Watershed of Zeuss-Khoutine and Bou-Hedma Biosphere Reserve

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1. Main dryland challenges at the project site

1.1. Introduction

Desertification threatens around 52 per cent of the land area of Tunisia that is suitable for agriculture, forestry and pasture farming (MEAT, 1998). Incompatible forms of land use have resulted in soil degradation and salinization, and water and wind erosion, triggering a loss in land productivity.

Tunisia has an ancient tradition of combating land degradation and desertification. In fact, for a long time the country has been seeking solutions to these problems through its own means and with international support. Moreover, investments and organized efforts to combat desertification began soon after independence within the framework of the various strategies for the protection and management of natural resources, and finally with the implementation of the National Action Programme to Combat Desertification (NAP-CD) ratified in 1998 as part of the United Nations Convention to Combat Desertification (UNCCD). The UNCCD stated that combating desertification could not be limited to only technical measurements but must, on the contrary, be considered as a complex unit of coherent actions that take into account its socioeconomic dimensions, as well as biophysical and environmental aspects. In fact, chapter 12 of Agenda 21 and Article 16 of the UNCCD recommends developing desertification control dashboards to enable a better understanding of the phenomenon, and for efficient joint action by decision-makers and stakeholders to curb its unfavourable effects. It is for this reason that the UNCCD signatories admitted the importance of controlling the monitoring/evaluation programmes to combat desertification, and that the national focal point (NFP) would have a global vision of the process of implementation of these programmes.

The decentralized implementation of NAP, by placing more importance on the role of local actors, strongly challenges the national decision makers to take up the challenge of decentralization, dialogue, and the coordination of actions between the various actors at the national, sub-national and local levels.

The Sahara and Sahel Observatory (OSS) developed an environmental monitoring programme that aims to

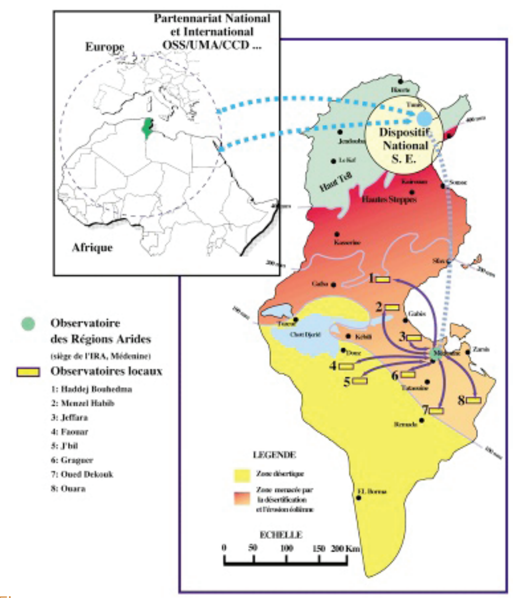

Figure 1.
Arid zone observatories in Tunisia (SUMAMAD study sites are found in 1 and 3) Source: Sghaier *et al*., 2006

support countries to set up dashboards on combating desertification that serve the implementation of national policies for environment protection and the sustainable management of natural resources. This programme includes projects and initiatives for environmental monitoring at various levels and by various means: from small scale studies in the field to large scale studies using satellite images. It focuses on supporting the establishment of environmental monitoring mechanisms by countries to support decisions for sustainable development.

Tunisia has set up a number of observatories based on agro-ecological and socioeconomic zoning (Sghaier *et al*., 2006), which are scattered throughout the country. The two study sites (Zeuss-Koutine watershed and Bou Hedma National Park) are among the eight observatories of the arid zones of the country (Fig. 1).

1.2 Background of the study area

1.2.1 Zeuss-Koutine watershed

The watershed of Zeuss-Koutine (including Oum Zessar watershed and the northern part of the Dahar plateau) is situated in southeast Tunisia, northwest of the city of Médenine. In fact, it represents a transect that stretches from the Great Oriental Erg in the east and the Dahar plateau in the west, crosses the Matmata mountains between Béni Khédache and Toujane and the open Jeffara plain, then the saline depression (Sebkha) of Oum Zessar before ending in the Gulf of Gabès (Mediterranean sea). The study site covers an area of 897 km^2 and the approximate coordinates of the central point are 33°16'N and 10°08'E.

The study site is characterized by steppe vegetation in an arid climate. There are some wadi beds and watercourses with a distinct species composition. Total rainfall is low (100–240 mm) and highly irregular. Temperature differences are extreme between the seasons ranging from -3°C (winter) to a high of 48°C (in summer). It is estimated that approximately 25,000 people live on this site. Anthropogenic pressure has increased considerably since the 1960s leading to environmental degradation with reduced vegetation cover and poor eroded soils. Olive production and cereal cultivation, based mainly on water harvesting systems, represents the main agricultural activity in the area, but there is also traditional breeding of camels and small-stock, especially in the northern part of the Dahar plateau, which contributes to the livelihoods of the population. The household economy is based on a diversification of activities seen as an adaptation strategy to climate, market and risk mitigation. Migration is also an important economic activity, generating a substantial income.

The main stakeholders in the region are government agencies, especially the services of the Ministry of Agriculture who are responsible for all the agricultural development programmes in the area, as well as professional organizations (farmers union, livestock breeders association, and so on), civil society associations (NGOs), and research institutions (Arid Regions Institute [IRA], and l'Institut de l'Olivier) for specific scientific and technical backstopping.

1.2.2 Bou Hedma National Park

Bou Hedma National Park (34°39'N and 9°48'E) covers an area of approximately 16,488 ha and was designated as a UNESCO biosphere reserve in 1977. The park is divided into different zones: three Integral Protection Zones (IPZ) or core areas, two buffer zones (BZ), and two agricultural zones (AZ) or transition areas. The altitude varies between 90 m and 814 m above sea level.

