Climate Change Management

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Climate Change-Resilient Agriculture and Agroforestry

Ecosystem Services and Sustainability

Springer

Climate Change Management

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Preface

Climate change and its impacts on agriculture and on agroforestry have been observed across the world during the last 50 years. They have been threatening the stability in ecosystems and people well-being. Increasing temperatures, droughts and biotic stresses and the impacts of extreme events have continuously decreased agroforestry systems' resilience to climate change. As it is now, we need a new vision for research, management, education and learning, since they are important drivers in achieving the Sustainable Development Goals as a whole, and SDG 13 (climate action) in particular.

There is a perceived need to adapt farming and agroforestry systems so as to make them better able to handle ever-changing climate conditions, and to preserve habitats and ecosystems services. More efficient management practices and new/innovative agroforestry solutions are required and must incorporate the regional and local abiotic factors of climate, soil, water and nutrient balances as well as the biotic conditions (e.g. pests, diseases and dispersal agents). Also fostering activities related to traditional culture and improving education and learning on biodiversity and ecosystem services are decisive as they are stepping stones for sustainable development supporting ecosystem's conservation, livelihood and sustenance of populations.

It is based on the need to tackle this topic that this book has been produced. It aims at assembling wide-ranging contributions from case studies, reviews, reports on technological developments, outputs of research/studies and examples of successful projects, as well conceptual approaches, which document current knowledge, raise awareness and help the agriculture and forest sectors to adapt to climate change as it brings the theme ecosystems' services closer to education and learning, as an added value to strategic principles for healthy and valued ecosystems and sustainable human development.

The book entails contributions in a variety of areas, including ecosystem services and incentive mechanisms for environmental preservation, unlocking the social–ecological resilience of High Nature Value farmlands to future climate change, climate-smart agricultural practices (CSA) adoption by crop farmers in semi-arid regions, future climate change impacts on agriculture based on multi-model results from WCRP's CMIP5 and the urgent need for enhancing forest ecosystem resilience under the anticipated climate portfolio.

The book contains also papers addressing the issue of sustainable food systems in culturally coherent social contexts, and multifunctional urban agriculture and agroforestry for sustainable land use planning in the context of climate change. All in all, an interesting set of papers gathering information and knowledge which outline the potentials and environmental risks related to agricultural and agroforestry landscapes under a changing climate.

We hope that this publication will prove useful to all those working in the field of climate change as it relates to agriculture and agroforestry, and that it may catalyse further initiatives in this important field.

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Terraced Agroforestry Systems in West Anti-Atlas (Morocco): Incidence of Climate Change and Prospects for Sustainable Development

Mohamed Ziyadi, Abdallah Dahbi, Abderahmane Aitlhaj, Abdeltif El Ouahrani, Abdelhadi El Ouahidi and Hafid Achtak

Abstract The Moroccan Anti-Atlas region contains all the "ingredients" of a hostile environment including an arid climate, a highly rugged topography, a low vegetation cover due to insufficient rainfall, and inexorable soil erosion. These harsh conditions incited local peasants to adopt simple but ingenious agricultural practices that fit the prevailing rigours and ensure their livelihood survival: Terraced Agroforestry System (TAS). TAS, one of the most ancestral agricultural practices, becomes a dominant feature of the Anti-Atlas landscape. This study aims to explore the Anti-Atlas TAS as a resilient approach to counter climate change impacts and ensure a sustainable development of this region. To this end, a prospective study was conducted to survey the indigenous peasants, to assess the status of TAS, to describe its biodiversity trends, and ultimately to ensure its sustainable development. The primary results revealed that the Anti-Atlas TAS are based essentially on the Argan tree (*Argania spinosa* L.) as the predominant vegetation crown layer. Accordingly, goats represented the main integrated livestock. The related annual crops are mainly represented by local varieties of cereals and legumes. Other dryland fruit trees, such as almond, fig, olive, and date palm are also sparsely planted. Beyond their purely aesthetic and economic role, this agro-cultural heritage contributes greatly to the conservation of several local varieties and their associated fauna. Furthermore, the results allows us to identify some serious climatic and

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social challenges faced by the persisting TAS in the Anti-Atlas region. In this regards, the regional climate change scenarios predict warmer and dryer conditions over the studied region, meanwhile the new generation of local peasants increasingly lacks interest to maintain TAS and prefers to seek new opportunities in the Souss-Massa plain valley. Consequently, this paper investigates major issues threatened social, economic, and ecological balances and provides a combination of adaptation solutions to help revive the agro-cultural heritage of TAS from the process of extinction.

Keywords Terraced agroforestry systems · Anti-Atlas · Morocco
Sustainable development · Climate change

1 Introduction

The Kingdom of Morocco is an African-Mediterranean country where agriculture sector, mostly rain-fed dependent, represents more than 15% of its GDP and employs about 4 millions of its active population (ADA 2009; RMS 2011; El Bilali et al. 2012). Despite the climatic hazards striking Morocco, including drought, flood, and storms, the key challenges facing the country today is its ability to ensure adequate food security and to shift its economy to low-carbon energy by investing in renewable alternatives. This vision was well reflected in the 22nd Conference of the Parties (COP22) held in Marrakech on November 2016, where Morocco launched the triple A initiative (Adaptation of African Agriculture) to stress the high impact of climate change on its economy tightly linked to climate variability.

