Long term agro-ecosystem observatories in the Mediterranean

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Introduction

Alleviating the impacts of climate change is a major challenge facing agriculture in the near future. It is however not the sole challenge, since agriculture is experiencing many other pressures, including a 30 percent increase in global world population, changing dietary patterns and intensifying competition for increasingly scarce land, water and energy resources. In the Mediterranean area, all these challenges are at a very high level since this region already faces a shortage in natural resources and food production and is a hotspot for biodiversity, climate change and population growth.

The adaptation and transformation of Mediterranean agriculture will therefore be necessary for improving productivity and ensuring better management and protection of water and soil resources. To this end, the prerequisites are to identify how both Mediterranean farming systems and climate change will impact soil and water resources over the long term and, in turn, to detect potential levers in agricultural and land management that can alleviate these impacts and favour resilience to climate change.

There are several difficulties involved. First, the nature of the impacts: whether permanent and gradual, or rare and sudden, they are difficult to identify or observe without knowing the base line of the processes. Second, the natural variability of climate and soil often blurs the specific impacts of climate change and agricultural management. Third, the large number of driving factors for water and soil resources makes it difficult to distinguish those that are essential to consider. Finally, there is a need to integrate processes at different scales, e.g. plot, field, catchment and landscape scales. Accordingly, documenting and identifying environmental impacts requires long-term field observations across several scales in order to sort out the processes at different time scales and to different spatial extents. Observations of environmental processes must also be coupled with observations of their human or natural driving factors.

Long term environmental observations can be obtained from natural archives such as ice covers or lake sediments, which enable environmental changes over the millennia to be examined. But archives are not available for all scientific purposes and long-term observatories are therefore needed. According to Loireau et al. (2014), their general objectives are to i) monitor environmental processes, ii) understand the processes at stake and iii) disseminate information. For those observatories that intend to address social issues, the additional objectives are to iv) provide a diagnostic of management options and v) advise managers on new orientations.

In this subchapter we first recall some milestones of long-term environmental observatories. We then present the objectives and main features of the "OMERE" observatories and illustrate with collected datasets the potential contributions of agro-hydrological observatories to better land management in the context of global change; finally, we advocate for intensifying long-term environmental observations in the Mediterranean region.

The development of long term observatories

One of the earliest examples of a long-term observatory is the long-term agricultural research experiment that started in 1843 at the Rothamsted experimental station in England and enabled the effects of different nitrogen fertilizations on crop growth to be analysed. Other thematically focused observatories set up later include, for example, those monitoring the impact of forest land management on water yield and quality, and floods (e.g. the Hubbard

Brook experimental forest in the US in 1955, Plynlimon in the UK in 1967). A broader thematic initiative took place in 1980 with the US Long-Term Ecological Research program (LTER) which now comprises 26 sites (Robertson et al. 2012), and led in 1993 to the foundation of the international LTER (ILTER), now joined by 43 countries.

In France, it is mainly since 2001 that long-term environmental observatories have become popular (Balland et al. 2001). In fact, at that time, atmospheric and oceanographic sciences and seismology had already set up dedicated long-term observatories, but the call for Environmental Research Observatories (ORE) launched in 2002 by the French Ministry of Research extended the concept to all environmental sciences. Thanks to this call, the long-term agro-hydrological observatories OMERE (Voltz and Albergel, 2002) were set up in 2003. In 2011, OMERE took part in the creation of the French network of drainage basins RBV (portailrbv.sedoo.fr). Other examples of observatories are the TERENO Network launched in Germany in 2008 and the Long Term Agro-ecosystem Research network (LTAR) launched in the US in 2011 (Walbridge and Shafer, 2011).

However, concerning the Mediterranean region, long-term environmental observatories are dramatically lacking. This is especially so for agricultural ecosystems. So far, at the landscape or regional scales, only three Mediterranean agricultural observatories are registered in the ILTER sites map (data.lter-europe.net/deims/global-sites-map), two of them being the OMERE observatories.

