3 RESOURCES 2-FOOD

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3.2 Food

Executive summary

Food production in the Mediterranean Basin, from both land and the sea, is impacted by climate change, more frequent and intense extreme events, jointly with land degradation, overfishing, ocean acidification and salinization of coastal soils. Climate extremes pose a threat to the entire agriculture sector. Extremes, such as heat stress, droughts but also floods, can cause crop yield losses/failures, crop quality reduction and impacts on livestock. Perturbations in the global agricultural markets may exacerbate the local impacts of climate change, especially because most Mediterranean countries are net importers of cereals and fodder/feeding products. Mostly due to unsustainable fishing, total fish landings in the Mediterranean Sea have declined by 28% from 1994 to 2017.

Climate projections show a decrease of water availability and an intensification of extremes in the Mediterranean region, and thus a higher risk for the agriculture sector. Crop yield reductions are projected for the next decades in most current areas of production and for most crops. The cultivation of some water demanding crops like maize or vegetables could become impossible in many Mediterranean regions if there will be no enough water for irrigation. This will potentially be worsened by emerging pests and pathogens, and perturbations in the global food markets due to environmental crises elsewhere.

Sea level rise will also negatively affect the agriculture sector by its direct impact on agricultural areas and associated increasing soil salinity, which could be multiplied by three. Rice production in Egypt and Spain could be the most affected.

Climate change is projected to heavily affect marine resources in the next decades. Warmer temperatures, acidification and water pollution will likely reduce marine productivity, affect species distribution and trigger local extinction of more than 20% of exploited fish and marine invertebrates around 2050.

In agriculture, there are large possibilities for adaptation consisting mostly in changing farming practices and application of more sustainable methods, including agroecological strategies. Successful strategies for sustainable development and enhanced resilience to environmental change are based on combining different approaches, i.e., reduced tillage, varieties, rotational patterns, and crop diversity or diversification of income. Sectorial co-designed climate services will represent a key asset to reduce the risk linked to unfavorable climate conditions and extremes.

Figure 3.13 | Total agricultural land in the Mediterranean countries in 2016 (% with respect to the total land at country scale). Source: World Bank (accessed February 2020).

Figure 3.14 | Total irrigated land in the Mediterranean countries (latest reported value in % with respect to the agricultural land at the country scale). Source of data: World Bank Data (accessed February 2020).

Sustainable intensification of farming systems offers greenhouse gas mitigation options by nitrogen fertilization optimization, improved water management, higher storage of soil organic carbon and carbon sequestration both in annual and perennial cropping systems, management of crop residues and agroindustry by-products.

3.2.1 Past trends and current situation

The ensemble of the Mediterranean countries has approximately 877 million ha of land, of which about 28% is devoted to agriculture *(Fig. 3.13)*. There is a pronounced spatial heterogeneity in the share of agricultural land, from 4% of Egypt to almost 76% of Syria *(Fig. 3.13)*. The agriculture sector is characterized by a variety of different farm structures and agro-management practices combined with pronounced differences in environmental conditions, rendering substantial variation in agricultural inputs (e.g., nutrients, pesticides, water for irrigation) and outputs (e.g., crop yields). Irrigation is practised only on 8% of the Mediterranean agricultural land area *(Fig. 3.14)*, however uncertainties characterize this value as data for several countries are neither available nor updated. Israel has the highest portion of agricultural land being irrigated (approx. 33%, *Fig. 3.14*).

The Mediterranean agriculture production is characterized by high spatial variability and differences *(Table 3.9)*. Annual crops include cereals (e.g., wheat, maize, barley and rice), and vegetables (e.g., potatoes and tomatoes). Together, wheat, maize, barley and rice cover, for almost all Mediterranean countries, more than 90% of the entire cereal production, with rice having a significant share (>3%) only in Egypt, Greece, North Macedonia, Portugal, Spain and Italy. Permanent crops consist of fruit, olives, grapes and dates. For cereals, France, Turkey, Egypt, Spain and Italy produce (2014-2018 average) about 66, 35, 23, 21, and 18 million t, respectively *(Table 3.9)*. As for fruit and vegetable production, the highest values (15-22 million t for fruit, and 13-24 million t for vegetables) come from Egypt, Italy, Spain and Turkey *(Table 3.9)*.

Although productivity has increased in recent decades, there are still large differences in the region, with for instance wheat yield ranging from approx. 1 to almost 7 t ha^{-1} (FAO 2017). These differences are also reflected in the estimated yield gap for wheat, maize and barley (e.g., Mueller et al. 2012; Schils et al. 2018). Improved agro-management practices can contribute to close the gap in regions where large differences exist between potential and farm yield. As an example, Pala et al. (2011) found that wheat yields can be increased 1.6–2.5 times in Morocco, 1.7–2.0 times in Syria and 1.5–3.0 times in Turkey.

Large spatial differences also characterize the livestock subsector, with meat (beef and buffalo) production varying from 0.1 to 143.9×10^4 t; while milk production varies from 0.4 to 262.7×10^5 t *(Table 3.9)*. Milk productivity also spans a vast range from

	Cereal	Fruit	Vegetables	Meat (beef & buffalo)	Milk
Albania	6.9	7.8	8.0	0.39	11.4
Algeria	40.4	67.6	63.4	1.57	35.8
Bosnia and Herzegovina	13.6	3.3	7.7	0.15	7.0
Bulgaria	92.5	4.9	4.6	0.18	11.3
Croatia	30.6	3.2	12.4	0.43	6.8
Cyprus	0.4	1.8	0.7	0.05	2.5
Egypt	229.7	150.8	158.2	7.89	51.6
France	662.6	92.2	52	14.39	262.7
Greece	38.5	40.5	25.2	0.43	19.4
Israel	2.9	13.8	14.9	1.29	15.4
Italy	175.8	175.3	125.9	7.75	119.3
Jordan	1.0	5.4	16.2	0.27	3.5
Lebanon	1.7	8.0	8.2	0.45	2.6
Libya	2.7	6.8	6.8	0.09	2.3
Malta	0.1	0.1	0.8	0.01	0.4
Montenegro	0.1	0.8	0.2	0.04	1.7
Morocco	84.7	57.3	40.3	2.61	23.9
North Macedonia	5.6	5.8	6.9	0.05	4.5
Palestine	0.5	1.2	6.4	0.08	1.6
Portugal	11.9	19.6	24.4	0.89	20.8
Serbia	95.2	16.5	8.5	0.69	16.0
Slovenia	6.2	2.1	0.9	0.34	6.4
Spain	211.6	192.7	128	6.32	80.2
Syria	31.4	25.1	17.9	0.70	22.3
Tunisia	17.8	20.9	30.3	0.59	13.8
Turkey	354.3	217.5	239.8	9.90	197.2
Kosovo	95.2	16.5	8.5	0.69	16.0

Table 3.9 | Production of cereals, fruit, vegetables, meat and milk in the Mediterranean countries, 2014-2018 average, 10^5 tonnes. Data source: FAOSTAT (accessed February 2020).

800 kg animal^{-1} in Libya to 5,500 kg animal^{-1} in Slovenia. Overall, Mediterranean countries of the MENA region have an average milk productivity of 700 kg animal^{-1}, compared to 1,800 kg animal^{-1} of the other countries and 2,300 kg animal^{-1} for the EU countries in the region.

