

Strategies for GHG mitigation in Mediterranean cropping systems. A review

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Abstract

In this review we aimed to synthesize and analyze the most promising GHGs mitigation strategies for Mediterranean cropping systems. A description of most relevant measures, based on the best crop choice and management by farmers (i.e., agronomical practices), was firstly carried out. Many of these measures can be also efficient in other climatic regions, but here we provide particular results and discussion of their efficiencies for Mediterranean cropping systems. An integrated assessment of management practices on mitigating each component of the global warming potential (N₂O and CH₄ emissions and C sequestration) of production systems considering potential side-effects of their implementation allowed us to propose the best strategies to abate GHG emissions, while sustaining crop yields and mitigating other sources of environmental pollution (e.g. nitrate leaching and ammonia volatilization).

Key Words

Cropping systems, GHG, Mitigation, N₂O, Mediterranean climate, review.

Introduction

The Mediterranean climate is characterized by annual precipitation ranging from 275 to 900 mm. The average winter temperature is below 15°C, but the number of hours per year with temperatures below 0°C does not exceed 3% of the total. This climate presents seasonal dryness and many of its subtypes are classified as semi-arid. It is generally located on the west coasts of continents and between latitudes 32° and 42° north and south of the equator (Figure 1). Over one half of the area with Mediterranean-type climate worldwide is found in the Mediterranean Sea Basin (Aschmann, 1973), but it is also present in four other different regions of the world namely California (USA), Central Chile, the Cape region of South Africa, and South-West Australia. Pedoclimatic conditions in Mediterranean soils shape soil processes in Mediterranean cropping systems, leading to different N₂O emission patterns than in temperate soils (Aguilera et al. 2013a). Nitrification and nitrifier-denitrification, and not denitrification, are very often the main pathways leading to

emissions of N oxides in rain-fed Mediterranean cropping system (Aguilera et al., 2013b). These two processes are favored by conditions of soil water content (i.e., water filled pore space, WFPS) under saturation. Denitrification may play a predominant role in anaerobic soil microsites of intensively managed and irrigated systems (e.g., Sanz-Cobena et al., 2012). Consequently, different cumulative N₂O emission has been proposed for rain-fed crops (0.7 kg N ha⁻¹ yr⁻¹) and for e.g., sprinkler irrigated crops in Mediterranean areas (4.4 kg N ha⁻¹ yr⁻¹) (Cayuela et al., 2016). It is thus clear that the importance and potential for N₂O mitigation and the best mitigation strategy highly differ depending on the cropping system. Increasing the generally low C content of Mediterranean soils, which must be considered a GHG mitigation strategy, is one of the most important priorities to prevent erosion and improve soil quality.

Regions with a Mediterranean climate

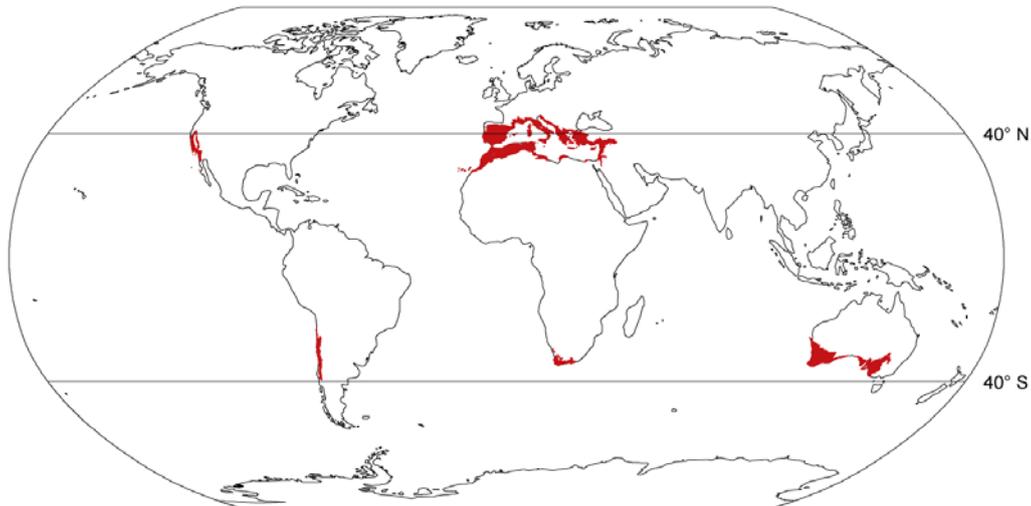


Figure 1. Regions of the world with Mediterranean climate and number of papers measuring field N₂O emissions in each region.