The OMERE Observatories

OMERE (in French “Observatoire Méditerranéen de l’Environnement Rural et de l’Eau”) focuses on the observation of the agri-environmental impacts of soil and water management in typical Mediterranean agro-systems (Voltz and Albergel, 2002). Its specific objectives are to:

i) create records of long term observations of the states and fluxes of soil and water resources as related to records of agricultural management practices in Mediterranean head-water catchments,

ii) study the impact of climate and land use change on water flow, erosion processes and soil-vegetation-atmosphere interactions,

iii) identify the main mechanisms governing long term quantitative and qualitative changes in water and soil resources from field to catchment scale,

iv) support the development of generic agro-hydrological distributed modelling approaches for designing new sustainable management practices,

v) identify levers and methods for a sustainable agricultural management and improved delivery of ecosystem services by Mediterranean agro-systems.

Figure 1
Location of the OMERE catchments.

OMERE consists of two catchments that are similar with respect to climatic conditions, but differ according to land-use (see Fig. 1). The Kamech catchment (263 ha), located on the Cap Bon peninsula in Tunisia, represents present trends in land use change in the southern Mediterranean, i.e. a progressive intensification of agriculture with full use of the area available for agriculture and an increasing application of fertilizers and pesticides. In the Roujan catchment (92 ha) located in southern France, intensification of agriculture has been present for a few decades, leading to severe water pollution, and land abandonment is now a problem. Monitoring started in 1994 for Kamech and in 1992 for Roujan and includes atmospheric inputs, surface flow, groundwater fluctuations, evaporation fluxes, land management practices, solute and erosion fluxes. More details on OMERE can be found on its web site (http://www.obs-omere.org).

Examples of outputs from OMERE observation records

Impact of climate variability on catchment runoff

Mediterranean headwater catchments provide water for lowland irrigated agriculture and for the coastal population. Changes in the amount of water that the catchments deliver may severely affect down-slope areas and populations. Figure 2 shows the relationships between rainfall and runoff that emerges from the time series recorded in the OMERE catchments since 1993. During that period, the two catchments received very similar annual rainfall amounts (medians of 634 and 637 mm/year^{-1} for Roujan and Kamech, respectively), with very large inter-annual variability. For large and medium annual rainfall amounts, runoff is decreasing in line with decreasing rainfall. The runoff decrease is slightly larger than half of the rainfall decrease. Below a threshold of annual rainfall, no runoff is observed anymore, which occurs 1 out of 4 years in Roujan and 1 out of 10 years in Kamech. It can be anticipated that no runoff will occur during 50% of the years with a 17% and 30% decrease of rainfall in Roujan and Kamech, respectively. These precipitation changes are in accordance with the AR5 IPCC predictions for 2081-2100 under the RCP8.5 scenario: 10-20% decrease in the Roujan area and 20-30% decrease in the Kamech area (IPCC, 2013). An important change in headwater catchment runoff can thus be expected at the end of this century.

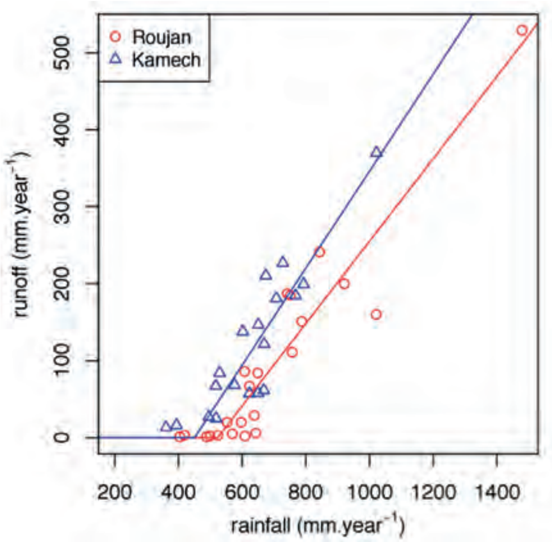

Figure 2
Rainfall-runoff relationships in the OMERE Catchments.
The figure covers the periods 1993-2015 in Roujan (France) and 1995-2013 in Kamech (Tunisia).