3.2.1.1 Demand for agricultural products, consumption and trade

Agricultural demand in the Mediterranean region is influenced by changing dietary patterns and by the socio-economic and political situation of each country, including population growth and import/export flows. In 2013, the Mediterranean diet has been recognized by UNESCO as intangible cultural heritage of humanity, involving not only food production, processing and consumption but also social behaviour and community identity. Its low environmental impact and its importance for a sustainable future have been highlighted in many studies (Sofi et al. 2010; Capone et al. 2012; CIHEAM and FAO 2015). Recent studies indicate a diet transition affecting the Mediterranean countries and posing a threat for the preservation and enhancement of the Mediterranean diet (Bonaccio et al. 2012, 2014; CIHEAM and FAO 2015). These changes may further affect nutritional issues and human health in Mediterranean countries, where already malnutrition (characterized by the presence of significant percentage of overweight and underweight population) takes place.

The food system of the Mediterranean also contributes to the ecological deficit as estimated by Galli et al. (2015) and updated in the National Footprint Accounts 2019[15]. The amount and the

[15] Global Footprint Network, http://data.footprintnetwork.org/

type of contribution are country dependent, and in some cases (e.g., Portugal, Greece, Spain, Malta, Croatia and Italy) characterized by a relevant component of meat, dairy and fish (Galli et al. 2017). Changes during the last decade (2000-2013) in meat consumption are not homogeneous in the Mediterranean region, with twelve countries showing a significant increase, six having characterized by a significant decrease and the others having a stationary pattern. For fish, fourteen countries show a significant increase, only two a significant decrease and all others have a stationary pattern *(Fig. 3.15)*.

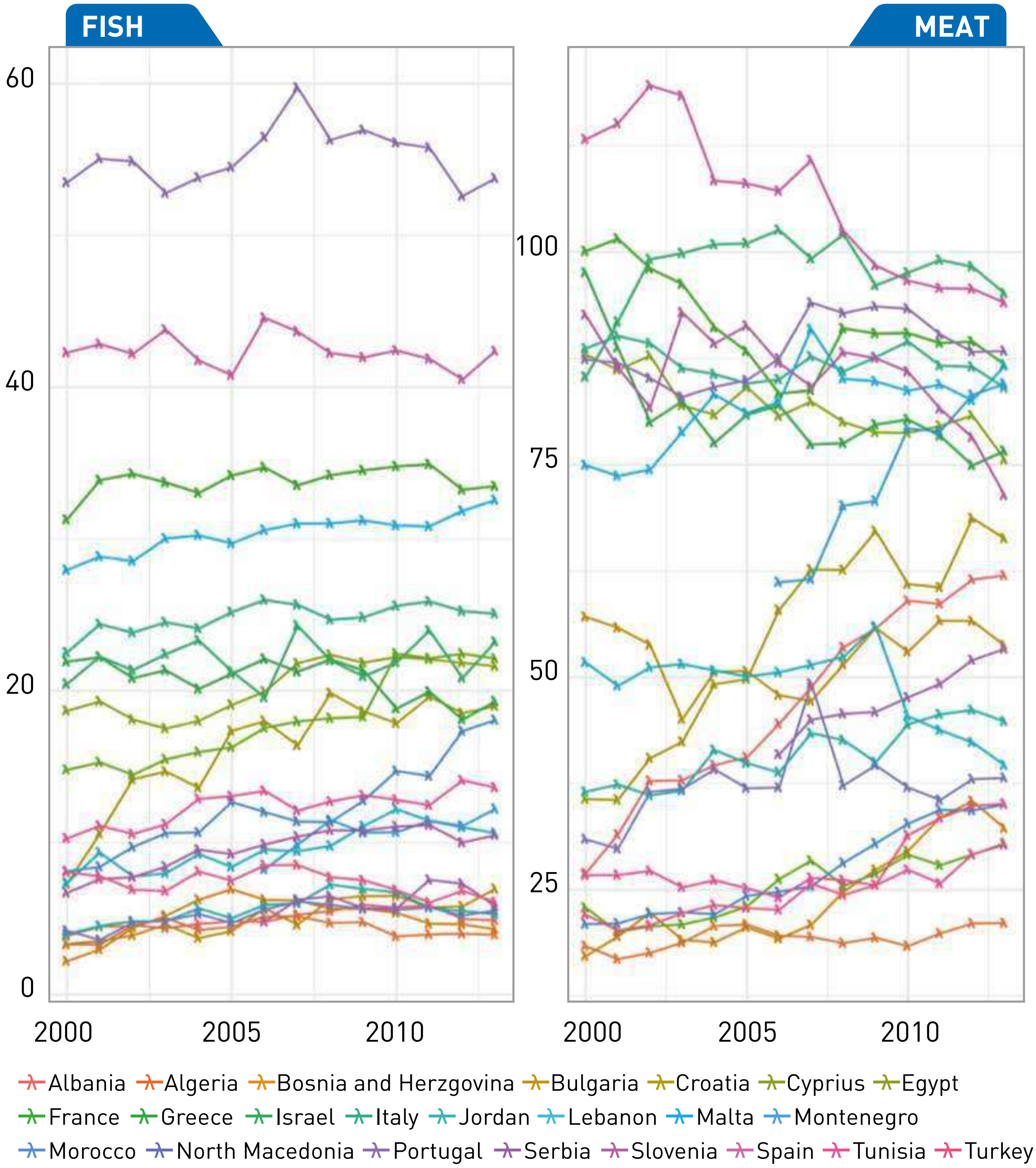

Figure 3.15 | Meat and fish consumption (kg capita^{-1} yr^{-1}) in Mediterranean countries from 2000 to 2013 (FAO 2017).

Trade patterns play a key role in the Mediterranean region, with most of the countries being net importer of cereal and fodder/feeding products (*Fig. 3.16* and *3.17*). Concerning cereal, four countries (Italy, Spain, Egypt, and Algeria) import 12-19 million t of cereal, while France exports about 29 million t *(Fig. 3.16)*. As for fodder and feeding products, five Mediterranean countries import more than one million t, with Turkey reaching about 4.3 million t *(Fig. 3.17)*. The current trade patterns have been reached by a profound transformation of the agricultural systems that has occurred in the last decades, often characterized by a decoupling of the crop and livestock producing systems (Lassaletta et al. 2014).

Overall, the Mediterranean region, in terms of nitrogen (N) import has moved towards a more unbalanced situation with most of the countries being net larger importer *(Fig. 3.18)* (Lassaletta et al. 2014; Sanz-Cobena et al. 2017). The decoupling of the crop and livestock producing systems caused a lower nutrient efficiency and issues associated with the lack of manure in cropping area and excessive manure in livestock farms (Lassaletta et al. 2012; Sanz-Cobena et al. 2017). The excessive manure production is difficult to manage, and over-application in areas close to high-density livestock systems can severely affect the environment. As a consequence, a high risk of catchment pollution has been estimated and reported in some studies (Lassaletta et al. 2012; Romero et al. 2016).

The Mediterranean is among the oldest examples of strongly coupled human-environment sys-tem that has undergone very profound land/landscape changes driven by activities such as the agriculture and by the human-water interaction (Barton et al. 2010, 2016) *(Section 4.3.1.1)*. Many factors have contributed to these changes in the Mediterranean, e.g., people's mobility towards the coast and the urban areas, tourism expansion, industrialization, agriculture intensi-fication (Bajocco et al. 2012; Niedertscheider and Erb 2014).

