Sub-chapter 3.5.2

Soils and desertification in the Mediterranean region

Houcine KHATTELI
IRA, Tunisia

Rafat RAMADAN ALI
Soils and Water Use Department, National Research Centre, Egypt

Gilles BERGAMETTI
IPSL, CNRS, France

Christel BOUET
IPSL, IRD, France,

Mohamed HACHICHA
IRNGREF, Tunisia

Belhadj HAMDI-AISSA
University of Ouargla, Algeria

Mohamed LABIADH
IRA, Tunisia.

Jean-Pierre MONTOROI
IRD, France

Pascal PODWOJEWSKI
IRA, Tunisia/IRD, France

Jean-Louis RAJOT
IRA, Tunisia/IRD, France

Alaa MOHAAMED ZAGHLOUL
Soils and Water Use Department, National Research Centre, Egypt

Christian VALENTIN
IRD, France

Introduction

The Mediterranean region – and more specifically North Africa – have been subject to climate change throughout the period 1860-2005 (Mariotti et al. 2015). Simulations predict an average rise in annual temperatures of more than 2°C with more intense heat waves. Precipitation is projected to decrease compared to 1980–2005 especially in Spain, Morocco, Tunisia and parts of the Middle East region. This is expected to modify soil temperature and soil water content, and consequently pedoclimate. Desertification processes can increase not only due to climate change and population growth but also as a result of ever more pronounced edaphic aridification processes (Floret and Pontanier, 1984).

In the Mediterranean zone, soils are usually much shallower than in the humid tropics and the temperate zone where pedogenesis is faster and erosion less ancient. In some part of the Mediterranean region, accelerated erosion was initiated several thousands of years ago (Butzer, 2005). Shallow soils with low nutrients and water storage capacity are a major constraint to natural vegetation and crop cover, which in turn affords a weak protection to soils from water and wind erosion.

The objective of this paper is to present a short review of (i) the main soil degradation (i.e. desertification) processes in the Mediterranean zone including water, wind and tillage erosion, and salinization; (ii) some soil management principles to combat land degradation and favour soil rehabilitation.

Main processes and factors of desertification: surface crusting, runoff and water erosion

Due to water scarcity, which limits biomass production, the soil organic matter of arid and semi-arid zones remains low, especially in sandy soils. As a result, exposed layers have low structural stability and physical crusts develop rapidly even under low quantity of rainfall (Valentin and Bresson, 1992). These crusts reduce infiltration and favour runoff (Podwojewski et al. 2011) even when these physical crusts are colonized by cyanobacteriae (Malam Issa et al. 2011). They also tend to promote sheet erosion and gully erosion downhill (Valentin et al. 2005). These crusts can be destroyed by trampling and tillage (Bertrand et al. 2014) but form again rapidly under rainfall.

Tillage erosion

Tillage erosion is the downslope displacement of soil through tillage. It mainly affects steep and convex slopes (Kosmas et al. 2001) and is often expressed by lighter-coloured soils than adjacent downhill soils (Photo 1). Due to the often steep cultivated slopes in the Mediterranean region, soil loss rates due to tillage erosion cannot be neglected (Benmansour et al. 2013) especially where tillage started a few thousand years ago (Butzer, 2005). Tillage erosion is therefore one of the major contributors to the variation of soil depth and properties in Mediterranean agricultural landscapes.

Photo 1
Tillage erosion evidenced by light coloured truncated soils, Mateur, northern Tunisia. Tillage erosion is a cumulative process and can have been initiated over on thousand years ago in this region.
C. Valentin.

