances to be used as feed (Steinfeld et al., 2006).

4.4 Effects of fisheries

Fisheries and aquaculture contribute global greenhouse gas emissions (GHGs) during fish capture or growth, processing, transportation and storage. However, there are many different kinds of fisheries with many different fuel requirements. These range from small low-power single engines to larger vessels. One of the primary differences between fuel use in developed- and developing-country fisheries is fuel efficiency, meaning the proportion of revenue spent on fuel, with developing countries spending up to 50 percent of total catch revenue on fuel (Daw et al., 2009). Fisheries management contributes to some of this inefficiency with policies that create a "race to fish". This refers to policies that inadvertently create incentives for more powerful engines to catch more fish, which can quickly lead to overfishing. Vessels then have to travel farther or to deeper waters and spend more to catch the same amount of fish as they have in the past. In addition to fuel emissions from fishing vessels, product transportation is the main source of emissions in the fisheries sector. Products are typically transported via freight on ships or plane, especially if they are moving from developing countries to developed-country markets. High-value species (e.g. tuna transported to Japan) are more likely to be shipped via airfreight, meaning their transport emissions are quite high.

Approaching climate change typically involves actions that either reduce the amount of carbon dioxide and other greenhouse gases (GHGs) in the atmosphere or prepare society for the impacts associated with climate change via adaptation.

5 Mitigation measures

Agriculture has a ***range of options*** to further reduce greenhouse gas emissions, either directly by reducing energy use and emissions of methane and nitrous oxide or by substitution of fossil energy use and carbon sequestration in soils. Advantage should be taken of the fact that some of the measures simultaneously may reduce the net emission of several greenhouse gases. Agriculture, both organic and conventional, has the potential to make a cost-effective contribution to mitigation (Smith et al., 2007). The Intergovernmental Panel on Climate Change (IPCC) estimates that agricultural greenhouse gas mitigation options are cost competitive with non-agricultural options in achieving long-term climate objectives.

Agriculture can help to mitigate climate change by a) reducing emissions of greenhouse gases (GHGs) and b) by sequestering CO_2 from the atmosphere in the soil. The potential of **organic agriculture** for both effects is high, as data gained from modelling both long-term field trials and pilot farms show (Niggli et al., 2007). The global warming potential of organic farming systems is considerably smaller than that of conventional or integrated systems when calculated per land area. This difference declines, however, when calculated per product unit, as conventional yields are higher than organic yields in temperate climates (Badgley et al. 2007). Under dry conditions or water constraints, organic agriculture may outperform conventional agriculture, both per crop area and per harvested crop unit.

Carbon sequestration can be achieved through decreasing deforestation rates, reversing of deforestation by replanting, targeting for higher-yielding crops with better climate change adapted varieties, and improvement of land and water management (Steinfeld et al., 2006). Soil organic carbon can be restored in cultivated soils through conservation tillage, erosion reduction, soil acidity management, double-cropping, crop rotations, higher crop residues, mulching and more (Steinfeld et al., 2006). Improving pasture management can also lead to carbon sequestration by incorporating trees, improving plant species, legume interseeding, introducing earthworms and fertilization. In addition, grass productivity and soil carbon sequestration could be improved by increasing grazing pressure in grasslands that have a lower number of grazing animals than the livestock carrying capacity. Improving grazing land management could sequester around 0.15 gigatons CO_2 eq*yr^{-1} globally (Henderson et al., 2015).

In 2015, at the COP 21, France launched the international initiative "4 per 1000." This program aims to show that agriculture, and in particular agricultural soils can play a crucial role in climate change mitigation through the adoption of agricultural practices allowing more efficient storage of carbon in soils. According to this initiative, an annual increase of "4 per thousand" (0.4%) of organic matter in soil would be enough to compensate for the global emissions of greenhouse gases (4 per 1000 initiative, 2018).