The park is characterized by an arid Mediterranean bioclimate with a moderate winter (Le Houérou, 1959), with a mean annual rainfall of 180 mm, a mean annual temperature of 17.2°C, and a minimum and maximum monthly mean temperatures of 3.8°C (December and January) and 36.2°C (July and August), respectively.

The Bou Hedma soils are skeletal in the mountainous area, superficial and stony in the piedmont, and sandy to sandy-loamy in low-lying flat areas. On the mountainous massif, natural vegetation is dominated mainly by vestigial forest species such as *Juniperus phoenicea*, *Periploca angustifolia*, *Rhus tripartitum*, *Olea europaea*, *Rosmarinus officinalis* and *Stipa tenacissima*. *Artemisia herba-alba*, *Anarrhinum brevifolium*, *Gymnocarpos decander,* and *Helianthemum kahiricum* colonize the piedmont. The flat area is dominated by pseudo-savannah vegetation with *Acacia tortilis* subsp. *raddiana* as the only tree stratum. However, the understory stratum is dominated by many species such as *Rhanterium suaveolens*, *Cenchrus ciliaris*, *Haloxylon schmittianum*, *Haloxylon scoparium* and *Salvia aegyptiaca*.

It is estimated that approximately 15,000 people live in scattered dwellings in the vicinity of the park. They practice mainly arboriculture (fruit and olive trees) and cereal cultivation, using water harvesting structures (tabias) and small scale irrigation, and livestock breeding.

1.3 Main features and challenges of the study sites

In Tunisia, drought and desertification particularly affect the arid and semi-arid regions, which are characterized by unfavourable climatological and hydrological conditions. Low and erratic rainfall results in frequent periods of serious drought, alternating with flood periods and causing major damage and soil erosion (Floret and Pontanier, 1982). Over the past two decades, the Tunisian government has engaged in a vast programme for the conservation and mobilization of natural resources with national strategies for soil and water conservation, forest and rangelands rehabilitation, and water resources.

In the Jeffara, which encompasses one of the study sites (Zeuss-Koutine), the traditional production systems combine a concentration of means of production in limited areas with an extensive exploitation of pastoral resources in the major zone. However, during the last forty years, the rapid and remarkable evolution of these production systems together with natural resource exploitation has increased the exploitation of groundwater aquifers by drilling for the development of irrigated crops and industry. This is coupled with the rapid extension of fruit tree orchards at the expense of natural grazing lands, which followed the privatization of collective tribal lands. In this context, the spatial agrarian system momentarily disappeared and was replaced with other interconnected and adjacent production systems. Those systems are marked by competition for access to the natural resources, especially for land ownership and water use (Genin *et al.,* 2006). Huge efforts for soil and water conservation and rangelands rehabilitation have been implemented whose immediate effects are visible, but their efficiency in the short and long term has not yet been assessed and evaluated in detail.

In the framework of the national strategy for the preservation of natural ecosystems, numerous national parks have been set up to represent the main ecological zones of the country. The Bou Hedma National Park is considered one of the most important national parks in the country because it covers a pseudo-savannah-like ecosystem where the endangered *Acacia raddiana* can be found; a key tree species in the pre-Saharan zone that survives on the fringes of the desert. A number of studies has already been conducted in the fields of phenology and ecophysiology on the Acacia trees. However, the dynamics of Acacia populations and their effect on the soil's physical and chemical properties have not been studied in detail.

In line with the UNCCD National Action Programme, in which desertification is considered a development issue, a search for alternative income-generating activities for the affected local population has become a priority so as to alleviate pressure on the natural vegetation, while reducing poverty.

Within this framework, the SUMAMAD objectives, as applied in the Tunisian research sites, are as follows:

TABLE 1.
AN OVERVIEW OF SUMAMAD ACTIVITIES AND OBJECTIVES

SUMAMAD activities	Objectives in Tunisia
Assessment of the current status of integration	Identify interactions between the evolution of resource utilization methods, production systems and land ownership.
Identification of practices for sustainable soil and water conservation	Assess and validate the various old and new practices for soil and water management and combating desertification.
Identification of training needs	Provide suitable training for the IRA team and its partners in the various themes within the project.
Identification of one to two income-generating activities	Identify alternative income-generating activities to improve the livelihood of the local population, while alleviating the pressure on natural resources.

2. Improved dryland agriculture and rehabilitation of degraded areas

2.1 Groundwater recharge by water harvesting techniques

In the framework of the implementation of the national strategy for soil conservation since 1990, numerous groundwater recharge structures (gabion check dams and recharge wells) (Fig. 2) have been installed to mobilize the runoff water for the replenishment of the underneath aquifers. Around ten recharge wells have also been installed to ensure the direct recharge of flood water retained behind gabion check dams to replenish the aquifers underneath. Previous studies (Yahyaoui & Ouessar, 2000; Ouessar, 2007) have shown that short-term effects are positive, but that the long-term impacts need to be investigated. The aim of this study is therefore to assess the performance of these structures. The work conducted in the watershed of wadi Hallouf (Médenine) involved the preparation of a field survey template and the implementation of surveys in the field. A total of 58 gabion recharge check dams were studied, which were constructed between 1993 and 1999 in the framework of the implementation of the national strategies for soil conservation and water resources mobilization.

The work conducted in the watershed of wadi Hallouf (Médenine) consisted of:

- Inventory and detailed characterization of the recharge wells.
- Collection of additional information: piezometric levels, gabion check dams characteristics and location, geological and hydro-geological settings, and so on.
- Analysis of the collected data.