The potential of agricultural management for alleviating the impact of droughts

Agricultural land use has also a large impact on runoff. Rainfall is evidently a major driver of runoff, as can be seen in Figure 2, but a large spread of runoff is observed for a given annual rainfall amount. This can be attributed to differences in the intensity and temporal distribution of rainfall events between years, but also to changes in agriculture practices and catchment management. OMERE provides observations that allow for the quantification of the specific effects of agricultural management on water resources. Figure 3 shows the variability in land uses that exists in the Kamech catchment (Fig. 3a) and the correlated variation in surface runoff between the land uses (Fig. 3b) (Mekki et al. 2006). The annual amounts of surface runoff vary six-fold according to land use. A similar observation was made on the Roujan catchment, where vineyards exhibit twice as much runoff when tillage is replaced by both no-tillage and chemical weeding that favour permanent soil crusting (Andrieux et al. 1998). Accordingly, the influence of land use and management on catchment runoff is even larger than the one expected from climate change, as estimated above. The choice of land use and of management practices therefore appears to be a main lever for controlling catchment runoff and alleviating, at least in part, the expected impact of increasing droughts. Research is now needed to determine how the spatial mosaics of land use can be optimized to meet both the requirements of rainfed agriculture and water harvesting for irrigation needs. Data collected at the landscape scale by observatories like OMERE may then serve as benchmarks for exploratory simulation approaches.

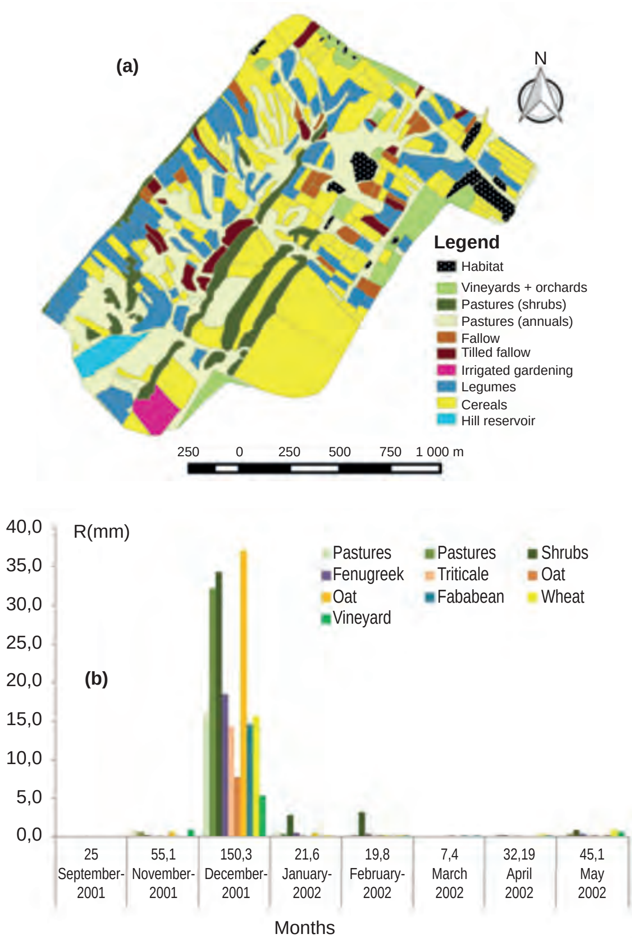

Figure 3
a) Land use map in Kamech, Tunisia and b) variation of monthly runoff amounts R (mm) for different crops from September 2001 to May 2002 (after Mekki et al. 2006). Numbers on the x-axis labels of b) indicate monthly rainfall amounts (mm).