Aware of this critical situation, and based on the national strategy for sustainable development, agriculture and food security remain among the key strategic sectors targeted by Morocco. Since 2008, Morocco has developed the “Morocco Green Plan” (MGP) which aims to modernize the agriculture sector to become more competitive and more integrated in the global market by creating wealth over the entire value chain, meanwhile considering human, social, and territorial development. The MGP promotes sustainable management of natural resources and identify necessary policies to support sustainable growth. Although there were specific programs of MGP which particularly targeted small scale farmers in remote areas, the Moroccan Anti-Atlas villages, where survival is largely depending on rainfed agriculture and pastoralism, are unable to fully benefit from MGP.

The Moroccan Anti-Atlas, 18,000 km^2 (Gunn 2004), is a mountainous chain with all the “ingredients” of a hostile environment including an arid climate, a highly rugged topography, a low vegetation cover, and a non-stop soil erosion. This region is by far the most vulnerable to climate change and therefore the most threatened in terms of sustainable livelihood assets in Morocco. Facing these harsh conditions, local peasants have adopted simple but effective agricultural practices that fit the prevailing rigours: Terraced Agroforestry System (TAS), which become a major component of the Anti-Atlas landscape and the main farming system.

TAS are certainly more adequate and most effective practice for soil quality and stability, for landscape preservation, and for biodiversity conservation in similar agro-ecosystems. Thought the aforementioned advantages of TAS, its overall situation seems deteriorating and its maintenance is abandoned in the Anti-Atlas region which put in danger all the potential roles played by these traditional agro-systems to maintain livelihood and survival of the local peasants. In this context, the aim of this study is to explore the human and the physical complexities of the Anti-Atlas that determine the future of TAS with specific focus on the province of *Chtouka Aït Baha*. The ultimate goal is to promote TAS as a resilient approach to counter climate change incidences and prospecting for best fit sustainable development model for this region.

2 Methodology

In order to explore the TAS of the western Anti-Atlas region, a prospective investigation was conducted in the province of *Chtouka Ait Bah*a with focus on rural communities in the mountains districts (Fig. 1). A multidimensional approach including the literature review to describe the state of the art and the evolutionary trends of these TAS, the social and the human dimensions via surveying elders of the communities and interviewing local groups. The analysis of cartographical data, and eventually the analysis of past and future climate change of this region, were also conducted.

2.1 Bibliographical Information for the State of the Art

A state of the art is reviewed based on available information and publications (reports, monograph, papers …) about the study area. A synthesis was developed in order to provide a thoughtful description of the study area including geology, geography, demography, infrastructure, land cover, climate, water resources and agriculture.

2.2 Survey and Data Analysis

Qualitative and quantitative data were collected from local population through semi-structured surveys. During two years, at least ten transects in the study area were carried out to survey individuals and within focus groups at least 100 individuals from different rural communities were questioned. We mostly targeted elderly farmers but also young people. The questionnaire was designed to explore information about the history of TAS, the farming system, the agro-diversity

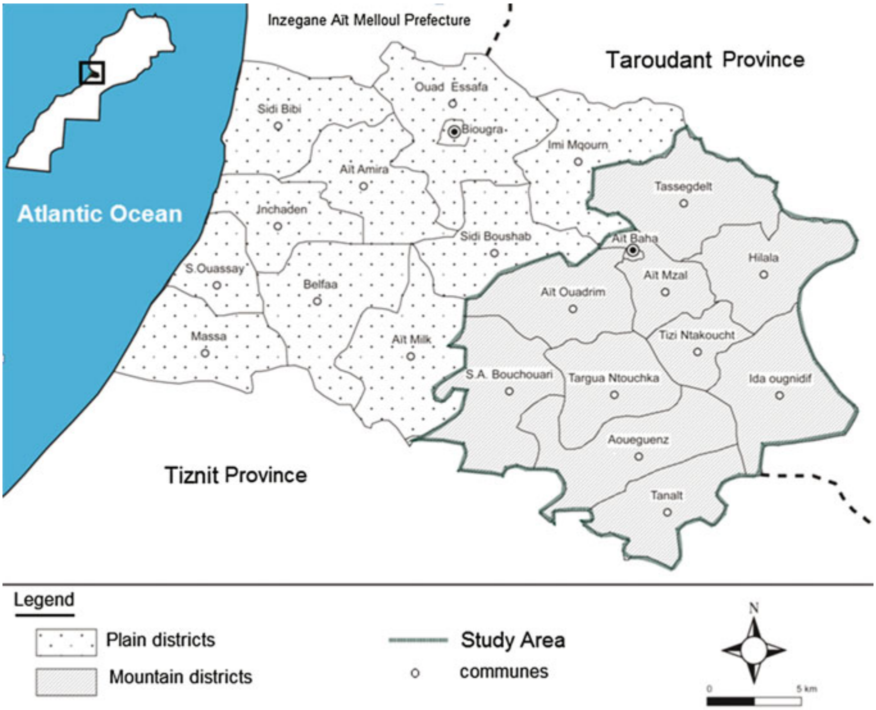

Fig. 1 Study area: the province of *Chtouka Ait Baha*

assessment, crop selection, and peasant perception of climate change, and possible adaptation solutions. These surveys allowed us to explore the trends of this traditional agroforestry practice in terraces.

2.3 Cartographic Data

The study area map and geographical information data were collected and developed using the MapInfo 12.5 software.