A total of 10 recharge wells have been studied.

Figure 2.
Gabion check dam (right) and recharge well (left). © M. Ouessar, M. Sghaier, M. De Boever, D. Gabriels

2.2 Dynamics and ecological impacts of Acacia plantations

2.2.1 Estimation of Acacia population and tree attributes

Forest ecosystems influence human well-being. About 30 per cent of the world's forests have groundcovers between 10 and 30 per cent. Although these forests are essential resources for millions of rural people in developing countries, they are badly and often under inventoried. Moreover, these open forests have special features that provide excellent opportunities for forest inventory using remote sensing. Hence, future trends in these forests are hard to predict (Ozdemir, 2008). The aim of this study is to perform a mono-temporal assessment of the amount of *Acacia raddiana* and their crown diameter classes in Bou Hedma National Park using high-resolution satellite images.

For satellite image processing, ground truth is required for the classification and calibration of empirical models to estimate the attributes of individual *Acacia raddiana* trees. In order to cover the different spatial arrangements of trees, a random sampling scheme was selected (Fig. 3). For each tree or tree group, different tree attributes were measured: bole diameter at the base and at breast height, total tree height, and crown diameter (Fig. 4). Stages of phenology (leaf, flower and fruit), soil stoniness, and erosion crust under and outside the tree canopy were visually determined using distinctive classes. Finally, vegetation under the tree canopy and outside the tree canopy was identified, together with the presence of animal faeces. Data were normalized and compiled in a relational database.

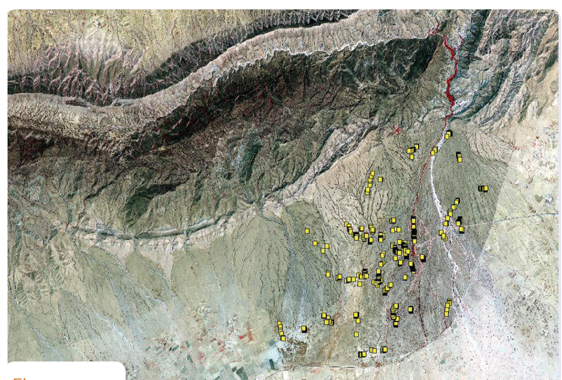

Figure 3.
Sampling scheme in Bou Hedma National Park.
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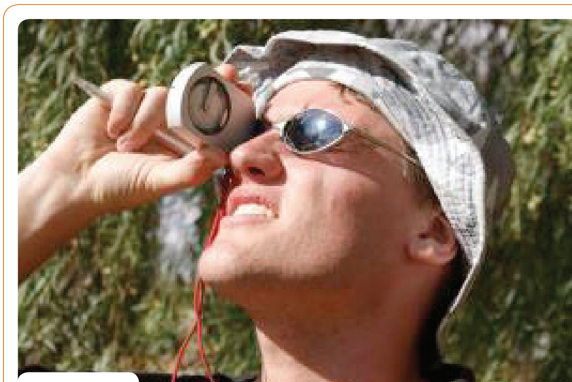

Figure 4.
Height determination of tree using a clinometer.
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2.2.2 Effects of reforestation on soil properties, near-surface water content and microclimate

The aim of this study is to quantify the effects of the Acacia plantation on chemical and physical soil properties, near-surface water content and microclimate. To enable the quantification of these effects, two sub-habitats were distinguished: tree-covered and open areas, and underneath and outside the canopy of Acacia trees, respectively (Fig. 5). Underneath the canopy, seven different sampling locations were selected: four along a transect to the north, and the remaining three in the other major wind directions (Fig. 6).

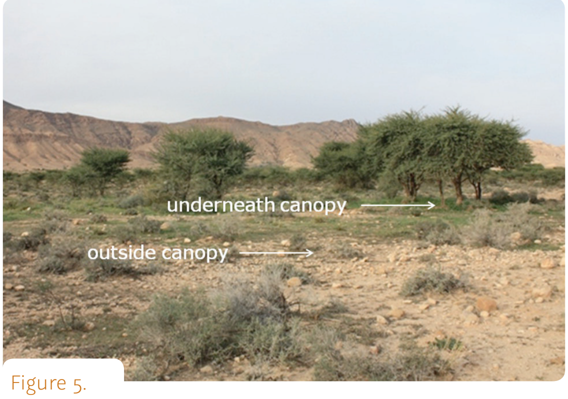

Figure 5.
Sub-habitats underneath and outside Acacia trees in Bou Hedma National Park. © M. Ouessar, M. Sghaier, M. De Boever, D. Gabriels

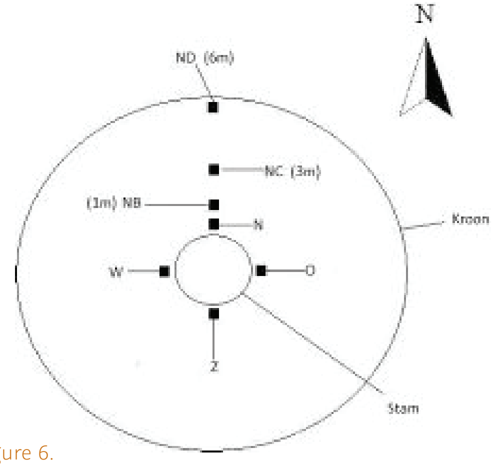

Figure 6.
Sampling scheme underneath an Acacia tree.
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Concerning the soil chemical properties, samples were taken of the top layer (0–10 cm) and analysed for pH, EC, %OM, %$CaCO_3$, Ca, K, Mg, Na and P. Concerning the soil's physical properties, infiltration measurements were undertaken underneath and outside the canopy with a tension disk infiltrometer to determine the unsaturated hydraulic conductivity at three different pressure heads (-3, -6 and -12 cm) and the derived saturated hydraulic conductivity (Fig. 7). In addition, undisturbed soil samples were taken (using a Kopecky ring) to determine the bulk density and the soil water retention curve. Beside the structural characterization of the soil, its texture was also determined.