These changes have contributed to alter land quality, productivity and to degradation. Changes have not been homogeneous as very different

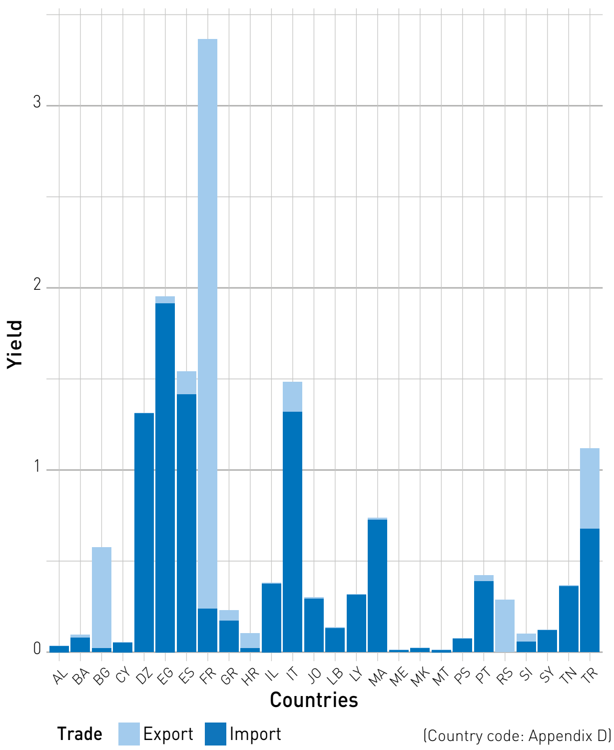

Figure 3.16 | Cereal trade patterns (average 2014-2017 values in tonnes x 10^7) in the Mediterranean countries: import (deep blue) and export (light blue) contribution for each Mediterranean country (identified by the ISO 3166-1 alpha-2 code) (FAO 2017).

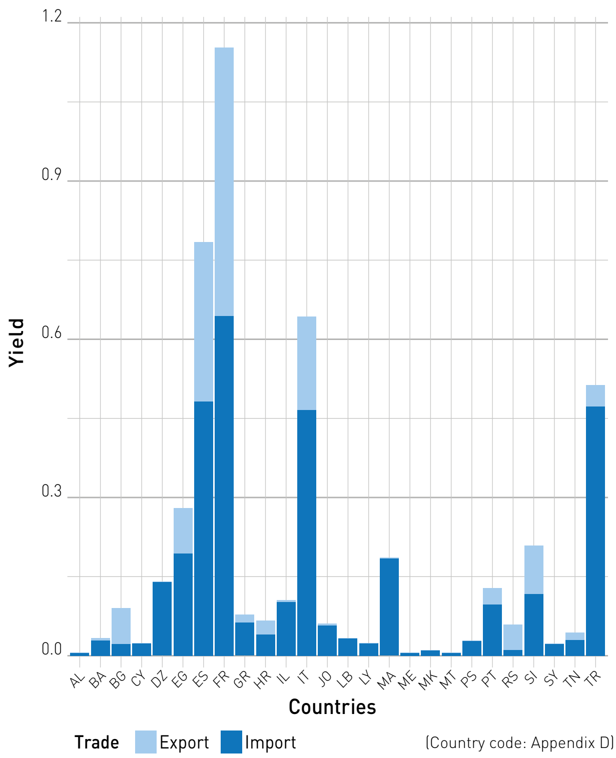

Figure 3.17 | Trade patterns in fodder and feeding products (average 2014-2017 values in tonnes x 10^6) in the Mediterranean countries: import (deep blue) and export (light blue) contribution for each Mediterranean country (FAO 2017).

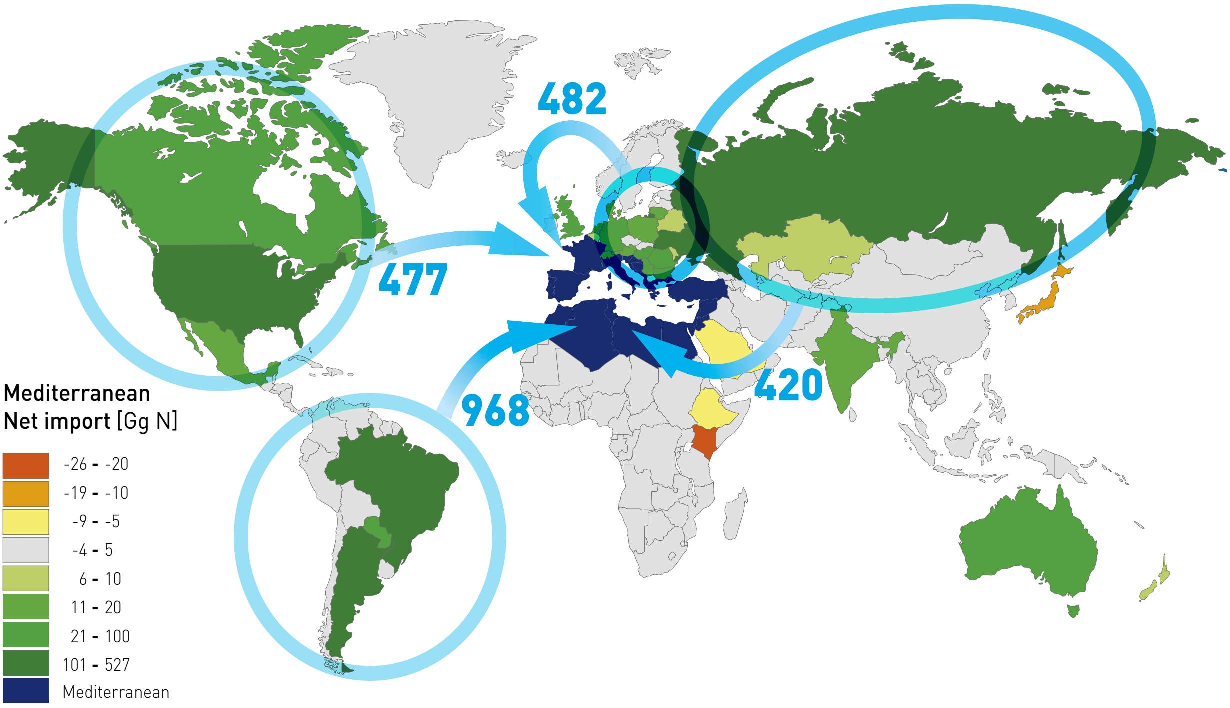

Figure 3.18 | Net protein fluxes (Gg N) of food and feed imported to the Mediterranean regions from the other countries in 2009. Green countries are net N exporters to the Mediterranean. Yellow/red countries are net N importing from the Mediterranean. Fluxes below 50 Gg N are not represented (adapted from Sanz-Cobena et al. 2017).

socio-economic conditions characterize the region as well as behavioural patterns in farming. For instance, in some areas of the western Mediterranean the abandonment of dryland farming, of farming activities in mountainous and/or re-mote regions, and the consequent afforestation modified the ecosystems and the services pro-vided (Kauppi et al. 2006; Falcucci et al. 2007; Padilla et al. 2010). Abandonment of agricultural terraces in mountainous regions has in some cases also favored erosion processes and loss of fertile soil (Arnaez et al. 2011). Land competition has also played a key role in some regions of southern Mediterranean, e.g., Morocco (Debolini et al. 2015). Mobility towards urban areas, evolving economic conditions, modified productivity in agricultural areas of Mediterranean countries also contributed to shifts in the cultivated crops. In Crete (Greece), for instance, a transition from cereal production towards olive cultivation characterized the 20th century (Karamesouti et al. 2015). In some countries, urbanization has forced agricultural expansion to-wards marginal areas requiring higher management levels in terms of irrigation and fertilization (Abd-Elmabod et al. 2019).