2.4 Analysis of Past and Future Climate Data

Past and future climate data were retrieved and analysed using DivaGIS 7.5 and SPSS 17.0. Drought incidence for Morocco was estimated using Palmer Drought Severity Index (PDSI) which is basically a proxy data based on cedar tree rings width covering a period of 1049–2001 (data source: Esper et al. 2007). The long term change in climate type over the study area was analysed using the Köppen-Geiger climate type classification change (Kottek et al. 2006). Observed and projected data covering two centuries (1901–2100) were retrieved from the World Maps of Köppen-Geiger climate classification then projected over the study area using DivaGIS software. The IPCC business as usual (BAU) scenario (A1FI) was adopted to estimate the worst climate change scenario until 2100 (IPCC 2007).

3 Results and Discussions

3.1 Geological Features of the Study Area

The Moroccan Anti-Atlas, a very old geological formation, is mountainous ranges with very steep slopes and ridges that culminate up to 2374 m above sea level in '*Jbel Lkest*'. The western part, where the famous '*Kerdous*' inlier, is dominated by the Precambrian (I) with schist, mica schist, and granite followed by the Precambrian (II) which provides a spectacular relief formed by a quartzitic cover of the '*Jbel Lkest*'. The whole is surmounted by a series of calcareous and dolomite sedimentary coverts which form the main mass of the Anti-Atlas. Epirogenic seizures followed with oscillating marine transgressions that only sporadically reach the mountain mass, causing large sedimentary gaps in its coverings series (Choubert 1963; Choubert and Faure-Muret 1972). The study area (Fig. 1) is located on this western part of Anti-Atlas (30° north latitude and −9° west longitude), fairly representative of the Moroccan Anti-Atlas. However, for a better observation of the agrarian systems, the study was focused on its Mountain districts slopes covering an area of approximately 3523 km^2.

3.2 Human Footprint and Demographic Data

Due to its abrupt and steep relief, and its hostile and uncertain climate, this region gives the sense of a harsh and inhospitable countryside. But as one go through the massif, the anthropogenic footprint appears omnipresent marking the landscapes. Indeed, the total population of these mountainous areas has been fluctuated throughout the last century. After being quite large along the three first quarters of the 20th century (Podeur 1995), the total population underwent a steady decline.

Though this observation contrasts oddly with the peasants' secular tying-up to their land, different settlements "*douars*" have lost more than the third of their population in just few decades. This continuous migration is clearly shown through contemporary censuses (1994, 2004, and 2014) (Table 1). The peasants' younger generation becoming more and more attracted to better jobs and opportunities offered elsewhere.

Table 1 Demographic evolution according to the last three consecutive censuses, in Mountain and Plain communes of *Chtouka Ait Baha* province of the Anti-Atlas

Communes	Census 1994		Census 2004		Census 2014		GR
	CTP	D	CTP	D	CTP	D	
Communes in mountain (n = 11)	63,281	148,47	57,189	179,82	47,157	201,81	**−1.63**
Communes in plain (n = 12)	176,811	217,19	240,056	344,58	323,945	482,42	**1.96**

Source Adapted from Haut Commissariat au Plan
CTP Commune total population, *D* Commune mean density, *GR* Growth rate during 20 years (1994–2014)

3.3 Terraced Agroforestry Systems

3.3.1 Learning from History

For many millennia, faced with abrupt relief and the scarcity of flat surfaces suitable to agriculture, many rustic techniques have been developed through peasants' generations in order to "overcome" the ungrateful environment. The slopes were completely transformed into innumerable floors, a kind of staircase of small terraced plots, conducive to a more rational use of soil and water resources. The use of these terraces goes back to a long history. According to most historians, this type of sloppy land management for soil conservation and water resources optimization would go back more than 1000 to 500 years before Christian era (Harfouche 2003). While for some others, such as Despois (1956), they were derived from the much older *'Amazigh'* civilization as the Anti-Atlas remained totally outside the area of Roman occupation.

3.3.2 Associated Management

Regularly restored and maintained, these terraced plots have not lost their authenticity. They remain perfectly arranged according to altitude contour lines and supported by walls made with dry stones of variable geological nature, locally called '*Igherman*'. This term evokes a common concept that embraces protection, resistance, and reinforcement. TAS is associated with multitude constructions which can be described as ancillary developments derived from the original topography of the land. Among these developments that can be observed while travelling across these mountains, the threshing floor locally called '*Inraren*' which testify the past cereal mass production in Anti-Atlas. Others constructions have in common the use of slope to harvest rainwater such as those many underground cisterns called '*Tanodfi*' that are found almost everywhere near the dwellings (Aziz et al. 2014). These ancillary constructions were built in the same way as the terraced fields: the peasants used the materials extracted on site and followed the same construction rules as the case of *Igherman*. Another associated structural development that can also be considered as complementary, since it is closely linked to agricultural terraces, is the famous fortified granaries named ‘*Igoudar*’ built on the tops of the hills, where peasants store their cereal supplies that have been produced on the terraced fields. Certainly, this type of management is found elsewhere, but those of the Anti-Atlas have their own peculiarities.

3.3.3 TAS: An Adapted Food Security Management in Anti-Atlas

The slopes of the Anti-Atlas, particularly those exposed to north-west influence, possess a well-diversified natural vegetation cover dominated by the endemic *Argania spinosa* “Argan tree”. This emblematic tree constitutes by far the major component of vegetation land cover under which lays not only agricultural activity in terraces but also other plants and animal species are intimately associated. It represents, along with other fruit trees, the basic natural resources for the dwellers. However, above 1500 m of altitude, and under the effect of low temperatures and high humidity, emerge other natural trees such as the green oak (*Quercus ilex* L.), more adapted to these extreme conditions (El Aboudi 1990; Peltier 1982).