To investigate the effect of the Acacia plantation on the near-surface water content (0–10 cm), a monitoring campaign, after an extreme rainfall event of 26.5 mm during autumn 2011, was executed using a TDR probe (Fig. 8). Measurements were taken underneath and outside the canopy, respectively at 0.5 and 10 m in the northern direction of each tree. To further investigate the soil water balance underneath (along a gradient) and outside the canopy of one tree, TDR sensors were installed at four different depths (5, 15, 25 and 40 cm) during autumn 2012 to automatically monitor soil water content over one year (Fig. 10).

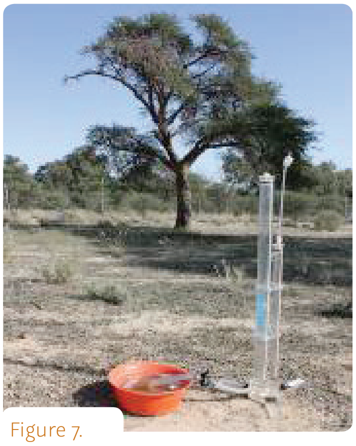

Figure 7.
Infiltration measurements using a tension disk infiltrometer.
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Figure 8.
Trime-FM TDR (Eijkelkamp Agrisearch Equipment, Giesbeek). © M. Ouessar, M. Sghaier, M. De Boever, D. Gabriels

In 2009, IRA installed a weather station in Bou Hedma National Park to automatically monitor some agro-meteorological parameters: temperature, rainfall, air temperature and humidity, wind velocity and direction, and global radiation (Fig. 9). To characterize the microclimate underneath and outside the canopy, and to link those measurements with the already installed weather station, measurements of the soil and air temperatures and humidity were done during autumn 2009 and 2011. In order to monitor those parameters automatically, a small weather station was installed under one tree during autumn 2012 (Fig. 10).

Figure 9.
Weather station inside Bou Hedma National Park installed by IRA. © M. Ouessar, M. Sghaier, M. De Boever, D. Gabriels

Figure 10.
Installed weather station and TDR sensors under one tree inside National Park Bou Hedma © M. Ouessar, M. Sghaier, M. De Boever, D. Gabriels

3. Scenarios for future landuse changes

The impact analysis of land use changes on livelihoods was based on the Sustainable Livelihoods Framework (SLF), which has been applied with a group of households located at four different agro-ecological and socioeconomic zones or land use type (LUT) of the Wadi Hallouf/Oum Zessar watershed (Médenine) (Fig. 11).

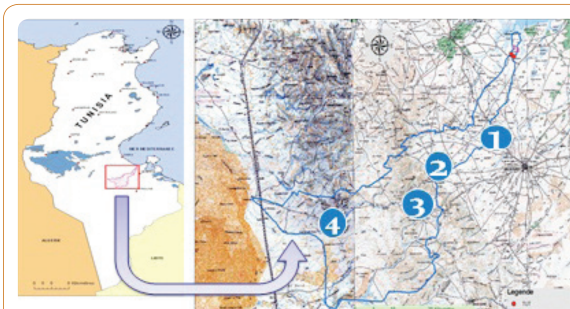

Figure 11.
Location of interviewed households by LUT
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TABLE 2.
LIST OF INDICATORS BY TYPE OF LIVELIHOOD CAPITAL

Physical capital	Natural capital	Human capital	Social capital	Financial capital
- Farm equipment - Mechanization - Transport	- Heads of livestock - Farm size (Land) - Land quality - Water quality - Rangeland quality	- Education - Household size - Number of workers - Know-how - Technical support	- Organizational affiliation - Access to land - Market Access - Access to health - Access to education - Access to safe water	- Subsidies - Farm income - Income from livestock - Off-farm income

A set of indicators given in Table 2 by type of livelihood assets was identified. These assets together enable people to pursue sustainable livelihoods.

4. Ensuring sustainable livelihoods through alternative income-generating activities

4.1 Aromatic and medicinal plants in the Matmatas (southeast region of Tunisia) as a source for alternative income generation[1]

The main aim of this activity is to combat natural resources degradation and improve the income of rural communities through rehabilitation, conservation and production diversification. For nearly a decade, aromatic and medicinal plants (AMP) in Tunisia have enjoyed renewed interest at the various departments, especially in agriculture, health, environment, industry, and scientific research. This sector is a means of diversifying agricultural production and the exploitation of fragile areas with limited economic potential. Thus, it can offer populations in fragile areas a relatively good source of income.

The overall objective is to increase and diversify sources of income for both women and men in the area through improved AMP productivity and market linkages. Two components have been addressed (Sghaier *et al*., 2011), as below.

Pilot development of the AMP value chain: this component aims to analyse the AMP value chain and to identify key constraints and entry points for smallholders in order to increase the value added retained at their level. The component will include the following activities:

- Assessing the AMP value chain in the areas of Médenine and Tataouine covered in this project. The assessment will result in the identification of constraints and opportunities for smallholders, traders and processors, as well as identification of collaborative initiatives between producers and processors. The result should also highlight activities that have the highest impact on women's economic empowerment.

1 This activity is carried out as part of a larger project, the Rehabilitation, Conservation and Promotion of Aromatic and Medicinal Plants (AMP) in the Matmatas (southeast region of Tunisia), coordinated by Prof M. Neffati (Rangeland Ecology Lab, IRA) and funded by ICARDA and IFAD.