Methods

In this review we aimed to synthesize and analyze the most promising GHGs mitigation strategies in Mediterranean cropping systems. We herein describe measures based on the best crop choice and resources management by farmers and practices including the use of novel technological developments (e.g., urease and nitrification inhibitors and advanced irrigation technologies). We have reviewed the performance of agronomical GHG mitigation practices in Mediterranean cropping systems aiming to i) decrease soil N₂O emissions; ii) enhance CH₄ oxidation and decrease CH₄ emission rates; iii) enhance soil organic C stocks and iv) have a reducing or neutral co-effect on other sources of environmental pollution (e.g. NH₃ volatilization and NO₃⁻ leaching). The effect on the global warming potential (GWP) components of the selected strategies was analyzed to establish an order of priority. Finally, we explored the potential of structural measures at the agro-food system scale for reducing GHGs emissions: i) food waste reduction, ii) change in the composition of human diet, and iii) reconnection between crops and livestock at farm or regional scale for optimizing N use.

Results

The most promising measures enhancing C sequestration and mitigating N₂O and CH₄ emissions were selected considering the GHG balance in each specific Mediterranean agro-ecosystem (Table 1). The dominant GHG sources of each cropping system and each particular area (local pedoclimatic conditions) should be considered for prioritizing the adoption of efficient techniques, but also taking into account all practices that could provide an optimum balance between GHG mitigation and crop yields while saving/maintaining farm expenses or leading to an efficient use of available resources.

The study of Aguilera et al. (2015a) pointed out that the main GHG sources in herbaceous cropping systems in Mediterranean areas were emissions from machinery due to the low direct GHG emissions in these systems. Guardia et al. (2016), in a non-irrigated cereal-legume rotation, also confirmed that the relative weight of N₂O losses was lower than that of farm inputs and operations, while C sequestration was the main

GHG mitigation component under No-Tillage (NT) adoption. There are however some uncertainties and variability that could be attributed to the C sink (e.g., the depth considered for calculation, the decrease of annual sequestration rate in the long term) (Álvaro-Fuentes et al., 2014), it appears that practices such as NT/Reduced-Tillage combined with crop rotations including legumes combined with crop rotations including legumes and cover crops, without removing of crop residues, are the most promising for minimizing fuel consumption and external inputs (e.g. conservation agriculture practices, as conventional ones, might rely on the use of pesticides), and promote C sequestration. These practices may provide the best GHG balance in rain-fed Mediterranean herbaceous crops, without negative side-effects on crop yields or N losses. Adjusting N fertilization rates to crop needs may improve the GHG balance of rain-fed herbaceous cropping systems through two components (N₂O emissions and CO₂ equivalents from production and transport of fertilizers) while reducing farm expenses, so this practice must be encouraged in Mediterranean areas.

In summer irrigated crops, conditions are propitious for high N₂O losses (Aguilera et al., 2013b). Consequently, agricultural practices based on an improved management of irrigation water (e.g., drip irrigation), N fertilization (e.g., adjusting N rates and timing, use of nitrification inhibitors) and both (e.g., fertigation) are the most promising measures in these agro-ecosystems. Since fruit orchards are broadly characterized by efficient water and fertilizer use (e.g., drip irrigation and drip-fertigation), other promising techniques are cover cropping (thus minimizing fuel consumption) and pruning residues management for enhancing C stocks (Aguilera et al., 2015a). Methane emissions are the main component on GWP in paddy fields (Aguilera et al., 2015b), so mitigation efforts should focus on water management for minimizing these losses. Reducing water consumption in vegetable cropping systems may lead to substantial GHG reductions (Aguilera et al., 2015a).