Wind erosion

Wind erosion is a threat in the arid areas of the Mediterranean region where the wind is often strong and the vegetation sparse. The type of soil also plays a major role since the most sandy soils are also the most prone to wind erosion (Khatteli 1996) whilst, due to low runoff volume and velocity, sheet and gully erosion remain limited. No coarse fragments increase the surface roughness of sandy soils, and the physical crust that develops when it rains does not significantly decrease wind erosion (Rajot et al. 2003), unlike crusts developed on more loamy soils (Belnap and Gillette, 1998). On the other hand, these sandy soils are the most efficient in stocking available water for plant growth (Floret and Pontanier 1984) so that, in undisturbed conditions, the vegetation cover that develops creates effective protection against wind erosion. Wind erosion increases when vegetation cover is decreased. As an example, soil losses reach very high levels when vegetation is removed a part of the year for cereal cropping (Houyou et al. 2014, Abdourhamane Touré et al. 2015). In olive groves, soil is kept bare by regular tillage to stop the vertical connectivity of pores and limit the capillary rise of residual soil moisture of the deeper horizons. Tillage severely depletes soil organic matter content. This favours the formation of microdunes high enough to render ploughing difficult (Photo 2). For the same type of soil, the type of plough used has also a significant effect on soil losses (see Bergametti et al. in this volume). Human activities currently create unsustainable levels of wind erosion on sandy steppe rangelands, which should incite policy makers not to allow their cultivation.

Photo 2
Olive grove on sandy soil, just after rainfall, region of Medenine, South of Tunisia, the dunes, up to 2m height, appeared after ploughing of the sandy soil. G. Hovhannissian.

Salinization

Salinization develops in time and space due to the gradual accumulation of soluble salts – whatever their nature – in or near the soil surface (saline crusts or efflorescences). Some salts, especially sodium salts, favour clay dispersion, degrade soil structure and hamper water infiltration. The processes of soil salinization and sodication are complex, occurring at all latitudes and in all climates, and are closely linked to the flow processes of surface and ground waters (Ghassemi et al. 1995; Montoroi et al. 2002; Hamdi-Aissa et al. 2004; Ali et al. 2016). Many natural factors generate soluble salts and their concentration (weathering and dissolution of rock and soil minerals, geothermal sources, decomposition of dead organisms, drying wind), transport (rain, rivers, groundwater, sea water, wind) and accumulation in soils (arid climate, temporary droughts), near the sea in coastal and delta areas, near a shallow saltwater table, aeolian deposits (sea spray, aerosols), endoreic zones (sebkhas, chotts). A so-called «secondary» salinization is induced by anthropogenic causes: mismanaged irrigation, old irrigation techniques, irrigation with waters rich in salts, deforestation, fertilizers containing potassium and nitrogen salts, atmospheric deposition near industrial sites. Above a given threshold of soil salinity, plant growth, crop production, water and soil quality are severely affected up leading to accelerated soil erosion and land degradation or ecosystem desertification (Gorji et al. 2015).

The soils of Mediterranean countries are particularly affected by salinization (Photo 3) because of the semi-arid to arid climate and the development of intensive irrigation for agriculture by building many storage and irrigation schemes (dams, hillside dams, canals and water distribution pipes). The consequences of climate change (increased rainfall variability and water scarcity, freshwater evaporation increase and higher plant evapotranspiration rates) will result in a concentration of soluble salts in the water bodies and the extension of soil salinization. The predicted sea level rise by the Intergovernmental Panel on Climate Change (IPCC) scenarios will impact coastal areas and wetlands (deltas of major rivers like the Danube, the Ebro, the Mejerdah, the Nile, the Po and the Rhone) and promote the saline contamination of coastal aquifers due to sea water intrusion. The overexploitation of upper fragile fresh water lenses overlaying denser brackish aquifers will intensify with the increased needs for agricultural, industrial, touristic and domestic activities which are mainly located along the coast (Kuper et al. 2009; Ashour and Al-Najar, 2012; Mansour and Hachicha, 2014).

Photo 3
Irrigated pomegranate crop in the clayey and saline soils of the Kairouan alluvial plain (Central Tunisia). The drip system is placed on the ridges for optimal water supply and salt leaching. The white spots (salt efflorescence) correspond to the highest soil salinity, where the trees are dead. The inter-ridges are ploughed to promote rainwater infiltration into the soil and prevent the invasion of weeds.
J.-P. Montoroi.

Main principles of desertification control and land rehabilitation: underlying ecological conditions and processes

A cover must be kept at soil surface to prevent crusting, water and wind erosion. To reduce the risks of tillage erosion, tillage operations and tillage depth should be limited. No-till agriculture associated with permanent cover is only possible where rainfall regimes allow sufficient biomass production. No-till farming can be very effective in reducing water erosion and runoff production at the plot scale. Attention must be paid on the plot length to reduce the risk of gully erosion.

