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Agricultural Technological and Institutional Innovations for Enhanced Adaptation to Environmental Change in North Africa

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1. Introduction

North Africa typically is a dry region, comprising the countries of Algeria, Morocco, Tunisia, and Libya, where four subregions may be easily distinguished, namely (i) a northern subhumid coastal subregion, bordering the Mediterranean sea (and the Atlantic Ocean for western Morocco), where average annual rainfall is relatively high, generally above 500 mm and where soils are relatively good for farming; (ii) a semi-arid elevated subregion flanking the first subregion from the southern side, from which it is separated by the Atlas mountains and where rainfall is around 300-500 mm, and soils are light calcareous silt-loam; it is bordered on the southern side by (iii) an arid, lower-altitude subregion, with silt-sandy soils and an average rainfall of 100-300 mm; and (iv) Sahara desert subregion covering the largest part of the countries. Libya is predominantly (90%) desert land, except for a narrow coastal area where some agriculture is practiced. Therefore, reference in this chapter will be mainly made to the 3 countries of Algeria, Morocco and Tunisia.

North Africa is marked by an acute water scarcity, combined with a highly variable Mediterranean climate. While the average world per capita share of fresh water is 7000 cubic meter (m^3), all three North African countries are below the water poverty threshold of 1000 m^3 (Table 1). Agriculture uses the largest share (up to 80%) of available water resources in North Africa where rainfed cropping predominates. The scarcity of natural water resources, combined with the highly variable and generally very low rainfall in most of the region explain in part the low agricultural productivity, especially of key crop commodities, and the reliance of North African countries on food imports to meet their growing national demands; this is especially true for Algeria that has the largest population, and the lowest agricultural contribution to country GDP and to total employment. Water scarcity is further exacerbated by the competition for water from domestic and industrial uses, and the increasing population and urbanization. Cereal crops, mainly wheat and barley, are the major crop commodities grown in North Africa, but their contribution to national food security and household income remains low (Table 1).

| Characteristic | Algeria | Morocco | Tunisia |
|---|---------|---------|---------|
| Population (million) | 34.4 | 31.6 | 10.2 |
| Total area (million ha) | 238.1 | 71.02 | 16.36 |
| Cultivated area (million ha) | 8.4 | 8.99 | 5.04 |
| Contribution of agriculture to GDP (%) | 8 | 17 | 10 |
| Rural population (% total population) | 35 | 44 | 33 |
| Employment in agriculture (% total employment) | 14 | 45 | 18 |
| Irrigated area (% cultivated area) | 6.9 | 16.6 | 8.0 |
| Total annual renewable water resources (km ³) | 11.67 | 29 | 4.6 |
| Annual per capita renewable water resources (m ³) | 339.5 | 917.5 | 451.9 |
| Wheat self-sufficiency (%) | 29 | 58 | 50 |

Table 1. Selected agricultural characteristics for three North African countries.

To lessen their dependence on highly unpredictable cereal harvests, small-scale farmers may also maintain a small-ruminant (sheep and goats) raising activity that provides them a buffer against poor crop harvest or crop failure in severe-drought years. In fact, the cereal-livestock system forms the backbone of agriculture in the semi-arid zones in contrast to the arid regions where small ruminant raising is the major agricultural activity. Horticultural crops and specific high value fruits (citrus fruits, grapes, etc.) are produced under moisture-favorable conditions in subhumid areas or under irrigation in other areas. Extensive cultivation of olives and other drought tolerant trees are generally produced under rainfed conditions in semi-arid and arid areas. Dates are produced in arid regions or in oases within desert areas.

The future of agriculture in North Africa is further threatened by unfavorable climate change that is expected to drastically affect agriculture productivity and people’s livelihoods. The rest of the chapter describes the perceived effects of climate change on natural resources and livelihoods of agropastoral communities in the region. Successful tools and approaches deployed to face climate change are highlighted, including both technological and institutional innovations.

2. Climate change and food security in North Africa

North Africa is widely known for its aridity and dry climate and for rainfall variability. Severe drought indeed has been common in the region, although the causes of such drought were not well understood (El Mourid et al., 2010).