Table 1. Main component and mitigation practices associated of each cropping system in Mediterranean areas

Crop type	Main component of the GWP		Main mitigation practice		Other pollutants	
	<i>Rain-fed</i>	<i>Irrigated</i>	<i>Rain-fed</i>	<i>Irrigated</i>	<i>Rain-fed</i>	<i>Irrigated</i>
Herbaceous	Machinery/external inputs; C seq. (NT)	N ₂ O	Reducing fuel consumption and external inputs, reduced tillage, crop rotations (including legumes), adjusted N rates, NIs	Water management (e.g. drip irrigation), N fertilization (e.g. adjusted N rates, Nis*)	Increased NH ₃	Increased NH ₃ , NO ₃ ⁻
Fruit orchards	C sequestration	N ₂ O	NA	Cover crops, pruning crop residues	NA	NA
Rice	NA	CH ₄	NA	Water management	NA	Increased N ₂ O

*Nitrification inhibitors

Management practices aiming at optimizing N fertilization and irrigation show a large potential for N₂O mitigation from Mediterranean crops. Adjusting N fertilization to crop needs is a sound and feasible practice in both irrigated and rain-fed systems and presents an N₂O mitigation potential up to 50% compared with a non-adjusted practice. Substitution of N synthetic fertilizers by solid manure can be implemented in both irrigated and rain-fed systems, and may abate N₂O emissions by about 20% under Mediterranean conditions, besides the indirect mitigation potential due to energy savings and the observed positive effects in crop yields. Substituting synthetic fertilizers by slurries does not lead to N₂O reductions and had drawbacks in crop yields. The use of urease and nitrification inhibitors enhances nitrogen use efficiency of the cropping

systems and may mitigate N₂O emissions up to 80% and 50%, respectively. Inhibitors can be used with both organic and synthetic fertilization but implies a higher fertilization cost.

Irrigation technology in the Mediterranean areas is a key driving factor on N₂O emissions. The mitigation potential of some irrigation systems in the Mediterranean region can be very high for some crops. Drip-irrigated systems have on average 80 % less N₂O emissions than sprinkler systems and drip-irrigation combined with optimized fertilization showed a reduction in direct N₂O emissions up to 50%. However, our analysis of the total life cycle emissions (including infrastructure production, electricity production, fertilizer production, and direct and indirect N₂O emissions) associated to irrigation and N fertilization revealed that all these factors beyond the plot scale may outweigh the reduction in N₂O emissions in some cases. The most suitable agronomical practices for potentially enhancing carbon stocks in Mediterranean soils are reduced soil tillage and a proper management of crop residues and by-products of the agroindustry. In all cases, significant effects on C sequestration have been observed in long term experiments, averaging 0.43 Mg C ha⁻¹ yr⁻¹. Although assessments are needed due to specificities of these practices affecting GHG fluxes, they are extensible to irrigated and rain-fed systems and, in general, present economic opportunities for farmers due to savings in resources and increased crop yields.

We identified three structural measures with large potential to mitigate GHG emissions beyond the plot scale: i) food waste reduction, ii) change in the composition of human diet, particularly in the proportion of animal products, and iii) reconnection between crop and livestock farming at exploitation or regional scale to optimize the reuse of nutrients in animal manure. Between 3 and 15% of N₂O emissions could be suppressed by avoiding food waste at the consumer level. A reduction of 40% of meat and dairy consumption would reduce GHG by 20 to 30%. The reintroduction of the Mediterranean diet (i.e., a back reduction to ~35% of animal protein) would therefore result in a decrease of GHG emissions from agriculture. All these changes strongly depend on individual choices, so for its implementation it would be necessary to better understand the drivers that would lead to its accomplishment (social barriers and incentives for the behavior change) through a further multidisciplinary work.

Conclusion

The results of this review indicate that GHG mitigation in the Mediterranean climate areas requires a specific approach that is different from temperate regions due to particular pedoclimatic and agronomical conditions. Hydrological regime is playing a key role in rain-fed as in irrigated systems principally to define the contribution of N₂O to the total GHG emissions. Efficient implementation will require an integrative approach that considers co-benefits or trade-offs for yields and pollution swapping that are specific for semi-arid regions.

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