In dry Mediterranean zones (annual rainfall < 300 mm) where vegetation cover cannot be continuous in space and time, the ubiquitous crusts should not be considered as a symptom of desertification because they are essential elements of arid and semi-arid zones. They favour natural water-harvesting through runoff-runon processes (Valentin and d'Herbès, 1999; Assouline et al. 2015). A wide range of water harvesting techniques has been developed for centuries in dry Mediterranean zone to enable crop and fodder production. Many of them, for example Jessour (photo 4) in southern Tunisia or micro-catchments in Israel (Zhang et al. 2013) are still in use and should be encouraged.

Photo 4
Jessour of the Dahars Range, Béni Khedache Road. Mean annual rainfall of 215 mm (period 1949-2001; Kallel, 2001), Average maximal temperature: 35.9°C (August period 1990-1996, Ouessar et al. 2006).
C. Bouet.

Considering the socioeconomic context

The abovementioned biophysical processes interact with many human decisions and constraints, including land users and policy makers. Both levels are crucial to lead to a successful control of desertification processes and soil rehabilitation. The top-down approach of terraces, check dams, deep drilling and reforestation has usually led to failures because the lack of involvement and interest of the land users. More success is expected through participatory and incentive approaches (De Graaf et al. 2013).

Conclusions

Climate change associated with land use changes in the Mediterranean region are expected to induce a major latitudinal shift of the pedoclimatic zones, resulting not only from the changes in climatic averages, but also from the higher frequency of extreme events (rain and wind storms, drought, long dry spells, heat waves...), and higher seasonal and inter-annual variability. These changes should render the already shallow soils even more vulnerable to various degradation processes (tillage, water and wind erosion, salinization) favouring a desertification spiral. To hamper these alarming changes, adaptation and innovative policies should be based on a sound knowledge of the interacting processes and consider the successful practices of soil and water conservation developed in more arid regions, especially those which have been readily adopted by land-users.

References

Abdourhamane Touré, A., Bergametti, G., Bielders, C., Bouet, C., Callot, Y., Dupont, S., Khatteli, H., Labiadh, M.T., Marticorena, B., Rajot, J.L., Valentin, C., 2015
Erosion éolienne dans les régions arides et semi-arides africaines: processus physiques, métrologie et techniques de lutte. *Revue des Regions Arides*, *36*(1). 258 p.

Ali, R.R., Saber, M., Nizinski, J.J., Montoroi, J.P., Zaghloul, A.M., 2016
Land surface analysis of salt affected soils using DEM and GIS. *European Journal of Scientific Research*, 138, 2: 197-202.

Ashour, E.K., Al-Najar, H., 2012
The Impact of climate change and soil salinity in irrigation water demand in the Gaza strip. *Journal of Earth Science and Climate Change*, 3:2, doi:10.4172/2157-7617.1000120

Assouline, S., Thompson, S.E., Chen, L., Svoray, T., Sela, S., Katul G.G., 2015

The dual role of soil crusts in desertification. *J. Geophys. Res.*, 120(10), pp.2108-2119.

Belnap, J., Gillette, D., 1998
Vulnerability of desert biological soil crusts to wind erosion: the influences of crust development, soil texture, and disturbance. *J. Arid Environ.*, 39: 133-142.

Benmansour, M., Mabit, L., Nouira, A., Moussadek, R., Bouksirate, H., Duchemin, M. and Benkdad, A., 2013
Assessment of soil erosion and deposition rates in a Moroccan agricultural field using fallout ^{13}Cs and $^{21}Pb_{ex}$. *Journal Environ. Radioactiv.*, 115: 97-106.

Bertrand, I., Ehrhardt, F., Alavoine, G., Joulian, C., Malam Issa, O., Valentin, C., 2014
Regulation of carbon and nitrogen exchange rates in biological soil crusts by intrinsic and land use factors in the Sahel area. *Soil Biol. Biochem.*, 72: 133-144.