To convene their needs in food, the peasants of Anti-Atlas have sought to make better use of the small land plots available by applying the concept of agroforestry. This concept consisted in associating seasonal crops such as cereals and legumes, and perennials ones including almond (*Prunus dulcis*), prickly pears (*Opuntia ficus-indica)*, and figs (*Ficus carica*). In addition to natural vegetation cover already spruce in place, the implementation of this type of agroforestry systems and the stable quantitative but also qualitative yield associated (Olivier et al. 2015) have largely contributed to the sedentariness of the local populations, which have largely focused their activities on agriculture and livestock breeding.

3.3.4 Advantages Beyond Food Security

Indeed, and beyond ensuring subsistence farming for peasants, agroforestry in terraces have some great advantages and positive repercussions at various levels:

Agronomic attributes: Soil erosion is a permanent concern for Anti-Atlas farmers. All surveyed farmers do not value their land unless it retains arable soil. The terraced fields are traditional but genius systems that effectively retain soil vitality. The presence of trees with rigorous root is an added value to limit soil erosion.
Water management: Agroforestry systems in terraces contribute not only to regulate rainwater flows (Noorka and Heslop-Harrison 2014), but also and above all prevent the siltation of small water reservoirs (Alahiane et al. 2016). At field level, TAS optimize irrigation system on numerous small flat surfaces using the dew water captured by the leaves of fruit trees and retaining by the walls, these systems retain and recycle significant amount of water resources. Down the valley, the

terraces which are closer to the water sources and stream paths benefit from a fairly regular irrigation. However those in high altitudes depend exclusively on rainfall.
Ecosystem sustainability: Agroforestry systems in terraces play multiple eco-systemic roles which go beyond a food production. These roles includes a number of important ecological benefits such as carbon sequestration, the creation of a microclimate that dampens thermal shocks, and the preservation of biodiversity (flora & fauna). Soils of TAS retain more water and are richer in micro-organisms and other invertebrates which enhance soil fertility. A wide range of animal and plant species are tightly associated with TAS. For instance, the interstices created at the level of *Igherman* shelter a multitude of very specific flora and fauna perfectly contribute to the ecological balances of these terraces. A non-exhaustive species list of Anti-Atlas TAS includes at least 44 endemic plants species and another 27 non-endemic, 9 mammal species, including the Barbary ground squirrel (*Atlantoxerus getulus* L.), 7 bird species, and 14 reptile species (source: Centre for Information Exchange on Biodiversity in Morocco). In addition, they constitute an ideal site for the development of an important Arthropod fauna, like spiders and *Hymenoptera*, mainly ant species, which constitute key actors in the biological control of various phytophagous that threaten crops. Thus, similarly to the concept of biodiversity "hotspot" areas (Myers et al. 2000), which identify priority areas for wildlife conservation, the traditional agroforestry areas in the Anti-Atlas deserve to carry such a designation, according to their high and specific associated biodiversity and landraces (Achtak et al. 2010; Brush 1995).
Socio-economic assets: Agroforestry systems in terraces are true mountain foci which concentrate and retain an important agrobiodiversity. Indeed, in the middle of Anti-Atlas, they form by excellence a kind of reservoir/refuge for traditional crops and very old seeds, genetically adapted to local conditions. These plant genetic resources, made up of varieties selected by traditional knowledge and maintained throughout the generations, constitute a "gene bank" available in situ in these systems. Moreover, the charred remains of wood, seeds and various fruits discovered on the site of *Igîlîz* by Ruas et al. (2015), are undeniably witness of great diversity of plant species that have been able to thrive terroirs (a unique micro-climate and traditional farming practices that affect a crop's phenotype) in terraces for centuries (96 plants of which 18 are cultivated).

In this context, our present investigation, far from being exhaustive, has nevertheless enabled us to detect the existence of well-adapted plant species of great socio-economic importance for the sedentary populations. Among these, and beyond Argan tree which dominate the arboreal stratum, almond and fig represent a second important source of income for peasants, then consecutively followed by the preckly pears, and Carob tree (*Ceratonia siliqua* L.) which is scattered all over, but with low density, green oak and Atlas pistache (*Pistacia atlantica*) in the highest altitudes. Medicinal plants such as lavender (*Lavandula stoechas* L.), cistus (*Cistus villosus* and *C. salviifolius*), cytise (*Teline segonnei*), mugwort (*Artemisia herba-alba*) and thyme (*Thymus satureioides*), continue to decorate, here and there, the cultivated terraces. For obvious reasons related to local knowledge and developed through centuries by the population in these areas, the medicinal virtues of these plants are keenly sought and used by the peasant population. This have recently evolved as a good income opportunity for women through the cooperative network, taking advantage of the renewed interest for natural products. This great diversity of plants also includes a melliferous flora, representing the basic variety of honey with a very high gustatory and medicinal quality and firmly associated with the sub-species of North African bees, *Apis mellifera sahariensis*. Less and less flourishing, its production in traditional apiaries according to secular methods and commercialization still provides a quite important income for numerous local households.

3.4 Terraced Agroforestry System: Significant Regression Trend in the Anti-Atlas

Given the many advantages associated with the practice of agroforestry in terraces, one should expect a prosperous state of these systems after a constructive repercussion of local population guided by their necessity to survive in a harsh environment. Yet, paradoxically, our investigations, although over a few limited slopes of the Anti-Atlas, reflect a clear regression of this practice. This regression affects both the quality and the number of terraces exploited. The diversity of species and plant varieties is greatly affected. They are gradually regressing and are experiencing changes both in species composition and in cultivated varieties. The number of fruit trees, for instance, and in comparison with agrosystems located in the Rif Mountains (northern Morocco) where the number of varieties exceeds a hundred, remains much lower in the Anti-Atlas slopes. A similar trend is also observed in cereals and legumes, which have always been important for food and feedstuffs. Considering cereals, for example, only three species are still cultivated (barley, wheat, and maize), often with only one variety per species.