3.2.1.2 Marine food resources

Mediterranean total fishery landings have been declining in the last years *(Fig. 3.19)* (Tsikliras et al. 2015; FAO 2018) and so are the reconstructed catches that included discarded, illegal and unreported and recreational fisheries catch (Pauly and Zeller 2016). Total landings of the entire Mediterranean Basin exceeded 1.16 million t in 1994 and declined to around 842,000 t in 2017, i.e., a decrease of 28% *(Fig. 3.19)*.

While the peaks occurred relatively early in the central Mediterranean (~1985) and eastern Mediterranean (~1994), the landings peaked much later in the western Mediterranean (~2006) *(Fig. 3.20)*. In 2017, the landings were relatively low: from 161,000 t in eastern Mediterranean to 325,000 t in central Mediterranean *(Fig. 3.20)*. In 2017, the highest contribution to the total landings in the Mediterranean came from Italy (22%), followed by Algeria (12%), Tunisia (12%), and Spain (10%)[16].

Small pelagic fishes constitute the vast majority of landings across the entire Mediterranean Sea, with European anchovy *(Engraulis encrasicolus)* and

[16] Data from FAO-GFCM, accessed March 2020. http://www.fao.org/gfcm/en/

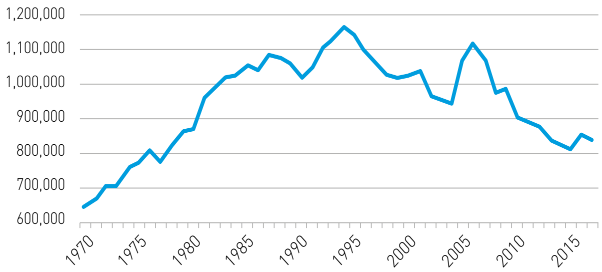

Figure 3.19 | Total fish landings (tonnes) in the Mediterranean Sea from 1970 to 2017. Data source: FAO-GFCM[16], accessed in March 2020.

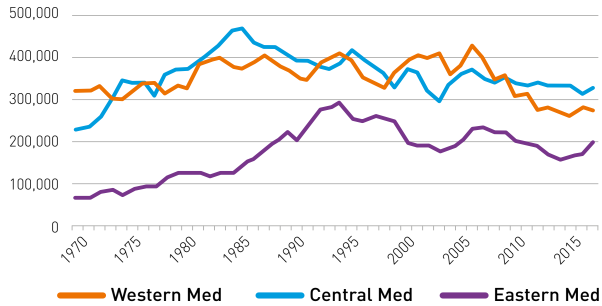

Figure 3.20 | Total landings (t) from 1970 to 2017 in the Mediterranean Sea. Data source: FAO-GFCM[16], accessed in March 2020.

European sardine *(Sardina pilchardus)* being the species with the most landings accounting for 34% of the 2014-2016 average annual landings (FAO 2018; Tsikliras et al. 2019). The main pelagic fish species landed in the western Mediterranean are European anchovy, European sardine and sardinella nei (*Sardinella* spp.) accounting for 46% of the total landings (FAO 2018). In the Ionian part of central Mediterranean, European sardine, sardinella nei, jack and horse mackerel nei (*Trachurus* spp.), and common Pandora *(Pagellus erythrinus)* account for 30% of the total landings (FAO 2018). While in the Adriatic part of Central Mediterranean, landings of European sardine and anchovy reach 61% (FAO 2018). Finally, in the eastern Mediterranean, European sardine, anchovy and European sardine are again the main species landed accounting for 33% of the total landings (FAO 2018) (*Sections 2.4.2, 4.1* and *4.2*).

3.2.1.3 Observed impacts of extreme weather and climate events on food production

Extreme weather and climate events (such as floods, droughts, storms, heat waves and cold spells) pose a threat for agricultural production (Lesk et al. 2016; Zampieri et al. 2017; FAO 2018). The impacts of heat stress occurring in critical phenological phases can induce serious crop yield losses and quality reduction. In Italy, for instance, early heat waves have been associated to durum wheat yield losses occurred in the last decades (Fontana et al. 2015; Zampieri et al. 2017). In Greece, recent trends in extreme temperatures reduced cereal yields by 1.8-7.1% per degree increase in maximum temperatures (Mavromatis 2015). Also milk production and quality are affected by heat stress (Bernabucci et al. 2010, 2015; Gantner et al. 2017) as well as livestock fertility (de Rensis et al. 2015). Temperature changes during important phenological stages such as blossoming may affect yields of maize, alfalfa, apples, almonds and other crops (Savé et al. 2012; Funes et al. 2016; Díez-Palet et al. 2019).

The entire agriculture sector in the region is also heavily affected by drought events (Blauhut et al. 2015; Zampieri et al. 2017). Severe socio-economic impacts triggered by drought events were reported on Moroccan agriculture (Verner et al. 2018), with the events of 2007 (Schilling et al. 2012) and 2015-16 that caused heavy losses on wheat, citrus and olive production, posing a threat for the livestock sector. Severe droughts can also modify the rural landscape, preventing the adoption of new crops and ultimately forcing farmers to emigrate (Ruaudel and Morrison-Météois 2017). The costs and the risks associated with climate extremes are not only related to direct losses, such as crop failures, but also to a wide range of indirect effects triggered by market reactions to events occurring in other producing regions of the world (Chatzopoulos et al. 2019).

The Mediterranean is also a high fire-risk region, where fires are the cause of severe agricultural, economic and environmental losses and even human casualties (San-Miguel-Ayanz et al. 2013; Moritz et al. 2014; Bowman et al. 2017). The abandonment of agricultural land leads to an increased risk of forest fires due to the occupation of what were agricultural lands by forest and the bushes, and increasing the biomass available for burning as well as its spatial continuity. Conversely, some forest fires may be triggered for the creation of more pastures for livestock or farmland.

3.2.1.4 Food policy and economics

Agriculture and the entire food system are generally influenced by socio-economic conditions, also in Mediterranean countries. The strong fluctuations in food markets are partly due to the characteristics of agricultural production itself (perishable products, climatic and health risks, seasonal production cycles, size of farms, distance from markets etc.), which, together with aspects of the overall economy, even of a geopolitical nature, can modify the food supply-demand balances (Reguant and Savé 2016). These conditions also endanger the capacity of Mediterranean countries to guarantee food security (Santeramo 2015). Among the Mediterranean countries, some in the southern and eastern shores have also suffered political instabilities and conflicts that have posed a challenge to the maintenance and development of the agriculture system (Tanyeri-Abur 2015; Petit and Le Grusse 2018).

The food system of the Mediterranean region in all its aspects (production, trade patterns, etc.) is under strong influence from the policies of high-income countries and, in particular, the European Union (Caracciolo et al. 2014). The tight links among Mediterranean countries imply that changes in the EU Common Agricultural Policy and in trade agreements may have important impacts on national agri-food sectors also outside the EU. For instance, the Euro-Mediterranean trade partnership between the EU and the southern and eastern Mediterranean non-EU countries (except for Syria and Libya, entered into force to promote trade and investments in the region) tends to influence market fundamentals in all Mediterranean countries. Furthermore, food quality standards and entry price mechanisms are very important for trade patterns (Cioffi et al. 2011; Santeramo and Cioffi 2012; Marquez-Ramos and Martinez-Gomez 2016; Bureau and Swinnen 2018).