Butzer, K.W., 2005
Environmental history in the Mediterranean world: cross-disciplinary investigation of cause-and-effect for degradation and soil erosion. *J. Archaeol. Sci.*, 32(12): 1773-1800.

De Graaff, J., Aklilu, A., Ouessar, M., Asins-Velis, S., Kessler, A., 2013
The development of soil and water conservation policies and practices in five selected countries from 1960 to 2010. *Land Use Policy*, 32:165-174.

Floret, C., Pontanier, R., 1984
Aridité climatique, aridité édaphique. *B. Soc. Bot. Fr. Actualités Botaniques*, 131(2-4): 265-275.

Gorji, T., Tanik, A., Sertel, E., 2015
Soil salinity prediction, monitoring and mapping using modern technologies. *Procedia Earth and Planetary Science*, 15: 507-512, doi: 10.1016/j.proeps.2015.08.062.

Hamdi-Aissa, B., Valles, V., Aventurier, A., Ribolzi, O., 2004
Soils and brine geochemistry and mineralogy of hyperarid desert playa, Ouargla basin, Algerian Sahara. *Arid Land Res. Manag.*, 18, 2: 103-126, DOI: 10.1080/1532480490279656.

Houyou, Z., Bielders, C.L., Benhorma, H.A., Dellal, A. Boutemdjet, A., 2014
Evidence of strong land degradation by wind erosion as a result of rainfed cropping in the Algerian steppe: a case study at Laghouat. *Land Degrad. Dev.*. doi: 10.1002/ldr.2295.

Kallel, M. R., 2001
Hydrologie de la Jeffara tunisienne. Rapport interne, DG-RE, Tunis, 65 pp.

Khatteli, H., 1996
Erosion éolienne en Tunisie aride et désertique, Analyse des processus et recherches des moyens de lutte. Thèse de Doctorat en Sciences Biologiques Appliquées, PhD, Université de Gent, Belgique.

Kosmas C, Gerontidis St, Marathianou M, Detsis V, Zafiriou Th., 2001
The effect of tillage erosion on soil properties and cereal biomass production. *Soil Tillage Res.*, 58: 31-44.

Kuper, M., Bouarfa, S., Errahj, M., Faysse, N., Hammani, A., Hartani, T., S. Marlet, S., Zairi, A., A. Bahri, A., Debbarh, A., Garin, P., Jamin, J.-Y., Vincent, B., 2009
A crop needs more than a drop: towards a new praxis in irrigation management in North Africa. *Irrig. Drain.*, 58: S231–S239, DOI: 10.1002/ird.533.

Labiadh, M.T., 2011
Quantification de l'érosion éolienne sur des surfaces anthropisées : simulation des flux en masse à l'échelle des zones arides tunisiennes. Thèse de Doctorat de l'Université Paris Diderot, Paris, France.

Malam Issa, O., Valentin, C., Rajot, J.L., Cerdan, O., Desprats, J.-F., Bouchet, T., 2011
Runoff generation fostered by physical and biological crusts in semi-arid sandy soils. *Geoderma,* 167-168: 22-29.

Mansour M., Hachicha, M., 2014
The vulnerability of Tunisian agriculture to climate change. In: P. Ahmad (Ed.) : « *Emerging technologies and management of crop stress tolerance* ». Elsevier Inc., 485-500.

Mariotti, A., Pan, Y., Zeng, N., Alessandri, A., 2015
Longterm climate change in the Mediterranean region in the midst of decadal variability. *Clim. Dynam.,* 44:1437-1456.

Montoroi, J.P., Grünberger, O., Nasri, S., 2002
Groundwater geochemistry of a small reservoir catchment in Central Tunisia. *Appl. Geochem.*, 17, 8: 1047-1060.

Ouessar, M., H. Taâmallah, Ouled Belgacem A., 2006
Un environnement soumis à de fortes contraintes climatiques. In: « Entre désertification et développement : La Jeffara tunisienne », IRD, Cérès Editions, IRA, Tunis, Tunisie, pp. 23-32.