The majority of the questioned peasants (only the elderly were considered), recognized a drastic decrease in numbers of cultivated species and local varieties. They agreed on the responsibility of climatic factor, and linked such a regressive trend with inadequate water resources and drought which is increasingly thump this region. However, down the valley, along the water streams and near natural water springs, several species persist. But the few streams that feed an extensive regional hydrographic network are largely dependent on rainfall irregularities. Increasingly dry, these streams only run for a few months, from November through April, sometimes with short but destructive and violent floods. In these conditions, species and traditional varieties, which have been selected for generations, and which are sometimes peculiar to the region, gradually give a lead to new varieties which are indeed more productive and therefore economically profitable but less relevant in many aspects. Consequently, a good number of terraced plots have been totally abandoned or at least poorly maintained and are no longer the centre of interest for "young" peasants (Fig. 2).

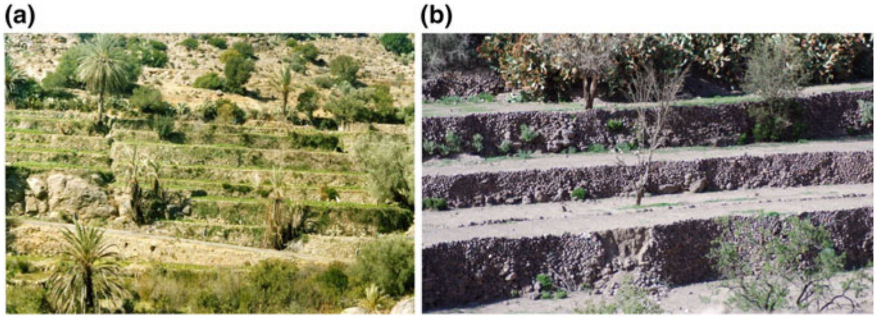

Fig. 2 An illustration of maintained (**a**) and abandoned (**b**) TAS

In reality, it would be fairly simplistic to attribute all these reasons to climate change alone, the problem seems to be more complex. To draw a more realistic and comprehensive view of the issue, it is wise to estimate the relative share inherent in other factors. In the case of Anti-Atlas region, the socio-economic and socio-cultural factors play significant role as well. The sharp decline in agroforestry practice among the Anti-Atlas farmers is partially due to their passive behaviour and incapability to endorse new adaptive techniques.

Throughout the survey, the primary impression is a dominant sense of carelessness of farmers towards the seriousness of the situation. But, after in-depth analysis, one realizes the rational and the purely economic reasons that explain the situation of TAS in Anti-Atlas. The high production costs combined with high risks due to rainfall irregularity have often been reported as the main reason by the surveyed farmers. Wild boar (*Sus scrofa*) visits become more and more frequent causing costly damages to the crops. Increasingly, these undesirable visits of a purely wildlife, in themselves translate the beginning of ecological unbalances that are not unrelated to climate change. On the other hand, and unlike farmers in other similar regions such as in the Rif Mountains (north of Morocco), those from our prospecting area seem to be investing less and less in improving agricultural practices and maintaining agricultural terraces. According to our observations, the cultivation and the maintenance of the installations and the arboriculture are limited to the irrigated terroirs and the surroundings of the farmers' houses. The further away one gets, the degradation of terraced fields becomes evident and very pronounced. Moreover, farmers use a very detrimental solution by overexploitation of natural forest through overgrazing and medicinal plants harvesting.

The traditions and the agricultural know-how of the sedentary populations outlined an important part of the cultural heritage accumulated and transmitted through peasants' generations. It is noted that women play major role in this transmission. The emotional connection that unites farmers to their land constitutes an indispensable prerequisite for the survival and the perpetuation of this traditional agroforestry system. Yet, there is no need to highlight that this link becomes more and more eroded and generally threatens the survival of these ecosystems.

Rationally destined to take over, the younger generation is facing the dilemma of "perpetuating the agricultural heritage versus significant decline in yield and future uncertainties".

This particular population aspires to a better future and look forward to explore other prosperous opportunities. The vast valley of *Souss-Massa* attracts most workforces from various regions, including from villages of the Anti-Atlas. This attraction contributes widely to the desertion of the Anti-Atlas agroforestry ecosystem.

3.5 Drought Incidence in Morocco and Anti-Atlas Region

There are many definition of drought, but all of them usually resulted from an accumulated water deficiency over a period of time (Natsagdorj 2012; Palmer 1965; Wilhite and Glantz 1985). As a Mediterranean country, Morocco is susceptible to alternation of drought hazards. A proxy data from Cedar tree rings (*Cedrus atlantica*) show clear intermittent of dry/wet regimes covering a period of 20–25 years. Two dry patterns periods were revealed; 1860–1900 and 1925–1950 (Chbouki et al. 1995). Based on these facts, Morocco is likely to experience a dry period between 2025 and 2050. For instance, an assessment of drought hazard near Rabat based on annual rainfall anomaly analysis identified 20 drought incidences over the period 1951–1997 (Natsagdorj 2012). To illustrate the consistency of these results, we will investigate the drought incidence over Morocco using the Palmer Drought Severity Index, and the Köppen-Geiger climate classification over Anti-Atlas region.