Trade has prioritized the export of fruits and vegetables and has widened the production-consumption gap of cereals, which are the main food of the most vulnerable segments of the population in the southern and eastern parts of the region (Larson et al. 2002; Cioffi and Dell'Aquila 2004; García Martinez and Poole 2004). The vulnerability of the cereal sector has enhanced the impact of food price fluctuation on food security, which may have severe impacts (e.g., in terms of income level and income distribution) depending on the capacity of the countries to be self-sufficient (Caracciolo and Santeramo 2013).

Pasture based systems are becoming less competitive, due to the high labor costs (on-farm resources are being substituted with external inputs) promoting intensive livestock systems near urban areas (Malek et al. 2018). This has resulted in the increase in landless livestock systems in the Mediterranean region.

Mediterranean countries are vulnerable to price fluctuations on international markets due to their dependence on imports of basic foodstuffs. Worldwide phenomena (e.g., food crisis) have accentuated the structural weakness of the agricultural production model adopted by these countries, increasing social and political frustrations (Reguant and Savé 2016). In this context, it is worth to mention initiatives such as the Mediterranean Agricultural Market Information Network (MED-Amin)[17] and the MedAgri platform[18] from FAO, the European Bank and the World Bank. The drivers of price volatility are numerous and complex (Santeramo et al. 2018b), but it seems there is a consensus that arbitrage, and price discovery mechanisms tend to have a positive impact on price stabilization (Santeramo and Lamonaca 2019).

Access to agricultural technology is unequally distributed across countries of the Mediterranean area and is usually more accessible to farmers in the north-western part. It is also true that most developed countries tend to provide higher subsidies (at least in nominal terms) to their agricultural sector. The adoption of risk management strategies, and the access to credit are also very unequally distributed and generally lower in the developing countries of the Mediterranean area (Santeramo et al. 2014). These peculiarities allow to conclude that the less developed countries, among the Mediterranean ones are likely to be the most vulnerable to food security issues. On the other hand, investments on technology, on policies to promote the agri-food sector, and in particular to promote risk management strategies may prove effective mechanisms to enhance resilience to food security.

3.2.2 Projections, vulnerabilities and risks

3.2.2.1 Agricultural resources

Climate projections indicate significant warming and drying in the Mediterranean Basin, together with intensification of climate extremes such as

[17] www.med-amin.org

[18] www.medagri.org

drought and heat waves (*Sections 2.2.5.2* and *2.2.4*). Thus, severe impacts on the agriculture sector are to be expected if no adaptation and mitigation will take place. These impacts include changes in phenology and growing cycle of many crops (Trnka et al. 2011; Funes et al. 2016), combined with higher water demands due to enhanced evaporation (Savé et al. 2012; Girard et al. 2015; Saadi et al. 2015; Valverde et al. 2015; Phogat et al. 2018). The wheat growing period in Tunisia is expected to be shortened by 16 days for 2.5°C and by 30 days for 4°C (Mougou et al. 2011). Additional constraints include water scarcity *(Section 3.1.4.1)* (Vicente-Serrano et al. 2017, 2018) and soil salinity (Lagacherie et al. 2018; Phogat et al. 2018).

As a consequence, potential yields of crops and livestock yields are projected to decline in many areas due to climatic and other stress factors without adaptation. Several regions of the Mediterranean might entirely lose their suitability for growing specific crops (Ceglar et al. 2019). Crop yields in MENA countries are expected to decline by approx. 30% with 1.5-2°C warming in Jordan (Al-Bakri et al. 2011) and similarly in North Africa (Drine 2011) and up to 60% with 3-4°C warming (Schilling et al. 2012). Maize is projected to be among the most affected crops (Webber et al. 2018; Zampieri et al. 2019; Feyen et al. 2020), with significant yield decline of, e.g., 10-17% in Italy, Bulgaria, and Greece by the mid-century (2021-2050, under the business as usual RCP8.5 scenario and assuming the current agro-management will still be in place). Wheat yield losses are projected for some European countries in the Mediterranean region (5%-22% in 2021-2050 under the RCP8.5 scenario with no adaptation) (Feyen et al. 2020) associated with higher inter-annual variability and decrease resilience of the production (Zampieri et al. 2020). Reductions in wheat yield in case of no adaption have been also reported for Algeria (Chourghal et al. 2016). However, reductions in water availability for maize irrigation could bring much bigger losses. Based on a meta-analysis of 16 studies available at the time, Waha et al. (2017) conclude that climate change constitutes a significant risk for crop yields across the MENA region *(Fig. 3.21)*.

Soil and agro-management influence on the projected changes has also been reported for wheat yield in an Italian region, showing moderate yield increase as well as heavy decrease (63% in 2040-2070 under the A1B scenario, which is close to the relatively high scenario RCP6.0) (Bird et al. 2016) according to the soil type. While a strong dependence on water availability has been pointed out for tomato yield in Tunisia, where a 10% reduction in

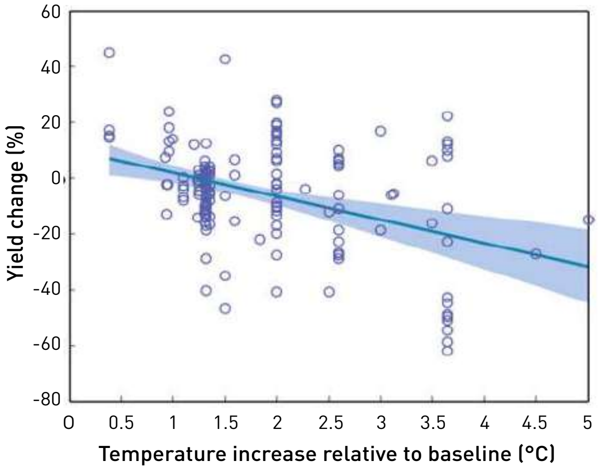

Figure 3.21 | Crop yield changes in the MENA region based on a meta-analysis of 16 different studies (Waha et al. 2017).

water for irrigation could make some productions not feasible (Bird et al. 2016). In Tunisia, wheat yields may increase in some producing areas (Annabi et al. 2018). However, recurrent drought events may induce losses of approximately -50% in olive production, and the increase in floods could lead to a decrease of -13% in rainfed cereal production (Requier-Desjardins 2010). The effects of changes in precipitation regimes on olive production in the entire Mediterranean region were investigated by Tanasijevic et al. (2014) that pointed to the likely absolute need of irrigation in future olive cultivation. Large climate impacts have been also estimated (assuming no adaptation) for agriculture in Egypt increasing over time and triggering exceptional food price increases (McCarl et al. 2015). Sea level rise will also pose a threat to agriculture in Egypt leading to area losses and affecting, for instance, rice production (Chen et al. 2012; Sušnik et al. 2015). Similarly, heavy impacts of sea level rise and associated increased soil salinity (estimated to be three times the current one) on rice production have been estimated at the end of the century in Spain (Genua-Olmedo et al. 2016).

The increase in the atmospheric concentration of CO_2 could bring beneficial effects in terms of yield under optimal growing conditions (especially for C_3 crops such as wheat and barley) and could buffer some days more under drought conditions (Kimball 2016) but may also bring new nutritional challenges (Uddling et al. 2018; Asseng et al. 2019). Results also highlight the limited beneficial contribution of elevated atmospheric CO_2 concentration under pronounced water-stress conditions. Reductions in wheat protein yield by 5-10% have been estimated at some south-western locations of the basin (2040-2069 under the RCP8.5 scenario) (Asseng et al. 2019).