Podwojewski, P., Janeau, J.-L., Chaplot, V., Grellier, S., Valentin, C., Lorentz, S., 2011
Influence of vegetal soil cover on water runoff and soil detachment in a sub-humid South African degraded rangeland. *Earth Surf. Proc. Land.*, 36: 911-922.

Rajot, J.L., Alfaro, S.C., Gomes, L., Gaudichet, A., 2003
Soil crusting on sandy soils and its influence on wind erosion. *Catena*, 53: 1-16.

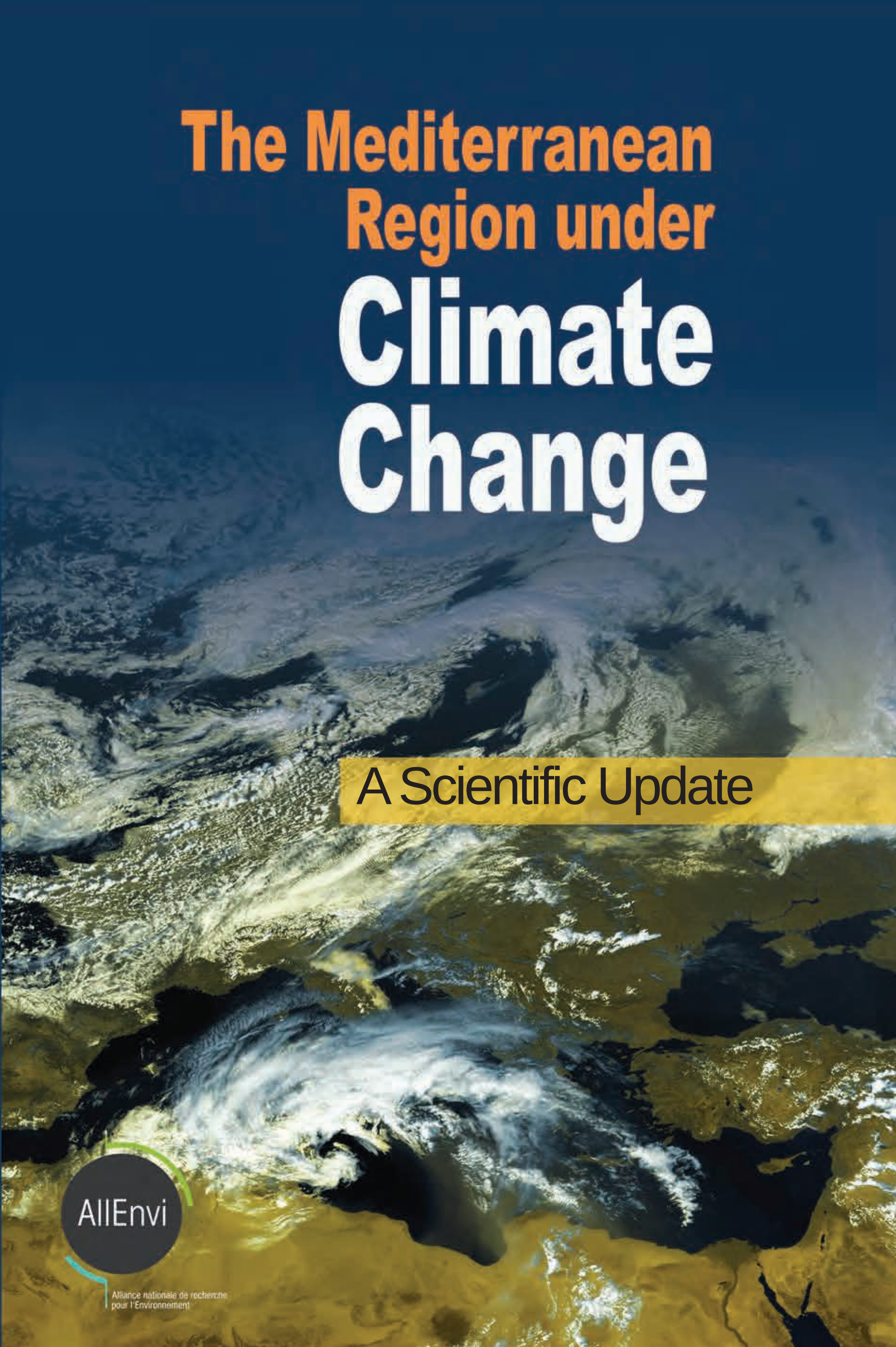
Valentin, C., Bresson, L.M., 1992
Morphology, genesis and classification of soil crusts in loamy and sandy soils. *Geoderma*, 55: 225-245.