- Based on the results of the assessment, the activity will pilot the development of market linkages between farmer groups, traders and processors. This implies the following: a) collaborating with local non-governmental organizations (NGOs) in the formation of farmer groups, while making sure that women are equally integrated in the groups; and b) the identification of traders and processors interested in piloting an improved AMP value chain.

Agricultural extension of the AMP production: this component aims to support farmer groups in the AMP quality production required by the market. This includes:

- Organizing training sessions for farmer groups and on-farm visits to members of these groups on AMP production, market standards, and the impact of quality change on sale price and producer margins. The sessions include practical training on complementary activities to AMP such as apiculture.

- Working with farmer groups to test and adapt the technical packages developed by IRA.

- Assisting farmer groups in the collection, conditioning and AMP seed production.

- Short technical briefs on market-oriented production of AMP, based on the results of the training and testing of technical packages produced by the project.

This part aims to describe and analyse the development work of an experimental value chain based on the mint species as an aromatic and medicinal plant. Mint has been identified at the first stage of the Arid Regions Institute (IRA) – International Center for Agricultural Research in the Dry Areas (ICARDA) – International Fund for Agricultural Development (IFAD) project as one of the priority target species for the project. Indeed, the study of the sector of the main aromatic and medicinal plants species has been utilized to implement the pilot dried mint project in the governorates of Tataouine and Médenine.

The choice and selection of this species were made following a consultation process with local stakeholders through planning workshops. These workshops were held in El Smar and Ghordhab (Tataouine Governorate) with the participation of researchers from the IRA, PRODESUD project staff, representatives of the Groupement de Développement Agricole (GDA)[2] of El Smar Farech, and a set of traders and farmers interested in AMP.

The main steps and activities in the implementation of the experimental value chain of mint can be summarized as follows (Fig. 12):

- Planning meeting with the GDA of Smar and El Ferch and farmers.
- Identification of producers (mainly women) in both regions.
- Plot installation for producers.
- Crop management.
- Harvesting and marketing the first fresh product at the local market.
- Training on techniques for drying and conditioning.
- Harvest products for packaging.
- Traditional drying.
- Drying and packaging industry (in Perfect Food, Médenine).
- Packaging design and prototyping.
- Production of packaging.
- Placing the goods in packaging.
- Supervision of merchant partners (upgrade).
- Distribution and sale of products to consumers.

2 Agricultural Development Group.

Figure 12.
Illustration of the main steps of the installation of the mint sector in the governorate of Tataouine.
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4.2 Solidarity tourism: a source for alternative income of rural families in the drylands of Tunisia[3]

Equitable (justice) and solidarity tourism is defined by tourism values that place the human being at the heart of the journey, and which are a clear indication of a will to develop territories. The involvement of local populations in the different phases of the project, respecting human beings, their culture, nature, and a more equitable distribution of all resources generated are the basis of this type of tourism.

It is under this umbrella that a group of NGOs[4] in southeast Tunisia are working together to develop a network for solidarity tourism in the region. SUMAMAD co-financed two workshops devoted to training members of the NGOs on the development of projects and activities in this field.

Figure 13.
First workshop (May 2011).
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Figure 14.
Second workshop (November 2011).
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3 This work was mainly conducted by: R. Jaafar, A. Hamrouni, M. Ouessar and M. Sghaier.

4 AJZ: Association de Jeunes de Zammour (Médenine); ASOC: Association de Sauvegarde de l'Oasis de Chénini, Gabès; ASNAPED: Association de Sauvegarde de la Nature et de Protection de l'Environnent à Douiret, Tataouine.

Meanwhile a specific programme has been launched between AJZ and Tamadi Voyages[5] – a travel agency based in France and Belgium specializing in this type of tourism.

5. Results obtained

5.1 Groundwater recharge structures

The rate of silting up the structures is very high and decreases from upstream (90%), middle stream (88%) to downstream (81%). Exceptional rainfall events could wash up large numbers of those structures: 51% of the structures are in very bad condition and 40% are in average condition after heavy floods.

Out of the 10 already installed recharge wells, only three of them are functioning properly. The major causes are: underestimation of the required depth to reach the groundwater or permeable layer, use of inappropriate drilling machinery that encounter difficulties in digging through the very hard layers, and unexpected geological settings (faults, geological layer) because of the absence of geophysical surveys.

5.2 Acacia plantations

5.2.1 Vegetation dynamics and tree attributes

Geographic Object-Based Image Analysis (GEOBIA) can correctly delineate trees with both small and large crown diameters. The distribution of crown diameters shows a clear presence of trees with diameters between 3 and 5 m. An exponential decrease is present for trees with larger crown diameters. Trees with smaller crown diameters seem to be less present. This is in accordance with field observations, however it is probable that smaller trees are not all detected by segmentation or classification algorithms, especially for crown diameters at 0–2 m. Moreover, this structure is highly influenced by reforestation actions, which were undertaken in 1963, 1966/1967, 1995/1996 and 2001 (Lazhar Hamdi, personal communication). Results indicate an uneven-aged forest structure, with a lack of small individuals. Reasons for the lack of small individuals are limited natural regeneration and no visual detection of small individuals during image processing.

Analysis of erosion crust classes revealed a higher erosion crust cover outside than under the tree canopy, indicating soil protection by tree cover. Stoniness classes were consistent with field observations with a gradient from the mountain towards the sandy plain.

Based on the presence of animal faeces, a clear preference for grazing by herbivorous fauna (*Oryx sp.*, *Addax sp.* and *Gazella sp.*) was found near larger trees. This is mainly driven by the amount of shade provided by larger trees.