Concurrent and recurrent extremes, not fully considered in the current impact assessments, may well pose the main threat to the stability and the resilience of the Mediterranean production systems. Climate extremes occurring in other regions of the world may also trigger impacts through increased market volatility and price spikes (Chatzopoulos et al. 2019; Toreti et al. 2019). New and re-emerging pest and pathogens, usually not fully considered in impact assessments, may contribute to larger than estimated losses (Bebber et al. 2013, 2014). Another threat to food security and quality may be represented by mycotoxigenic fungal pathogens and higher level of contamination (Medina et al. 2017). Agriculture in the region may be also affected by increased risk of large fires, with a 34 to 140% rise according to the location and the scenario *(Section 4.3.2.1)*.

3.2.2.2 Marine food resources

Projected climate change is also expected to heavily impact marine food resources, which are overexploited already. Ocean warming, acidification, water pollution and constrained migration possibilities to cooler areas (due to sea enclosure) may lead to local extinction of up to 50% of exploited fish and marine invertebrates around 2050, affecting also endemic fishes, including commercial ones (e.g., Cheung et al. 2016) (*Section 4.1.2.1).* Pollution from anthropogenic activities also affects fish population, notably in the Nile delta, with potentially serious consequences on human food security.

Besides warming, marine ecosystems are also sensitive to increasing atmospheric CO_2 concentration due to its rapid dissolution in seawater, which causes alterations in the chemistry of inorganic carbon with a lower pH and higher concentration of carbonic ions (Doney et al. 2009). The carbonic ion is an essential element for organisms that depend on the deposition of calcium carbonate ($CaCO_3$) through biomineralization for the formation of calcareous structures, such as the mollusk shells. If the biomineralization process does not occur properly, organisms reduce their growth rate and may present morphological anomalies that cause, for example, the loss of capacity of fixation to the substrate and diminishes feeding activity.

The joint effects of ocean warming and acidification may also include a number of biological alterations such as decreased ocean productivity (Behrenfeld et al. 2006), reduced growth and survival of calcifying organisms (Hoegh-Guldberg et al. 2007), changes in species distributions, altered food dynamics (Vergés et al. 2014), and altered incidence of disease (Burge et al. 2014). These effects can be translated into a diminution of the abundance and, therefore, of the fisheries production. The affected activities would be both extractive fishing (shellfish, in this case) and aquaculture that is extensively used in coastal areas (Gazeau et al. 2014; Prado et al. 2016). The example of mollusks is perhaps the most quoted but we should not forget that other organisms are subject to biomineralization processes for the formation of the skeleton (e.g., fish), and thus, can also be negatively affected. The effects on habitats can also be quite important because at lower pH some plants can be affected directly or indirectly and even calcareous substrates of biological or mineral origin. All this has to be added to the benthic organisms with calcareous structures that are not commercial species but are the base of the food web for upper trophic groups.

To fully understand the potential effects of global change, it is important to focus on population bottlenecks, which are usually early developmental and reproductive stages (Thorson 1950). Survival of adult and juvenile bivalves shows little dependence on pCO_2 (Berge et al. 2006; Hendriks et al. 2010; Range et al. 2012), although increasing temperature may result in increasing mortality and metabolic rates (Basso et al. 2015). In contrast, gametes, embryos, and larvae are generally more sensitive to both temperature and elevated pCO_2 stress (Havenhand et al. 2008; Parker et al. 2009, 2010) because the deposition of $CaCO_3$ shells and skeletons begins in these stages (Kurihara et al. 2007). Yet, there is also a wide natural variability in pH ranges of seawater (7.5-8.5, with even lower values possible in semiconfined waters; Flecha et al. 2015) which may partly account for observed differences in the responses of calcifying organisms to acidification and complicates the generalization of patterns across species and ecosystems (Kurihara 2008).

3.2.3 Adaptation and mitigation

3.2.3.1 Adaptation of the food system to environmental change

The assessment of how climate change will affect crops is essential for policymakers, planners, farmers and all the other actors of the agriculture sector to develop, propose and implement adaptation and mitigation strategies at the local/regional scale to make agriculture more resilient to changes (Liebig et al. 2016). For instance, future water availability and water demands put the current management model in question, so adaptation choices have to be necessarily developed (Iglesias and Garrote 2015; Ronco et al. 2017). The projected water scarcity and increase of drought events will limit adaptation actions based on irrigation. Under some scenarios combining climate change and population growth, half of the Mediterranean countries (mainly in the southern and eastern shores) are projected to be unable to cover irrigation water demands by the end of the century (Fader et al. 2016) *(Section 3.1.5.2).*

Crop distribution, diversity, varieties, rotation patterns, and agro-management represent key elements of adaptation strategies at the farm scale (Valverde et al. 2015; EEA 2019). Breeding and sowing new varieties water and heat stress tolerant (del Pozo et al. 2016, 2019; Hatfield and Dold 2019), adapting the crop calendar (Ronco et al. 2017), using optimal crop diversification (Lin 2011) could be all used as adaptation strategies. The inclusion or reintroduction of wild food plants, neglected and underutilized crops, also add to diversifying the agricultural portfolio of crops with potential resilience against climate change. North-south differences were estimated for the adaptive capacity in agriculture (Grasso and Feola 2012), mainly associated with soft factors (e.g., information) rather than with other more structural ones (such as technological and infrastructural perspective). Looking at the implemented adaptation strategies in the Mediterranean (Harmanny and Malek 2019), the most common ones are farming practices (diversify and change crop types, adjust crop rotation), water management (modify irrigation practices), and farm management (diversify source of income). The main drivers of such adaptation actions are water scarcity, environmental factors (climate change, soil degradation and erosion, sustainability), and socio-economic factors (Harmanny and Malek 2019).

Combining several actions can also lead to better results in terms of crop yield. Higher wheat yield under different water conditions in Lebanon were achieved by using a drought-tolerant variety, conservation tillage and precise irrigation during grain filling[19]. A higher degree of diversification, more varieties of the main crops, earlier sowing, and hedgerow planting were also identified as actions to increase the resilience in a pilot farm project in southern France[20]. Crop productivity (vines, corn, apples, lucerne) was increased using different agronomical practices to increase water availability by plants without increase water from irrigation in Spain[21]. Some strategies have also additional indirect benefits, such as soil organic carbon accrual due to agroforestry (Chatterjee et al. 2018), cover crops (Aguilera et al. 2013b; Vicente-Vicente et al. 2016), and local crop varieties with a higher residue and root biomass production (Carranza-Gallego et al. 2018) *(Section 6.4).* Improved soil erosion control, increasing soil fertility, retaining soil moisture and resource efficiency are the dominant drivers for conservation agriculture, organic farming and agroforestry (Lagacherie et al. 2018). Conservation agriculture represents a relatively widely adopted management system that aims to sustain long-term crop productivity and system's sustainability (Kassam et al. 2012). The environmental and economic benefits of no-till implemented as its core principle combined with other practices have been pointed out in several studies (Peigné et al. 2007, 2015; Cooper et al. 2016; Vincent-Caboud et al. 2017). The use of sectorial climate services (Buontempo et al. 2020; Ceglar et al. 2020) at different spatio-temporal scales will also be a key adaptation measure to reduce the risks and alleviate the impacts of extreme events.