In 2007, The Intergovernmental Panel on Climate Change (IPCC) confirmed (IPCC, 2007) that North Africa is among regions most affected by climate change (CC) with a temperature rise of 1-2°C during the past period 1970-2004, and that it will continue to be affected by global warming at the average rate of 0.2°C per decade for the coming 2 decades. In fact, anthropogenic green house gas (GHG) emissions from within North Africa are very low (Table 2) in comparison to developed countries that have an average emission rate of 14.1 ton CO₂ equivalents (TE-CO₂) and the climate change impacts in North Africa are essentially the result of global GHG emissions. According to the IPCC report, the winter season in North Africa will be shorter, leading to reduced yield and increased diseases and insect outbreaks. Precipitation will undergo a 20% drop by the end of the century, which would reduce crop yield and increase livestock losses. Heat waves also would reduce yield, while expected intense storms will cause soil erosion and damage the crops. High sea level rise

will lead to salt water intrusion and salinization of irrigation water (IPCC, 2007). In fact, the frequency of drought in Morocco, for example, has been independently reported (Magnan et al., 2011) to have increased from 1 in 8 years during the period 1940-1979, to 1 in 3 years during 1980-1995, and to 1 in 2 years during 1996-2002. Also, North Africa has been identified as a hot-spot for vulnerability to climate change, based on the analysis of NDVI (Normalized Difference Vegetation Index) data for the period 1982-2000 (De-Pauw, 2008).

| GHG emissions | Algeria | Morocco | Tunisia |
|---|---------|---------|---------|
| Total emissions (million TE-CO ₂) | 103.14 | 63.34 | 20.8 |
| Annual per capita emissions (TE-CO ₂) | 3.0 | 1.98 | 2.15 |
| Emission composition (%): | | | |
| - carbon dioxide (CO ₂) | 64.5 | 67 | 72 |
| - Methane (CH ₄) | 29.7 | 18 | 14 |
| - Nitrous dioxide (N ₂ O) | 5.9 | 14 | 14 |
| Agriculture contribution to total emissions (%) | 5.9 | 25 | 20 |

Table 2. Greenhouse gas (GHG) emissions in North African countries (2000).

The livestock sector has been described as a major contributor to global warming, accounting for 18% of the world anthropogenic GHG emissions, namely carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) (Koneswaran & Nierenberg, 2008; Steinfeld et al., 2006). Such large contribution of livestock to global warming is primarily the result of the highly intensive livestock system in well endowed, temperate regions of the world. In contrast, the livestock system in North Africa is primarily extensive in nature, where the dominant animals are sheep and goats, essentially raised in open rangeland fields, within the arid and semi-arid areas receiving less than 200 mm of rainfall and no fertilizer, apart from grazing animal manure. Such livestock contributes comparatively little to GHG emissions as compared to intensive livestock systems found in Europe and similar regions. However, rangelands in North Africa are subject to severe degradation, primarily because of cropping encroachment, which is responsible for 50% of rangeland degradation, versus 26% accounted for by overgrazing and 21% by fuel wood utilization. This trend opposes clearly that of the temperate areas, where overgrazing accounts for 70 % of land degradation (Le Houerou, 2000).

The food commodity crisis of 2008 brought-up awareness of the serious threat to food security in many of the world areas, including North Africa, where policy makers realized the importance of food production uncertainty imposed by the vagaries of changing climate and the repercussions it may impose on social and political stability. In all North African countries, swift decisions were taken to encourage farmers and other food producers assure the highest degree possible for self-sufficiency in strategic food commodities. All countries prepared a multi-year plan to boost local agriculture production, taking into consideration climate change and necessary mitigation and adaptation measures. For example, Tunisia developed a national strategy for dealing with climate change (CC) based on the implementation of specific CC studies and a national action plan for adapting to CC. The studies indicated that by year 2020, temperature will have increased by 0.8°C-1.3°C and rainfall dropped by 5-10%, depending on region (Dali, 2008). These effects will impact unfavorably on water resources, ecosystems and agro-systems (including olives, fruit, livestock and rainfed annual crops). Results also indicated a possible 50-cm sea level rise by year 2100, threatening coastal ecosystems and marine biodiversity. Several projects have