3.5.1 Palmer Drought Severity Index (PDSI)

Palmer Drought Severity Index (PDSI) for Morocco was calculated based on Cedar tree rings width data (Esper et al. 2007, 2009), which allows capturing long-term changes in PDSI over the period 1049–2001. Since 1900, PDSI highlights drier years than wetter years (around 1960s). It shows a remarkable trend in sever (<-3) and extreme (<-5) droughts mainly since 1980s (Fig. 3).

During this period (1900–2001), PDSI ranged from −5.97 to +3.98 and expected to be −3.1 by 2050 and −4.1 by 2100. The correlation between date and PDSI is negatively significant ($r = -0.317$; $p < 0.001$). In other words, Morocco is expecting dryer future ahead.

This expected dryness was also confirmed in Anti-Atlas. Several studies investigated the impact of climate change on argan forest (Charrouf and Guillaume 2009; Kenny and De Zborowski 2007; Le Polain de Waroux and Lambini 2012; Morton and Voss 1987). The results predicted noticeable deficiency of an annual precipitation and prolonged drought periods which put extra risk toward the extinction of argan forest. Certainly, the area of argan forest in Anti-Atlas has

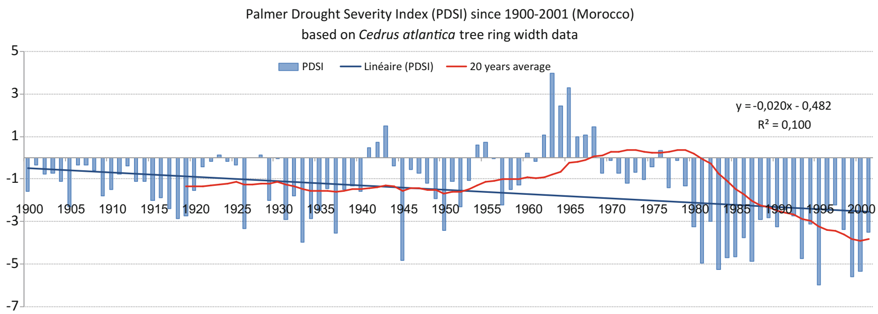

Fig. 3 PDSI covering a period of 1900–2001, based on *Cedrusatlantica* tree ring width data (*data source* Esper et al. 2007)

decreased by 44.5% between 1970 and 2007. This deforestation is consensually believed to be largely caused by the increasing frequency of drought incidences.

3.5.2 The Köppen-Geiger Climate Classification

The climate type classification data (Köppen-Geiger) make it possible to reveal a changing climate over a specific region with resolution of 0.5° latitude and longitude. We downscale this data to fit the Anti-Atlas region, specifically over Chtouka Ait-Baha province. The data allows presentation of observed (including proxy data) as well as future estimates based on IPCC scenarios (Kottek et al. 2006). Data, 1901–2100, were retrieved from World Maps of Köppen-Geiger climate classification then imported to DivaGIS software.

The result (Fig. 4) shows three maps representing observed (Ob 1901_1925) and projected (A1FI 2001_2025 and A1FI 2076_2100) data of 25 years each. The legend gathers three letters that follows Köppe-Geiger climate classification which designs the type of dominated climate. The first letter provides an indication about the main climates (here: B refers to arid climate and C to warm temperate climate), the 2nd letter designates the main precipitation regime (here: W refers to desert, S refers to steppe, and miniscule "s" refers to dry summer), and the 3rd letter designates a type of temperature regime (here: k refers to cold arid temperature, and h to hot arid temperature). The legend of Fig. 4 can be read as, BWh: arid climate with deserted environment and hot arid temperature; BSk: arid climate with steppe vegetation cover and cold arid temperature; BSh: arid climate with steppe vegetation cover and hot arid temperature; Csa: warm temperate climate with dry and hot summer; and Csb: warm temperate climate with dry and warmer summer.

From Fig. 4, we can state that the climate type over the study area (white circle) shifted from BSh in the first quarter of the 20th century to BWh in the last quarter of the 21st century. In other words, this northwards shift results mainly from the change in precipitation regime which shifted from a steppe to a desert environment. The precipitation deficiency is expected to be the major determinant to put this