Enteric fermentation is a source of methane emissions that can be reduced through practices such as improvement of animal nutrition and genetics. Examples of practices for mitigating enteric fermentation are: increasing dietary fat content, providing higher quality forage, increasing protein content, providing supplements (e.g. bovine somatotropin, feed antibiotics) and the use of antimethanogens (vaccines to suppress methane emissions). However, there is high uncertainty in the efficacy of these practices because various studies have demonstrated that the initial reductions of enteric fermentation achieved are only temporary (Rojas-Downing et al., 2017).

Most methane emissions from ***manure management*** are related to storage and anaerobic treatment. Although manure deposited on pasture can produce nitrous oxide emissions, the mitigation measures are often difficult to apply because of the manure dispersion on pasture (Dickie et al., 2014). Therefore, most mitigation practices involve shortening storage duration, improving timing and application of manure, used of anaerobic digesters, covering the storage, using a solids separator and changing the animal diets. Anaerobic digestion can reduce methane emissions while producing biogas (Gerber et al., 2008). Anaerobic digesters are lagoons or tanks that maintain manure under anaerobic conditions to capture biogas and combust it for producing energy or flaring. This process reduces the potential of GHG emissions by converting methane into CO_2.

Fertilizer application on animal feed crops increases nitrous oxide emissions. The global warming potential of conventional agriculture is strongly affected by the use of synthetic nitrogen fertilizers and by high nitrogen concentrations in soils. Organic agriculture, in contrast, is self-sufficient in nitrogen. Mixed organic farms practice highly efficient recycling of manures from livestock and of crop residues by composting. Leguminous crops deliver additional nitrogen in sufficient quantities (on stockless organic farms this is the main source). Badgley et al. (2007) calculated the potential nitrogen production by leguminous plants via intercropping and off-season cropping to be 154 million tonnes, a potential which exceeds the nitrogen production from fossil fuel by far and which is not fully exploited by conventional farming techniques. In organic agriculture, the ban of mineral nitrogen and the reduced livestock units per hectare considerably reduce the concentration of easily available mineral nitrogen in soils and thus N2O emissions. Therefore, mitigation measures such as increasing nitrogen use efficiency, plant breeding and genetic modifications (Dickie et al., 2014), using organic fertilizers, regular soil testing, using technologically advanced fertilizers, and combining legumes with grasses in pasture areas may decrease GHG emissions in feed production (Dickie et al., 2014).

Nitrogen management is an integral measure to decrease N losses. Nitrogen management is based on the premise that decreasing the nitrogen surplus (N surplus) and increasing N use efficiency (NUE) contribute to abatement of NH3 emissions. On mixed livestock farms, between 10% and 40% of the N surplus is related to NH3 emissions. Nitrogen management also aims to identify and prevent pollution swapping between different N compounds and environmental compartments. Establishing an N input-output balance at the farm level is a prerequisite for optimizing N management in an integral way.

Gaseous N losses from livestock production originate from the feces (dung) and urine excreted by the livestock. The animal feed composition and the feed management has a strong influence on animal performance and on the composition of the dung and urine, and thereby also on the emissions of NH3.

Livestock feeding strategies decrease NH3 emissions from manure in both housing and storage and following application to land. Livestock feeding strategies are more difficult to apply to grazing animals, but emissions from pastures are low and grazing itself is essentially. Livestock feeding strategies are implemented through (a) phase feeding, (b) low-protein feeding, with or without supplementation of specific synthetic amino acids and ruminal by-pass protein, (c) increasing the non-starch polysaccharide content of the feed, and (d) supplementation of pH-lowering substances, such as benzoic acid. Phase feeding is an effective and economically attractive measure even if one that requires additional installations. Young animals and high-productive animals require more protein concentration than older, less-productive animals. Combined NH3 emissions for all farm sources decrease roughly by 10% when mean protein content decreases by 10 grams (g) per kg (1%) in the diet.