Hydrological infrastructures as means for soil and water conservation

In Mediterranean cultivated landscapes, small dams are often used both for protecting downstream areas from flooding and silting and for harvesting water. Stored water enables the temporal shift to be managed between drought periods, usually during spring and summer, and rainy periods, during fall and winter. Dams are therefore levers for agriculture adaptation to climate variability. With a current capacity of 93,000 m^3, the water stored at the Kamech small dam is equivalent to 35 mm of rainfall over the whole catchment, corresponding roughly to one tenth of crop water needs. However, all stored water is not necessarily available for agricultural use due to losses, especially infiltration losses that are still poorly quantified. The detailed monitoring of hydrological fluxes in OMERE has led to insights into the rate, variability and control factors of this process. The water balance of the Kamech dam (Fig. 4) reveals that infiltration of stored water is in fact a major loss, two to five times larger than evaporation (Bouteffeha et al. 2015). From a local point of view, infiltration may thus jeopardize the small irrigated area around the water reservoir. However, infiltration may also recharge the regional aquifer and thus increase groundwater resources. Small dam networks constitute a moderate but real water resource for crops. Their actual impacts on water resources must be considered at both local and regional levels. This requires an integrated analysis that can be performed with agro-hydrological models calibrated on reliable hydrological records, as those provided by permanent observatories.

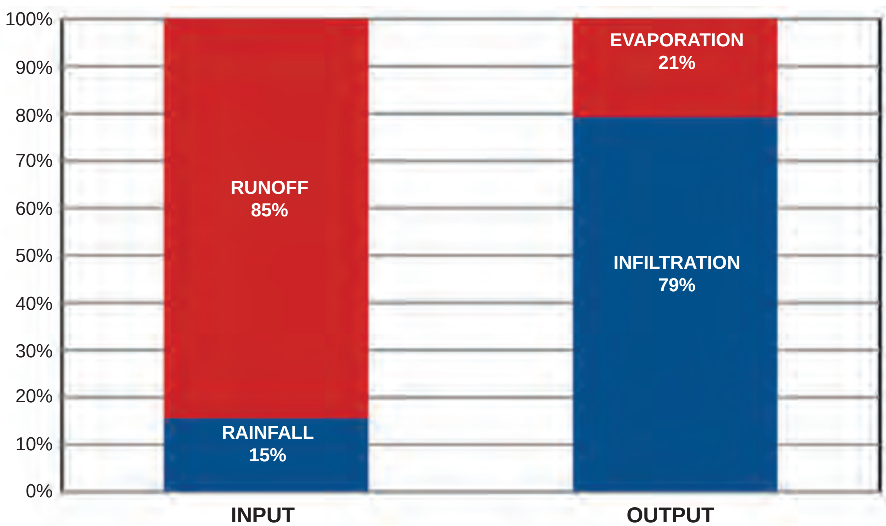

Figure 4
Terms of dam water balance for the hydrologic year 2010/2011 in Kamech, Tunisia. Note that i) runoff corresponds here to the amount of surface water exiting the uphill catchment and entering the dam reservoir and ii) no outflow from the reservoir was observed during the observation period.

Conclusion: advocating a long-term agro-ecosystem research network in the Mediterranean

Long-term observations deliver important records that not only help to improve our understanding of agro-ecosystem functioning but also provide quantitative references for sustainable land management. OMERE was one of the first observatories in the Mediterranean area developed to collect long-term observations of agricultural systems at the landscape and catchment scales. More observatories are clearly necessary since the two OMERE catchments represent only partly the diversity of ecological and agricultural systems in the Mediterranean. Moreover, the OMERE observatories are mainly focused on agro-hydrological issues, while other data concerning soil carbon sequestration, green house gas emissions or biodiversity conservation are also needed to address the agriculture and climate change challenges in the Mediterranean.

The development of a network of long-term agro-ecosystem observatories is therefore highly desirable. It would enable the study of a large range of Mediterranean agro-ecosystems, thereby comparing records and processes and analysing their representativeness and variation. It would also enable a large range of issues for the future management of agro-ecosystems to be addressed and favour transdisciplinary research. It requires however that the concepts and needs of long term environmental observatories spread across countries. This depends on the commitment of scientists from different disciplines and institutes.