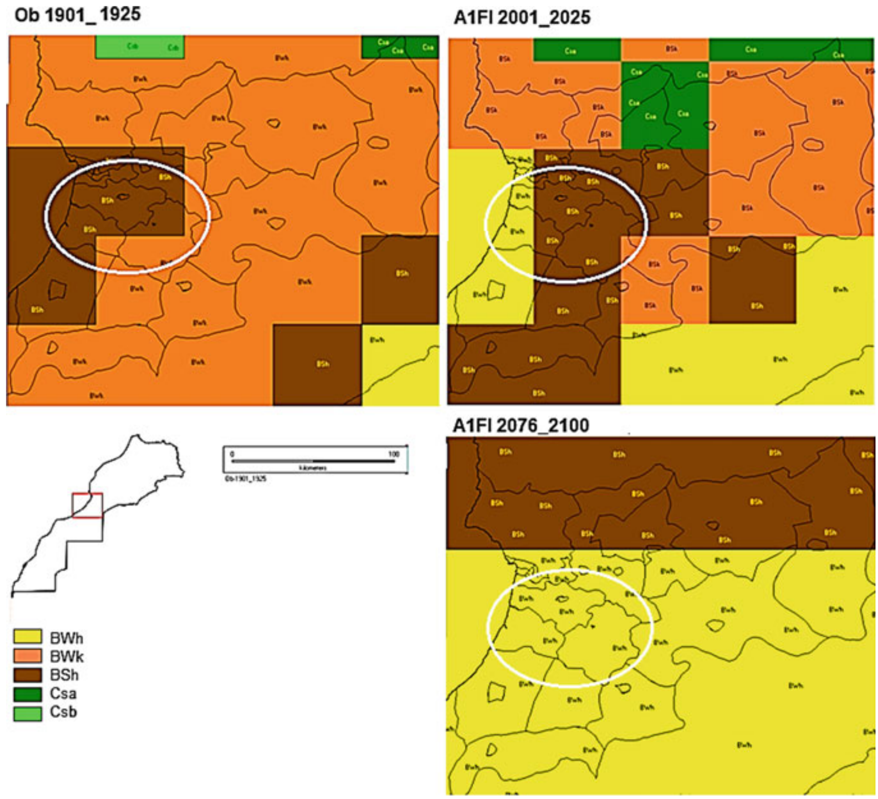

Fig. 4 Observed (Ob) and projected (A1FI) climate type shifts: Ob1901_1925, A1FI2001_2025, and A1FI2075_2100, based on the Köppen-Geiger climate classification world maps, using IPCC fossil intensive (A1FI IPCC) scenario. White circle refers to the study area, more legend embedded in the text

region under high risk of desertification. Therefore, the agroforestry systems are expected to face an arid/desert climate featured with low precipitation and hot temperature in summer.

In brief, the Anti-Atlas region is better to be prepared for more drought incidences if we are going to safeguard this famous agro-biodiversity heritage from total extinction.

3.6 Prospect for Sustainable Development in Anti-Atlas (Chtouka Ait Baha)

According to our results, prospect for sustainable development in Anti-Atlas can only be though by ensuring food security and prosperity for its communities. Food security is ensured by TAS productivity which in turn linked to climatic conditions (Brown and Funk 2008; David et al. 2008). While prosperity of its community depends on their resilient capacity. Unfortunately, these communities are living at the expense of their surrounding natural resources, and thus are economically fragile and socially vulnerable. The situation is more complex and emanates from a set of factors which can be summarized into two major but non-exclusive categories: climatic and human factors.

3.6.1 Climatic Factors

Mixed agriculture (trees/intercropping) in TAS maintains high quality soils with better microbial resilience (Lacombe et al. 2009; Rivest et al. 2013), high water retention, and enhance mineral uptake (Olivier et al. 2015). Also, the rhizosphere is conducive to the development of a diversified pedofauna (Cromack et al. 1988). Nevertheless, the ongoing warming and the ever-increasing scarcity of water resources put into risk the subsistence of well featured crop species in these systems. Our investigations show that many traditional varieties, known as "*beldi*" (or autochthon), underwent a long selection history and adaptation process by peasant's generations, have progressively or even totally disappeared over the last decades. Their replacement by mono-varietal crops and the ongoing intensive genetic erosion in these agroforestry systems represent a true threat to food security of local population (Esquinas-Alcazar 2005). This situation is unlikely to end here, rather the climatic disturbances could even have an impact in the near future on small-scale cereal crops (Lobell et al. 2008).

According to the farmers questioned, the water stress caused by the dysfunction of the climate is to a large extent no longer allowing a satisfactory yield. Trees, such as argan and almond, were always and will continue to be the backbone element of these traditional agro-systems. The microclimate generated by these trees in TAS is indeed helping the good development of intercropping. However, although trees persist today, they have experienced a significant decrease in density, which exacerbates the already detrimental effects of global warming in this region. Alarming signs have already shown up in the argan forest. During the twentieth century, its area has been reduced by half and, in some places, tree density is 66% lower than it was 50 years ago (Charrouf and Guillaume 2008, 2009; M'Hirit et al. 1998). This severe forest decline was also highlighted using gridded tree counts on aerial photographs and satellite images and was linked mainly to the increasing aridity. However, no effect of grazing by local livestock was found (Le Polain de Waroux and Lambin 2012). Therefore, the expected drought incidences found in our analysis will certainly affect a large wild fauna and flora that is dependent on argan forest agrosystems. The consequences will no longer be limited to merely agricultural shortfall rather it will affect all ecological balances and ecosystem services in a more holistic manner in this region.

3.6.2 Human Factors

Much of these factors represent a straightforward, sometimes obsolete, response to the consequences of climate change. Increasingly overwhelmed by the adverse consequences of drought incidences, farmers were continually forced to seek alternatives to mitigate such effects. Thus, some crops considered more resistant to thermal and water stresses have already substituted old crops, just few decades ago were prosperous in terrace systems. In our opinion, the example of the lentil (*Lens culinaris* L.), virtually disappeared from these systems, is most representative of this upheaval change in terraced crops. This disappearance is not due to a lack of interest for this food; rather it is an actively sought-after crop as an essential ingredient of farmers' everyday meal. Sadly, it is only available in the week markets (souks). Worse still, the local varieties become progressively more dominated by commercial ones, which is less tasty with low gastronomic quality. This impoverishment in the "reservoir" of plant species and genetic resources occurring in the Anti-Atlas agroforestry systems, have certainly led, in just few decades, to a total transformation of the local botanical landscape, with an alarming decline in species richness accompanied with a parallel erosion of traditional genetic resources.