In practice, protein levels in animal feed are often higher than actually required. Safety margins in the protein content of the diet are used to account for: (a) suboptimal amino acid ratios; (b) variations in requirements between animals with different genotypes; (c) variations in requirements caused by differences in age or production stadiums; and (d) variations in the actual content and digestibility of essential amino acids in the diet. The protein content of the diet and the resulting N excretion can be reduced by matching the protein/amino acids content of the diet as closely as possible to the animal's requirements. The fraction of feed intake not digested, absorbed and retained by the animal is excreted via dung and urine. The excess N in the feed is excreted in the form of protein (organically bound N), urea, uric acid and ammonium. The partitioning of N over these compounds together with the pH of the dung and urine affects the potential for NH_3 loss. There is large variation in the composition of dung and urine from dairy cattle, finishing pigs and chickens, due to variations in animal feeding.

Low-protein animal feeding is one of the most cost-effective and strategic ways of reducing NH_3 emissions. For each per cent (absolute value) decrease in protein content of the animal feed, NH_3 emissions from animal housing, manure storage and the application of animal manure to land are decreased by 5%– 15%, depending also on the pH of the urine and dung. Low-protein animal feeding also decreases N_2O emissions and increases the efficiency of N use in animal production.

Low-protein animal feeding is most applicable to housed animals and less for grassland-based systems with grazing animals, because grass is in an early physiological growth stage and thus high in degradable protein, and grassland with leguminous species (e.g., clover and lucerne) have a relatively high protein content. While there are strategies to lower the protein content in herbage (balanced N fertilization, grazing/harvesting the grassland at later physiological growth stage, etc.), as well as in the ration of grassland-based systems (supplemental feeding with low-protein feeds), these strategies are not always fully applicable.

For animal housing, abating NH_3 emissions is based on one or more of the following principles: (a) Decreasing the surface area fouled by manure; (b) Rapid removal of urine; rapid separation of feces and urine; (c) Decreasing the air velocity and temperature above the manure; (d) Reducing the pH and temperature of the manure; (e) Drying manure (especially poultry litter); (f) Removing (scrubbing) NH_3 from exhaust air; (g) Increasing grazing time (Bittman et al., 2014).

Livestock feeding strategies can influence the pH of dung and urine. The pH of dung can be lowered by increasing the fermentation in the large intestine. This increases the volatile fatty acids (VFA) content of the dung and causes a lower pH. The pH of urine can be lowered by lowering the electrolyte balance (Na + K – Cl) of the diet (Patience, Austic and Boyd, 1987). Furthermore, the pH of urine can be lowered by adding acidifying components to the diet, e.g., calcium sulphate ($CaSO_4$), Ca-benzoate and benzoic acid. A low pH of the dung and urine excreted also results in a low pH of the slurry/manure during storage even after a certain storage period. This pH effect can significantly reduce NH_3 emissions from slurries during storage and also following application (Aarnink and Verstegen, 2007; Canh and others, 1998a, 1998b, 1998c and 1998d).

For manure storages, abating NH_3 emissions is based on one or more of the following principles: (a) decreasing the surface area where emissions can take place, i.e., through covering of the storage, encouraging crusting and increasing the depth of storages; (b) decreasing the source strength of the emitting surface, i.e., through lowering the pH and ammonium (NH_4) concentration; and (c) minimizing disturbances such as aeration. All principles have been applied in category 1 (i.e., scientifically sound and practically proven) techniques. These principles are generally applicable to slurry storages and manure (dung) storage. However, xi the practical feasibility of implementing the principles are larger for slurry storages than for manure (dung) storages (Bittman et al., 2014).

Urine excreted by grazing animals often infiltrates into the soil before substantial NH_3 emissions can occur. Therefore, NH_3 emissions per animal are less for grazing animals than for those housed where the excreta is collected, stored and applied to land. The emission reduction achieved by increasing the proportion of the year spent grazing will depend, inter alia, on the baseline (emission of ungrazed animals), the time the animals are grazed and the N-fertilizer level of the pasture. The potential for increasing grazing is sometimes limited by land availability, soil type, topography, farm size and structure (distances), climatic conditions, economic considerations, etc. It should be noted that additional grazing of animals may increase other forms of N emission (e.g., N_2O, NO_3). The abatement efficiency may be considered as the relative total NH_3 emissions from grazing versus housed systems (Bittman et al., 2014).