Advanced agricultural technologies may also influence the ability of the region to produce food (Asseng et al. 2019) and adapt to the changing climate and environment. Precision agriculture will make possible a targeted monitoring of plant growth and thus a more efficient use of resources (water, pesticides, nutrients) by combining technologies for data collection (e.g., in-field sensors, weather stations, imaging) with analytical tools, computer vision and artificial intelligence technologies (Bhakta et al. 2019). Precision agriculture has been already applied by some Mediterranean countries (e.g., Israel, Italy, Spain), in viticulture and other crops, and holds a significant technological innovation potential. At the same time, bio and nanotechnologies may help to ensure food security and increase productivity (King et al. 2018; Santeramo et al. 2018a). Cultured, plant-based and insect-based meat are emerging technologies for producing alternatives to meat-

[19] Results from the SWIM-project ACLIMAS, www.aclimas.eu

[20] Results from the LIFE-project AGRI-ADAPT, www.agriadapt.eu

[21] Results from the LIFE-project MEDACC, http://medacc-life.eu/

derived proteins whose demand is growing. High costs and consumer reluctance appear to be be major obstacles to the implementation of these techniques (Santeramo et al. 2018a; Gómez-Luciano et al. 2019).

3.2.3.2 Mitigation of climate change drivers

Mediterranean climatic conditions host two main crop production systems, rain-fed and irrigated, largely differing in terms of management and, consequently, emissions of N_2O, a potent greenhouse gas. Rain-fed systems are usually characterized by periods with low soil moisture and cold temperatures, thus with decreased soil micro-biological activity and N_2O fluxes. Recent reviews have shown that N_2O emission factors (EF) from rain-fed Mediterranean cropping systems are much lower than the IPCC-default EF threshold of 1% (Aguilera et al. 2013b; Cayuela et al. 2017). Rain-fed crops in Mediterranean regions have lower EFs (EF: 0.27%) than irrigated crops (EF: 0.63%). Irrigated systems usually receive large amounts of water and nitrogen inputs, which create favorable soil conditions for N_2O emissions. Emission factors in these systems fluctuate greatly according to water management and the type and amount of fertilizer used (e.g., synthetic, solid or liquid manures). Sprinkler irrigated crops lead to N_2O emission factor of 0.91%; whereas, drip irrigated systems emit at a lower rate (EF:0.51%) (Cayuela et al. 2017).

Among the most relevant mitigation strategies, there are: nitrogen fertilization optimization; improved water management; better storage of soil organic carbon and carbon sequestration in soil and perennial wood structures of woody crops; management of crop residues and agroindustry by-products.

Nitrogen fertilization optimization

Optimized nitrogen fertilizer application (in terms of input rate and time of application), as well as the careful selection of the type of fertilizer used are crucial to improve crop productivity while reducing N_2O emissions (Sanz-Cobena et al. 2017). An additional effect could be achieved by applying already existing nitrogen (organic fertilizer) when possible or with the use of nitrification and urease inhibitors. Reduction of nitrogen application rates according to soil nitrogen availability and crop yield potential may decrease nitrogen surpluses and subsequent direct and indirect N_2O emissions, while saving energy and abating other greenhouse gas emissions (e.g., associated to manufacturing synthetic fertilizers). Significant effects of nitrogen application timing on N_2O emissions have been reported from cereal crops in Mediterranean countries such as Spain (Abalos et al. 2016). The estimated N_2O mitigation potential, through adjusted fertilization (rate and timing) in Mediterranean agro-ecosystems ranges between 30% and 50% compared to non-adjusted practices. Replacing mineral nitrogen with organic fertilization provides not only nitrogen, phosphorus, potassium (NPK) and micronutrients to the soil and crop, but also organic carbon when using solid fertilizers (i.e., solid manure, composts, etc.), which is highly beneficial in Mediterranean soils with low organic carbon contents (Aguilera et al. 2013a; Funes et al. 2019).

In areas were croplands co-exist with livestock farms, using a farm sub-product allows the reuse/recovery of farm products, thus decreasing the volume of waste that needs to be managed, and then avoiding the emission of greenhouse gases both in the management of such wastes and in the manufacturing of new synthetic fertilizers. In Mediterranean areas, the efficient use of manure of fertilizer should be encouraged, and this could be facilitated by increased cooperation between farmers´ unions. The use of organic sources of fertilizers may also decrease the need to import synthetic sources thus decreasing greenhouse gas emissions from the production and transport stages. Unfortunately, current intensive livestock production systems are often decoupled from agricultural systems (Sanz-Cobena et al. 2017).

The N_2O emission reduction at plot scale depends on the form of manure used. Solid manures have proved to significantly decrease N_2O emissions (ca. 23%) in Mediterranean systems (Aguilera et al. 2013b), although there is some contradictory information in the scientific literature (Webb et al. 2004; Thorman et al. 2007). For liquid manures (i.e., slurries), no significant differences have been observed when these substitute synthetic nitrogen sources. This seems to be a consequence of the strong similarities between available nitrogen, in the form of NH_4^+, in both fertilizer types (Meijide et al. 2009; Plaza-Bonilla et al. 2014).

Trade-offs in the form of NH_3 emissions, odors, enhanced denitrification rates due to coexistence of high soil water contents and organic carbon suitable for denitrifiers, must be considered together with the application technology used to fertilize with liquid manures. Nitrification and urease inhibitors (NI) are used in a wide range of agro-climatic regions (Akiyama et al. 2010; Gilsanz et al. 2016). In Mediterranean soils, NIs have shown high mitigation efficiency in rain-fed and irrigated fields, with a likely indirect effect on denitrification in the latter systems (Meijide et al. 2010). Soil texture may regulate mitigation efficiency (Barth et al. 2008) but to a limited extent, since soil texture has been shown to have a small influence on the inhibition of nitrification (Gilsanz et al. 2016).

Improved water management

The different soil conditions between irrigated and rain-fed crops affect soil microbial processes, which control the fluxes of carbon (carbon dioxide, CO_2; methane, CH_4; organic carbon) and nitrogen (nitrous oxide, N_2O; molecular nitrogen, N_2; nitrate, NO_3; ammonia, NH_3). Soil moisture is a key factor affecting N_2O losses (del Prado et al. 2006; García-Marco et al. 2014), hence the potential for N_2O mitigation linked to irrigation technologies is high, even above 50% (Sánchez-Martín et al. 2008, 2010; Guardia et al. 2016). The lower amounts of water applied in subsurface drip irrigation (SDI) or normal/superficial drip irrigation (DI) through more frequent irrigation events, generate "dry" and "wet" areas in the soil, lowering the overall soil moisture and favoring nitrification over denitrification (Sánchez-Martín et al. 2010), thus reducing N_2O emissions. Drip irrigation systems have shown an N_2O emission factor of only 0.18%, compared to 1% in sprinkler systems (SI), showing the mitigation potential of irrigation technologies in the Mediterranean region (Cayuela et al. 2017). Optimized irrigation techniques to decrease greenhouse gas emissions from Mediterranean regions are particularly used in perennial crops and intensive vegetable cropping systems and in paddy soils (water table management). Other strategies which have been shown to be effective increasing nitrogen use efficiency and reducing N_2O emissions are fertigation and sub-surface drip irrigation (Ayars et al. 2015).