Empirical equations to estimate individual *Acacia raddiana* tree attributes (bole diameter, stem volume and tree height) were modeled and performed with acceptable root-mean-square error (RMSE) values.

Density was determined by counting the number of Acacia trees (both groups and individuals) per ha. A mean density of 8.4 trees per ha was found, in line with the historical density of trees in Bou Hedma National Park (4 to 25 trees/ha).

5.2.2 Soil properties and microclimate

Significant differences were found in soil chemical properties, but there was no real consistency between them. A trend of decreasing values was

5 www.Tamadi.org

observed when moving away from the stem in the transect to the north, and this for all the parameters. In comparison with a previous study in the same area executed during the growing season of 2003–2004 (Abdallah *et al.*, 2008), a general improvement of the chemical quality of the soil can be noticed, especially the organic matter content and this outside of the canopy. These findings suggest that the positive effects of Acacia plantations are already extended to the open area.

Soil and air temperature were much lower underneath than outside of the canopy, especially during the hot summer months. The trees have a buffering effect on the microclimate, and extreme conditions are avoided. Higher relative air humidity was observed under the canopy than outside the canopy. The relationship between the meteorological parameters underneath and outside the canopy and their effect on the soil water balance will be further investigated.

Clear differences were found in the soil hydraulic properties and soil water retention underneath and outside the canopy of Acacia trees. Acacia plantations have a positive effect on the initial water content due to enhanced infiltration, and the related water retention capacity of the upper soil layer due to the improved soil structure. Moreover, Acacia trees can ameliorate the transpiration and productivity of the ground cover vegetation by favouring the climatic conditions underneath and in the direct neighbourhood of their canopies (see Annex for poster of De Boever *et al.* (2012), presented at the Eurosoil 2012 conference).

5.3 Scenario for future landuses

In Figure 15, we show how these livelihood capitals have changed or shifted in the four locations during 2000 and 2010. It was noted that the natural capital has significantly decreased for most of the households in location 1 with very little increment in financial capital. Conversely, the financial capital of households in location 3 has increased due to income from off-farm employment, although the natural capital has declined. The human, social and natural capitals of households in location 2 have all decreased, but interestingly the financial capital has remained unchanged. Location 4, in the rangelands, appears to perform well with notable increases in human, physical and financial capitals and a very small decline in natural capital, indicating that the agro-pastoral system remains a viable livelihood with limited negative impact on the natural resource base, especially if the system is well managed. Ultimately, the consequences to livelihoods vary depending on the local environment and its socioeconomic conditions.

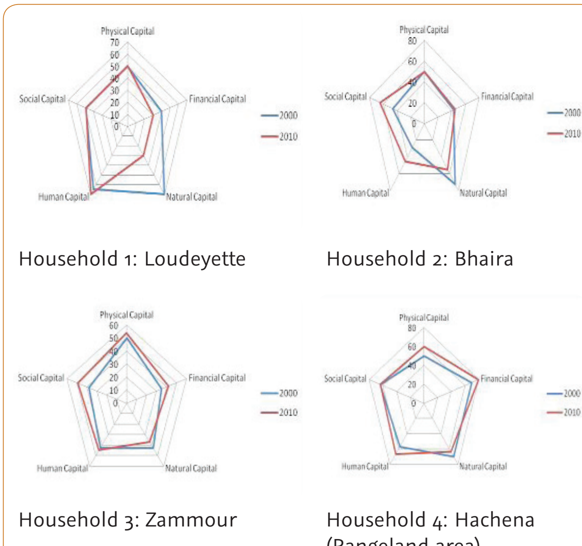

Figure 15.
Differences in livelihood structure during 2000 and 2010.
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The livelihood trends in terms of five capital assets are presented in Figure 16. Indeed, social capital increases rapidly compared to human, physical and financial capitals at the expense of the natural capital, which shows a downward trend due to intensification, over-extraction and poor management.

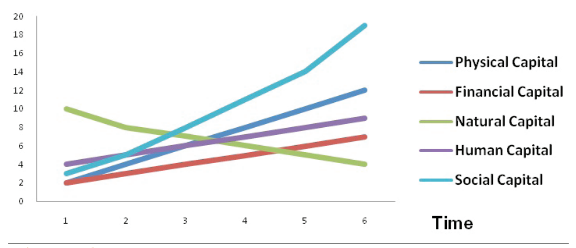

Figure 16.
Trends of different livelihood capitals over time.
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To conclude, land use is distinctively marked as either rangeland or cropland. Land use change was primarily driven by the land privatization policy and population growth. The pattern of land use change was linear, that is, from rangelands to agro-pastoral and croplands, although variability within these land uses is quite high. Land privatization triggered sedentary agro-pastoral systems, agricultural expansion in rangelands, and the intensification of crop and livestock system, which opened up opportunities for agriculture development, pushing farmers to graze and farm in marginal areas. However, optimal production is basically at odds with low and irregular rainfall, hence, the expansion of irrigated perimeters continues through the exploitation of surface and deep groundwater aquifers, running the risk of over-exploitation and the depletion of this very important resource.

Furthermore, the process of land degradation continues through soil, water and wind erosion, despite efforts to mitigate them. Biodiversity loss has been also observed with the conversion of native rangelands into agriculture. The consequence to livelihoods has been ambivalent. The livelihoods analysis has shown that social capital has increased more rapidly than human, physical and financial capitals at the expense of the natural capital. This could mean that building social capital has seen the greatest impact of past and ongoing interventions. Furthermore, the livelihood analysis also suggest that increases in financial capital is only marginal, even if the natural resources were to be depleted this will become more serious if the status quo is left unchallenged. Among the many land management options, the jessour and tabias, spillway and resting techniques were commonly preferred, while plantation and contour stone ridges were rated low.