Most studies are focused on reducing GHG emissions on the supply-side of the livestock production system. However, less research has focused on the demand section related to ***consumption of livestock products***. The greatest potential for reducing greenhouse gas emissions from agriculture would be to change consumer behavior. Production of meat requires inputs that are seven times as high as the inputs needed to produce the same quantity of non-meat calories. Organic agriculture aims at precisely this goal: consumption of less-processed products and increased consumption of products like cereals, potatoes, pulses and oils (Niggli et al., 2007). A reduction in meat consumption may significantly reduce GHG emissions. Because beef accounts for a large portion of GHG emissions from the livestock sector and it is the least resource-efficient animal protein producer (Stehfest et al., 2009), the mitigation potential is high for the beef component of the livestock sector. Research to understand why populations feel compelled to increase animal protein consumption when they rise above the poverty line is needed, as well as why those at the top of the economic ladder are compelled to improve their diets by reducing meat consumption and returning to a more vegetarian diet. This conundrum stands at the center of the challenge faced by the state of knowledge and policies surrounding the livestock sector.

Although fisheries and aquaculture do not emit large volumes of GHGs when compared with other industries, industry GHG emissions could be reduced. Improving fuel efficiency by switching to more efficient gear types or vessels, switching to sails or changing fishing practices would reduce emissions from fishing activities. This would also reduce fuel costs, although switching to more efficient vessels and/or gear may only reduce fuel use by 20 percent (FAO, 2007). Product transport is where more sectoral emissions come from, and emission reductions are possible. Using bulk sea freight rather than air freight or non-bulk sea freight or increasing consumption closer to the source (reducing travel distance) would reduce fuel use. Even if international fishing continues to increase, including fish from developing countries travelling to developed country markets, these changes in product transportation can ensure that fishery contributions to GHGs do not increase at the same rate (Daw et al., 2009). In addition to emissions reductions, there is the potential to store carbon in some coastal ecosystems. Carbon storage, especially in these coastal ecosystems (seagrass beds, salt marshes) has the potential to remove and store atmospheric carbon at much greater rates than terrestrial ecosystems (McLeod et al., 2011). Some of these systems, such as salt marshes, also provide additional benefits to communities through flood control, buffering coastlines from storms, water quality, and provide habitat for juvenile fish.

Within agriculture, organic agriculture holds an especially favorable position, since it realizes mitigation and sequestration of CO_2 in an efficient way. Compared to other agricultural systems, organic farming is a well-defined system that is already based on certification and that could easily be extended to meet the standards of CDM. Organic production has great mitigation and adaptation potential, particularly with regard to soil organic matter fixation, soil fertility and water-holding capacity, increasing yields in areas with medium to low-input agriculture and in agroforestry, and by enhancing farmers' adaptive capacity. Paying farmers for carbon sequestration may be considered a win-win-win situation as a) CO_2 is removed from the atmosphere (mitigation), b) higher organic matter levels in soil enhance their resilience (adaptation) and c) improved soil organic matter levels lead to better crop yield (production). Improvement is needed, however, with regard to yields and methane emissions. Organic agriculture, with its holistic multi-target approach, offers further relevant advantages with regard to lifestyle changes, for example, primarily in developed countries. Its numerous co-benefits could greatly assist the development of rural societies in southern countries (Niggli et. al., 2007; Smith et al., 2007).

In spite of some weaknesses, organic agriculture is so far the most promising approach for mitigation and adaptation to climate change. Organic agriculture represents a positive example of how farmers can help mitigate climate change and adapt to its predictable and unpredictable impacts. It can serve as a benchmark for allocating development resources to climate change adaptation, or to measure progress in implementing climate-related multilateral environmental agreements (Niggli et al., 2007).

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