Soil improvement

Most Mediterranean agricultural landscapes are subject to soil organic matter depletion, particularly in the southern and eastern parts of the basin (Ryan et al. 2006). In the northern part of the basin, the issue of low soil organic matter (SOM) is of particular concern for perennial systems such as orchards and vineyards (Meersmans et al. 2012). Maetens et al. (2012) showed that bare soils, vineyards and orchards in Europe are prone to high mean soil losses (10-20 t ha^{-1} yr^{-1}), while cropland and fallow show smaller values (6.5 and 5.8 t ha^{-1} y^{-1}) largely because the latter occupy land exhibiting little or no slope. SOM in the Mediterranean countries is somewhat affected by climate change, with land use types such as permanent pasture and cropland being more sensitive than forests (Fantappié et al. 2011). Large losses of SOM may also be caused by erosion caused by the torrential storms that frequently occur in Mediterranean regions (Lagacherie et al. 2018). Likewise, rainfall shortage limits net primary productivity and, in turn, soil carbon buildup. Low carbon inputs driven by limited soil moisture availability are exacerbated by the adoption of certain management practices. Crop residues competition for livestock feeding or the introduction of long fallowing in the crop rotation are two examples of typical management practices in the Mediterranean region that have contributed to the reduction of carbon inputs returned into the soil.

Besides decreases in carbon inputs, agricultural management may also cause soil organic carbon (SOC) losses. Reduction or complete cessation of tillage decreases the direct incorporation of fresh organic debris into deeper soil layers. The absence of tillage (NT) slows down aggregate turnover and increases the physical stabilization of SOC within soil aggregates (Álvaro-Fuentes et al. 2008; Mrabet 2008; Plaza-Bonilla et al. 2010). When tillage is avoided, an approximate annual increase of 1% in SOC can be observed in Mediterranean croplands (Aguilera et al. 2013a). These estimates are highly dependent on soil depth, since vertical SOC distribution in no tillage (NT) and conventional tillage (CT) systems are different (Cantero-Martínez et al. 2007). Further, the assumption of a steady and linear C sequestration may not hold true, because the annual carbon accumulation rate tends to decrease in the long-term (Álvaro-Fuentes et al. 2014).

Long crop rotations have been proposed in rain-fed Mediterranean systems to enhance carbon sequestration and restore soil fertility and structure (Benlhabib et al. 2014). The effect of crop rotations on carbon sequestration is highly dependent on time with no significant effect reported in short-term studies (Saber and Mrabet 2002; López-Bellido et al. 2010). Positive effects in long-term experiments (>15 years) could appear if crop biomass is properly managed after harvest (Masri and Ryan 2006; López-Bellido et al. 2010; Martiniello and Teixeira da Silva 2011). The effect of crop rotations on SOC stocks is also dependent on the type of crops included in the rotation (Triberti et al. 2016) and the management of crop residues. The introduction of perennial crops has shown benefits (di Bene et al. 2011; Pellegrino et al. 2011). The substitution of bare fallows by any crop has been associated with SOC stabilization in NT systems (Álvaro-Fuentes et al. 2009), and to reduced soil erosion (Boellstorff and Benito 2005). The effect of inclusion of grain legumes in rain-fed yearly rotations on carbon sequestration is uncertain, due to their low biomass production, although their conversion to stabilized soil organic matter could be more efficient than that of cereals (Carranca et al. 2009). Consequently, the highest potential of fallow and legumes for mitigating greenhouse gases from these types of cropping systems comes from the avoidance of fertilizer production emissions.

Estimating the greenhouse gas mitigation potential of using crop residues and organic by-products from agroindustry in Mediterranean areas implies accounting for: (i) soil amendments to improve SOM and enhance SOC sequestration (Aguilera et al. 2013a), (ii) feedstock for bioenergy production (di Giacomo and Taglieri 2009; Spinelli and Picchi 2010), (iii) co-substrate for composting (Santos et al. 2016), (iv) feed for livestock (Molina-Alcaide and Yáñez-Ruiz 2008) or (v) construction materials (e.g., animal beds, buildings). The potential to increase SOC levels by using agroindustry by-products, as in crop residues, depends on their composition and degradability. However, agroindustry by-products vary widely in their chemical composition and therefore in their degradation rates. For example, olive and mill waste as they have very low degradation rate in the soil have been found to be good amendments to increase SOC when applied to the soil (Saviozzi et al. 2001).

Besides the potential direct greenhouse gas reduction that any strategy involving the return of the crop residues and agroindustry by-products to the soil may cause (Kassam et al. 2012; Plaza-Bonilla et al. 2014), applying these materials, treated or untreated, as soil amendments can also deliver environmental co-benefits. These benefits include erosion reduction when raw products are used for mulching (Blavet et al. 2009; Jordán et al. 2010) or, in general, the closing the nutrient cycles, with associated potential reductions of fertilizer use and reductions in draught force and fuel consumption for soil tillage (Peltre et al. 2015). Trade-offs may occur with some of the strategies that may results in larger greenhouse gas mitigation potential. For example, the use of crop residues on the soil surface might pose a risk of fire in some Mediterranean areas and, sanitary, pollution and legal constraints may apply, especially if the by-product is applied to crops e.g., fresh vegetables without pre-treatment.

3.2.3.3 Synergies and trade-offs between adaptation and mitigation

Developing sectorial adaptation strategies requires considering also the mitigation needs and efforts (Sanz-Cobena et al. 2017). For N_2O mitigation and its links with adaptation measures, the pedoclimatic conditions for soil processes in Mediterranean cropping systems imply different N_2O emission patterns as compared to temperate soils (Aguilera et al. 2013b). Nitrification and nitrifier-denitrification, and not denitrification, are very often the main pathways leading to emissions of nitrogen oxides in rain-fed Mediterranean cropping systems (Sánchez-Martín et al. 2008; Kool et al. 2011; Aguilera et al. 2013b; Norton and Ouyang 2019). These two processes are favored by conditions of soil water content (i.e., water filled pore space, WFPS) under saturation (i.e., 40–60% WFPS). Denitrification may play a predominant role in anaerobic soil microsites in intensively managed and irrigated systems (Sanz-Cobena et al. 2012, 2014). Consequently, different cumulative N_2O emissions have been proposed for rainfed crops (0.7 kg N_2O-N ha^{-1} yr^{-1}) and for e.g., sprinkler irrigated crops in Mediterranean areas (4.4 kg N_2O-N ha^{-1} yr^{-1}) (Cayuela et al. 2017).

The importance and potential for N_2O mitigation and the best mitigation strategy differ greatly depending on the cropping system, being highly affected by adaptation strategies regarding to soil organic carbon and water management in cropping systems. In this sense, increasing the generally low carbon content of Mediterranean soils is an important greenhouse gas mitigation strategy (Robertson et al. 2000), and is also a priority for preventing erosion and improving soil quality. Soil organic carbon content of Mediterranean soils is typically lower than in temperate areas (Chiti et al. 2012), and degradation processes are present in many areas (Lahmar and Ruellan 2007), a trend that is expected to be exacerbated by climate change in the coming decades (Al-Adamat et al. 2007). However, SOC in Mediterranean croplands is also highly responsive to management changes such as organic amendments, cover crops and tillage reductions, and there is a high potential for SOC storage through land restoration. Significant carbon sequestration rates have been observed after the application of recommended management practices and organic management in Mediterranean cropping systems (Aguilera et al. 2013a). This high responsiveness is reflected in SOC storage rates nearly one order of magnitude higher than the 0.4% annual SOC increase proposed by the "4 per 1,000" initiative, as reported in a recent meta-analysis (Chabbi et al. 2017; Minasny et al. 2017) . This meta-analysis underlined the differences between herbaceous and woody crops regarding the carbon sequestration potential and the practices to be applied in each system. Thus, organic fertilizers, tillage reduction and residue retention are effective practices in herbaceous systems. Woody systems, in which the storage potential is higher, would greatly benefit from maintaining a soil cover and making use of agro-industry byproducts, such as composted olive mill waste, as a source of organic matter (Vicente-Vicente et al. 2016).

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