5.4 Alternative income generation

5.4.1 Mint value chain

The approach channel aimed primarily at poor families and rural women (52 women). It allowed the mobilization of various socio-professional categories (farmers, mostly women, GDA, traders, industrialists, and so on). The value chain approach has increased the profit margin of mint (200 to 800%) and created new sources of income for families and rural women. It has also trigged the establishment of local dynamics based on partnership between actors (farmers, GDA, CRDA, IRA, and so on).

The sector has also developed synergies between partners, stakeholders and the local population (IRA, ICARDA, CRDA, PRODESUD, GDA, women, men, UTAP FIU authorities, and so on).

The sale of dried mint allows different operators (GDA, herbalists and intermediate traders) to obtain a higher profit margin than for the sale of fresh mint. More operations in the sector developed processes for packaging and processing, plus the industry generated a higher gross margin without touching or reducing the share of producers, who maintain their profit margins at a satisfactory level.

5.4.2 Solidarity tourism

The project contributed towards the capacity building of some members of the main NGOs operating in the region (southeast Tunisia) in the domain of solidarity tourism as a form of alternative income generation for the local population. In the mountain region of Beni Khedache (province of Médenine), the NGO of AJZ, which is an active collaborating partner of IRA, succeeded in integrating their intervention area (Zammour) in one of the official circuits of one of the more reputed international travel agencies specializing in solidarity tourism (Fig. 17).

6. Recommendations for sustainable drylands management

6.1 Natural resources management

- Reconsidering the main roles assigned to groundwater recharge structures so as to increase their efficiency.
- Many factors need to be considered for the selection of the recharge well sites. The approach applied represents one of the approaches to be followed.
- Reforestation of degraded drylands is possible and has major beneficial environmental impacts on ecosystem services.

6.2 Policy decision-making system

The situation in the study area indeed requires an integrated natural resources management (NRM) approach that is embedded in the broader context of rural development. Participatory integrated NRM however, requires a shared understanding of what multiple stakeholders expect to get out of the watershed, as a basis for broader collective action with local, regional and central government actors. The use of participatory tools could contribute substantially to:

- Mutual learning among local and external actors by sharing experience and jointly reflecting on current and potential problems and potential management options.

Figure 17.
The Zammour circuit is now officially endorsed by the Tamadi network.
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- Create a common understanding of problems, potentials and opportunities by integrating external and internal perceptions.
- Strengthen trust and collaboration among concerned stakeholders.
- Identify existing and new NRM technologies.

6.3 Income generation

- Small scale projects could be launched based on the aromatic and medicinal plants in order to provide employment and/or alternative income-generation activities.
- Better organization of the marketing channels can assist in promoting MAP programmes.
- Encourage solidarity tourism to expand in the region.

7. Research institution and team composition

Partner institution
Institut des régions arides (IRA)
Route du Djorf Km 22.5 Médenine - Tunisia

Team leader
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Project team members
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Geography
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Rachid Jaafer
Association des Jeunes de Zammour à Béni Khédache (Youth Association of Zammour in Beni Khédache) (AJZ)

8. List of national seminars

In addition to the various informal meetings and exchanges, seminars and workshops have been organized to which national partners and local authorities were invited to attend.

TABLE 3.
LIST OF NATIONAL SEMINARS

Date	Participants	Organizations	Main Outcomes/ recommendations
11/11/2009	17 (10 M; 7 F)	CRDA, ODS, NGOs	First hands on the project's phase II: Background, objectives main expected results.
10/06/2010	22 (14M, 8F)	CRDA, ODS, OEP, UTAP, NGOs	Better integration of research actions in development programmes. Specific attention to be given to climate change impacts and adaptation.
17/06/2011	20 (15M, 5F)	CRDA, NGOs, OEP, Gov.	Evaluation of government efforts/ programs.
06/09/2012 04/12/2012	24 (18M, 6F) 14 (12M, 2F)	CRDA, NGOs, OEP, ODS, Gov.	Mainstreaming of risks and changes Develop strategic planning program

9. Publications as a result of SUMAMAD

De Sadeleer, K. 2010. Influence of afforestation on soil properties and microclimate in Bou-Hedma National Park in semi-arid Tunisia. MSc thesis, University of Gent, Belgium.

Delaplace, K. 2010. Monotemporal assessment of amount of Acacia's (individuals, tree groups) and estimation of crown diameter classes of *Acacia raddiana* in Bou-Hedma National Park, Tunisia. MSc thesis, University of Gent, Belgium.

Delaplace, K., F. Van Coillie, R. De Wulf, D. Gabriels, K. De Smet, M. Ouessar, A. Ouled Belgacem, H. Taamallah. 2010. Object-based assessment of tree attributes of *Acacia tortilis* in Bou-Hedma, Tunisia. Poster presented at the GEOBIA 2010 Conference, June 29–July 2, 2010. Ghent, Belgium.

Delaplace, K., F. Van Coillie, R. De Wulf, D. Gabriels, K. De Smet, M. Ouessar, A. Ouled Belgacem, H. Taamallah. 2010. Object-based assessment of tree attributes of *Acacia tortilis* in Bou-Hedma, Tunisia. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. XXXVIII-4/C7.