Valentin, C., d'Herbès, J.-M., 1999
Niger tiger bush as a natural water harvesting system. *Catena*, 37: 231-256.

Valentin, C., Poesen, J., Yong Li, 2005
Gully erosion: impacts, factors and control. *Catena*, 63: 132-153.

Zhang, S., Carmi, G., Berliner, P., 2013
Efficiency of rainwater harvesting of microcatchments and the role of their design. *J. Arid Environ.*, 9:22-29.

The Mediterranean Region under Climate Change



A Scientific Update

AllEnvi

Alliance nationale de recherche pour l'Environnement

The Mediterranean Region under Climate Change

A Scientific Update

Preface by
Hakima El Haité

Postface by
Driss El Yazami

Address by
HSH the Prince Albert II of Monaco

IRD Éditions
Institut de recherche pour le développement

Marseille, 2016

Revision and translation
Daphne Goodfellow
Andrew Morris

Graphics
Michelle Saint-Léger
With the collaboration of:
Desk
Gris Souris

Layout
Desk

Cover layout
Michelle Saint-Léger

Page layout
Pierre Lopez

Coordination production
Catherine Plasse

Cover illustrations
© Météo France – RGB composite imagery, *METEOSAT-10*, 07/04/2016 at 12 UTC.
© IRD/B. Moizo – The town of Chefchaouen, Morocco.
© Ifremer/D. Lacroix – The port of Bizerte, Tunisia.
© IRD/J.-P. Montoroi – Olive trees, Seblet Ben Ammar, Tunisia.

ISBN : 978-2-7099-2219-7

This book, coordinated by AllEnvi, is published
on the occasion of the 22nd Conference of the Parties
to the United Nations Framework Convention
on Climate Change (COP22, Marrakech, 2016)

Scientific Direction

Stéphanie Thiébault
Jean-Paul Moatti

Scientific Committee

Isabella Annesi-Maesano
Yildiz Aumeeruddy-Thomas
Robert Barouki
Gilles Boulet
Jean-Luc Chotte
François Clin
Wolgang Cramer
Michel Crépon
Véronique Ducrocq
François Dulac
Benoît Fauconneau
Eric Gaume
Jean-François Guégan
Joël Guiot
Eric Hamonou
Denis Lacroix
Pascal Marty
Yunne-Jai Shinne
Jean-François Soussana
Emmanuel Torquebiau
Jean-Denis Vigne

Editorial Committee

Marie-Lise Sabrié
Elisabeth Gibert-Brunet
Thomas Mourier

AllEnvi

AllEnvi, *the French National Alliance for Environmental Research*, is tasked with making the great environmental transitions work, coordinating French research into major societal issues such as food, water, climate and territories. AllEnvi i) sets policy guidelines and research priorities for advance planning before approaching funding agencies, ii) supports the emergence and structuring of research organizations, iii) coordinates innovation and technology transfer policies between public research operators, businesses and industries, and iv) contributes to the European research environment and international programme development.

Alliance nationale de recherche pour l'environnement, AllEnvi coordonne la recherche française sur les enjeux des grands défis sociétaux que sont l'alimentation, l'eau, le climat et les territoires pour réussir les grandes transitions environnementales. AllEnvi i) définit les orientations et priorités de recherche pour la programmation à l'amont des agences de financement, ii) soutient l'émergence et la structuration d'infrastructures de recherche, iii) coordonne les politiques d'innovation et valorisation entre opérateurs publics de la recherche, entreprises et industries, et iv) participe à l'Europe de la recherche et favorise l'émergence de programmes internationaux.

Executive Secretary/Secrétariat exécutif :
Benoit Fauconneau
Christine Douchez
Elisabeth Gibert-Brunet