Thus, like other traditional agro-systems (Achtak et al. 2010; Brush 1995; Hmimsa and Ater 2008), those in terraces that formed a sort of hotspot zone for cultivated plants, have gradually lost such a patrimonial characteristic. This situation has indisputably been exacerbated by a total ignorance of climate change issue among farmers and climate-terraces associated particularities. Furthermore, the total absence of any land/crop maintenance using either classical or innovative techniques (e.g.: density and distribution of cultivated plants for better management of root competition over water/mineral intake and light) is rather striking and has hardly resisted this trend of decline in agrobiodiversity.

Agroforestry systems have proved to be the best fit to adapt to climate change. For instance, the Rif agroforestry systems (northern Morocco) are sheltering panoply of traditional plant species despite noticeable but less severe climate change effects (Achtak et al. 2010; Hmimsa and Ater 2008). The study of mountain oases in northern Oman (Gulf) recorded a rich agro-biodiversity with 107 crop species belonging to 39 families, including 33 fruit species (Gebauer et al. 2007). However, the future of agroforestry terraces systems in the Anti-Atlas is strongly threatened and evolves towards extinction. Particularly, the increasingly deprived peasants resort to the deforestation of the argan forest which does little to help the situation. Furthermore, the greed for argan oil, increasingly sought-after for its culinary, cosmetic virtues, and better valued on the national and international markets in particular, which ultimately poses a real threat to this endemic and highly emblematic specie (Lybbert et al. 2011).

The most important issue and probably the most critical one is that the young generation is more and more disinterested in this kind of livelihood and look for alternatives income even outside the agricultural sector. Only the elderly peasants persevere with limited techniques, funding, as well as motivation based hope. The plots are not only less maintained, but they become less and less abundant and sometimes even left without regular farming practices. Such a social shift was inevitable and was likely to occur as a result of the growing economic needs of an increasingly demanding young generation combined with plentiful job opportunities in the high-yielding cultivated plains of the great adjacent Souss valley (El Fasskaoui 2009). The accelerating effect of climate change is certainly the main cause promoting the migration of young peasants after experiencing decades of a continuous fall in terraced agro-systems productivity, and subsequently the subsistence incomes of peasant household. In these regions, the rate of population growth, normally positive and even higher than in urban areas, remains strangely negative. The shock wave of climate disturbances is therefore no longer socially restricted and limited geographically, but its resonance even reaches the social equilibrium of large cities with a strong economy. In addition to this, food insecurity adds another social dimension, no less threatening, felt more and more in the megacities, hub of immigration.

We certainly believe it is urgent time to revive the relationship between the younger generation and their land. For instance, financial incentives may be one of the alternatives. However, such an approach should be only to trigger the rehabilitation process and cannot constitute the core resilience measure in the long term.

In this study, we intended to emphasize the Moroccan Anti-Atlas as one of the most fragile and the most destabilized region affected by global warming, and to urge all stakeholders to take action to safeguard this precious ancestral heritage. Although the Moroccan policy promotes the protection, conservation, and valorisation of ancestral agricultures in remote areas, including the Anti-Atlas, it is still far from reaching the expected results. By far, such policy requires the involvement of all actors and ensuring enough financial resources which public fund cannot afford alone. If no resilience and adaptation measures are undertaken at different levels to preserve crop diversity and to improve production for a sustainable development (Mooney et al. 2005), the situation will undoubtedly lead to the disruption of ecosystem equilibrium. The dramatic and multidimensional consequences, already on the horizon, will emerge on the social, heritage, and ecosystem levels.

If it is not possible to act on the problem upstream, as climate change is global and depends on a complexity and a conjuncture of events and macroeconomic factors, it is quite possible to propose appropriate actions further downstream. These should not be merely operations of technical supervision of farmers, distribution of selected seeds and seedlings, creation of cooperatives here and there, valorisation of local products such as argan oil, or establishment of tourist activities, but rather regional/communal/local strategies based on long term commitment and participatory approaches involving all stockholders. The aim is not only to warn and prevent, but also, and above all, to develop decision-making tools in order to better cope with a less favourable and rapidly changing climate, environment, and social realities.

4 Conclusion

Generally, the impacts of climate change deeply affect the structure and the balance of an ecosystem. In Morocco, the Anti-Atlas region is by far the most affect, since it is located at the gates of the Sahara. The regression of agroforestry systems has multiple and interdependent consequences operating at various levels. If the ecosystem component is largely unbalanced via the central ecological role played by this very particular and advantageous agricultural system, the social aspects are even more unbalanced and seem to be highly fragile by this regression.

Faced with this scenario, and in addition to a major ecological disruption, the threat of food insecurity hangs seriously in Anti-Atlas. Indeed, our finding of climate data analysis over the study area are in agreement with the 4th and 5th IPCC report predict dry periods in North Africa in the coming decades (IPCC 2007, 2014). The resilience measures undertaken remain timid, minor, less integrated, and unable to cope with the magnitude of such a metamorphosis of the landscape and the surrounding climate. If more influential measures are more urgent than ever, they must emerge from preliminary research of multidisciplinary studies carried out in these regions, which integrate different sectors and dissect all the parameters, causes, and effects relationships that govern the complex functionalities of this yet unknown landscape.

Although the threat perspectives are certainly diverse, two synergistic approaches seem to be of great interest within the perspective of safeguarding of this traditional agronomic abode. First, the use of the Payment for environmental services (PES) process can be effective in this context and could persuade and encourage the younger generation to take back these increasingly neglected systems. Nevertheless, it is clear that such a purely financial motivation, devoid of any local identity and cultural values, cannot by itself produce the expected results. A parallel support cantered on the true valorisation of local and traditional products will certainly contribute to revive these agro-systems from the process of extinction.

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