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11. Annex

Influence of Acacia plantations on the soil water content in arid zones of Tunisia

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Background

- important role of trees in arid regions
  - reduction of negative effects of soil aridity and climate (Anderson et al., 2001)
  - strong influence on the environments under their canopy (Belsky and Canham, 1994)
  - effective measure against soil erosion and desertification (Young, 1989)
- *Acacia raddiana*
  - keystone species persisting on the edge of the desert
  - important woody species in pre-Saharan Tunisia
  - able to resist extreme droughts

Objective

To investigate the impact of an *Acacia raddiana* plantation on the near-surface soil water balance and more specific on the water content and the water-holding capacity of the soil

Study area

Fig. 1. Geographical location of National Park Bou-Hedma (Tarhouni et al., 2007)

- National Park Bou-Hedma (Fig. 1 & 2)
  - location: central Tunisia
  - total surface: 5.115 ha
  - pseudo-savanna ecosystem
  - climate:
    - arid with moderate winter
    - annual rainfall of 180 mm
    - rainfall season from Sept. till Dec.
  - since 1950: different afforestation programmes with *Acacia raddiana*
- 3 study locations:
  - two sub-habitats inside National Park Bou-Hedma (Fig. 3):
    - underneath canopy Acacia
    - outside canopy Acacia
  - outside National Park Bou-Hedma (Fig. 2)

Fig. 2. Inside (white border) and outside National Park Bou-Hedma (zone between white and red border)

Fig. 3. Inside National Park Bou-Hedma with sub-habitats underneath and outside the canopy of Acacia

Methodology

Soil water content

- monitored for 21 days
- after extreme rainfall event of 25.6 mm
- upper soil layer (0-10cm)
- simultaneously inside (underneath and outside canopy) and outside the park
- using TRIME-FM TDR (Time Domain Reflectometry) with 3 rods of 12 cm (Fig. 4)

Fig. 4. Trime-FM TDR (Eijkelkamp Agrisearch Equipment, Giesbeek)

Soil water retention curve

- soil water retention curve (SWRC) relates the pressure head to the water content of the soil
- used to determine the soil water-holding capacity, i.e. the water content between field capacity (F.C.) and permanent wilting point (P.W.P.)
- Sandbox apparatus (Eijkelkamp Agrisearch Equipment, Giesbeek, The Netherlands) was used to determine SWRC points at high pressure heads
- Pressure plate apparatus (Soil Moisture Equipment, Santa Barbara, CA) was used to determine SWRC points at low pressure heads

Results

- soil water content
  - highest underneath the canopy, second highest outside the canopy and lowest outside the park one day after the rainfall event (d1) (Table 1)
  - inside the park, the decline in water content was similar underneath and outside the canopy during the first week (d1-d8) (Fig. 5)
  - during the second and third week (d8-d21), the decline in water content was more than twice larger underneath than outside the canopy
  - outside the park, the decline in water content was limited
- water-holding capacity
  - significantly higher ($p<0.05$) underneath than outside the canopy: 0.27 ± 0.04 vs. 0.22 ± 0.02 $m^3\ m^{-3}$ (Fig. 6)

Table 1. Mean and standard deviation (SD) for soil water content inside (under and outside canopy) and outside park

($m^3\ m^{-3}$)	under canopy	outside canopy	outside park
θ(d1)	0.30 ± 0.03	0.25 ± 0.04	0.14 ± 0.01
θ(d21)	0.08 ± 0.01	0.07 ± 0.01	0.04 ± 0.01
θ(d1-d8)	0.14	0.14	0.07
θ(d8-d21)	0.09	0.04	0.03

Table 2. Mean and standard deviation for organic matter content (O.M.) and soil texture inside (under and outside canopy) and outside park

	under canopy	outside canopy	outside park
O.M. (%)	2.32 ± 1.04	0.72 ± 0.11	0.60 ± 0.08
Soil texture	Sandy Loam	Sandy Loam	Sand
clay (%)	4.1	6.0	-
silt (%)	29.8	28.0	-
sand (%)	66.1	66.0	-

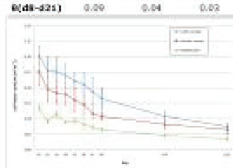

Fig.5. Change of mean soil water content (with error bars for SD) for 21 days after rainfall event under and outside canopy (inside park) and outside park

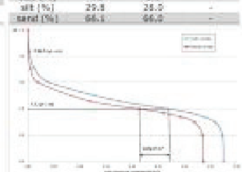

Fig. 6. pF curve under and outside canopy inside park with indication of difference in field capacity (F.C.) and similarity in permanent wilting point (P.W.P.)

Discussion

- difference in initial soil water content underneath and outside the canopy (Fig. 5) can be related to their difference in water-holding capacity of 0.05 $m^3\ m^{-3}$ (Fig. 6) and the latter will be affected by organic matter content but not by texture (Table 2)
- higher evapotranspiration underneath compared to outside the canopy starting from the second week (Fig. 5)
- as evaporation will be reduced underneath the canopy due to shading, the decline in water content can mainly be addressed to increased transpiration of the ground cover vegetation
- low initial soil water content outside the park can be explained by the combined effect of rapid evaporation of the water before entering the soil, sandy soil texture and low organic matter content (Table 2)

Conclusions

- positive effect of the Acacia plantation on the initial water content and the related water holding capacity of the upper soil layer can be clearly noticed
- Acacia trees can enhance the transpiration and productivity of the ground cover vegetation by favoring the climatic conditions underneath and in the direct neighborhood of their canopies

Future research

Fig. 7. Soil water balance underneath and outside canopy (modified from Joffre and Rambal, 1993)

- impact of Acacia plantation
  - on the soil water balance and related ecosystem services
    - ΔS = P - (R) - ETa - D (Fig 7, with ΔS: change in soil water content, P: precipitation, R: runoff, ETa: actual evapotranspiration and D: drainage)
  - estimation of ETa underneath and outside canopy

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