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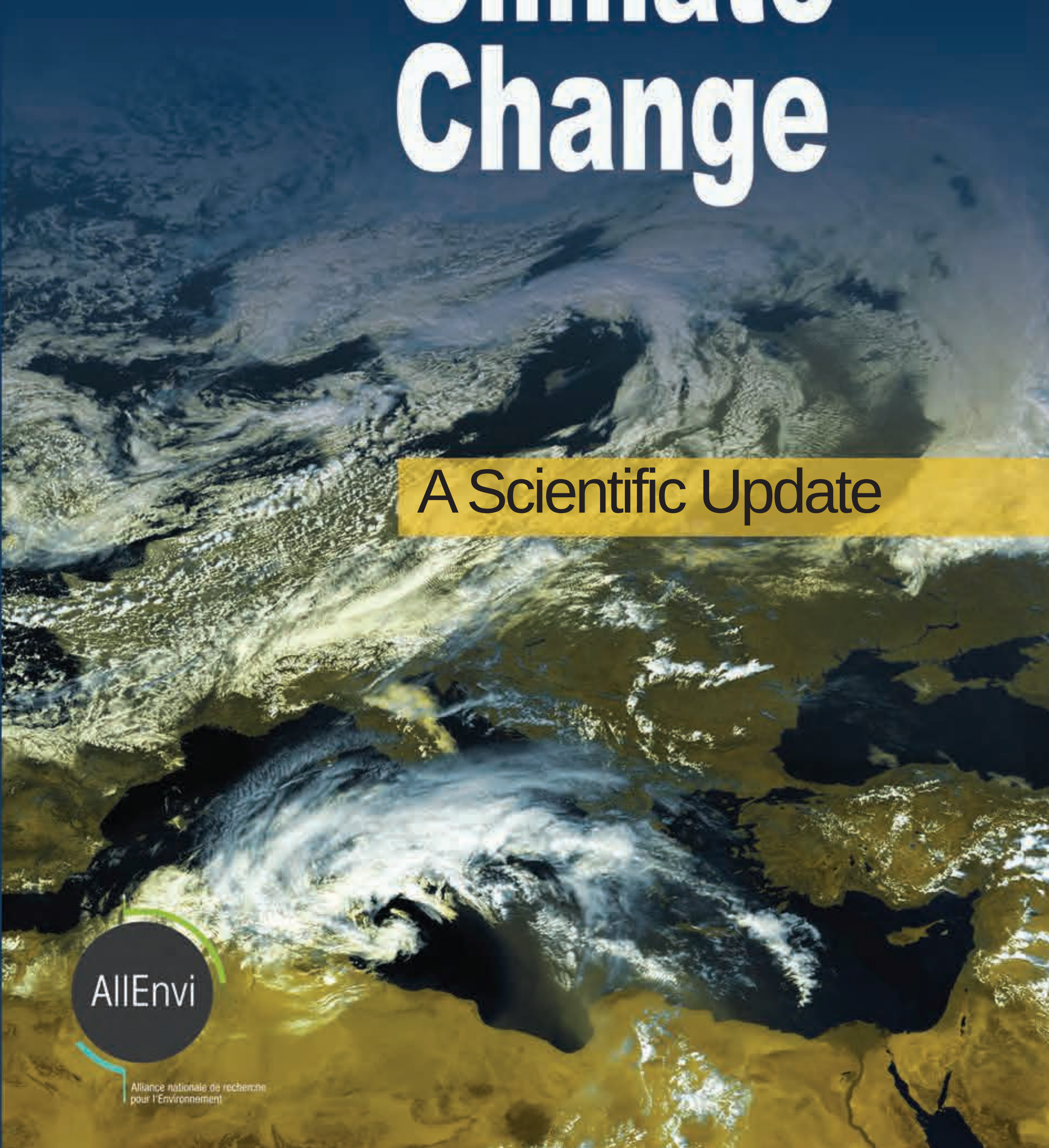
The Mediterranean Region under Climate Change

A Scientific Update



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