been developed within the framework of the Clean Development Mechanism (CDM) and are being implemented to reduce GHG emissions and launch actions for sustainable development across the country. In November 2008, Tunisia hosted an International Solidarity Conference on CC strategies for the African and the Mediterranean Regions. In Morocco, the Green Morocco Plan, a 10-year (2010-2020) program, has been started to upgrade the Moroccan agriculture through intensification of key production commodities and combating rural poverty across the country (Badraoui & Dahan, 2011). A new dimension was added to foster the capacity of smallholders cope with the impacts of climate change. Previously, Morocco hosted the Seventh Conference of the Parties to the UN Framework Convention on Climate Change (COP7) at Marrakech, in November 2001. In Algeria, the national 5-year plan (2009-2014) (Cherfaoui, 2009) for the “Renewal of agricultural and rural economy” aims to achieve food security and sustainable development through improved agricultural productivity, enhanced capacity building and employment, and preservation of natural resources, in the context of a changing environment.

3. Technological innovations for enhanced adaptation to climate change in North Africa

The International Center for Agricultural Research in the Dry Areas (ICARDA) has established strong partnership in dryland research jointly with national agricultural research systems (NARS) of North African countries with a focus to reduce food insecurity and enhance sustainable livelihoods of farming communities in the region. During the past 30 years, ICARDA scientists conducted joint dryland research with NARS partners, providing genetic resources and germplasm for selection of cereal and legume crops, and consultancy and training in soil, water and crop management, in integrated pest management, and in rangeland management and small ruminant husbandry. The joint work has been conducted in all North African agro-ecologies under the evolving stresses imposed by the ever-changing climate and the trend of increasing drought and high temperature. The chapter highlights some of the NARS-ICARDA achievements in the area of adaptation to unfavorable environmental changes.

3.1 Soil and water conservation and use

Arable lands cover only a small fraction of total land area in North Africa (Table 1) soils vary widely both in depth and fertility (Matar et al., 1992). Most soils are shallow, with low water-holding capacity, and highly vulnerable to soil erosion. Saline soils are less frequent and apart from those found in desert areas called “sebkha” or “shott”, they may be encountered in localized irrigated areas. Over 45% of the agricultural land in North Africa is experiencing some form of degradation. Deep clay soils (Vertisols) are found in certain fertile plains of the North Africa region. However, arid and semi-arid soils are more common, and often are nutrient deficient, generally with low organic matter content (1% or less). These soils are deficient in nitrogen (N) to such an extent that N fertilization has become the norm in cereal cropping systems in North Africa. As most soils also are high in calcareous, and have high pH, they all present P deficiency, which led to deliberate and continuous application of phosphorous by cereal growers, resulting in wasteful application of this mineral. ICARDA researchers have promoted awareness of the necessity for soil analysis as a guide to sound fertilizer application (Ryan & Matar, 1992). In contrast, North African soils are not deficient in potassium for most crops and this mineral is therefore not applied to cereal crops.

In the past, cereal-based cropping systems in North Africa were dominated by the cereal-fallow rotation and the continuous mono-cropping. While the cereal-fallow rotation in semi-arid areas has the advantage of storing some moisture in the fallow season for use by the cereal crop in the following season, the system is inefficient, especially in favorable or moderately favorable environments. ICARDA researchers have advocated and shown the benefits of replacing the fallow with a legume crop, such as vetch, lentil, or faba bean (Ryan et al., 2008). Research results indeed show a favorable effect of legume-based rotations on crop yield and water use efficiency. The introduced legume crop also leads to a beneficial build up of soil N, thus improving soil quality and contributing to sustainability of land use in the semi-arid regions. Cereal-legume crop rotation is now widely adopted by North Africa farmers, especially where annual rainfall is about or above 350 mm.

Because of the dominant aridity and fragile nature of land resources in North Africa, NARS and ICARDA researchers developed efficient technologies for soil and water conservation and management to minimize runoff and soil erosion and improve water retention and infiltration. In arid areas, rainfall is rare, unpredictable, and sometimes comes in unexpected violent bursts causing erosion and floods, and quickly evaporating under the dry and hot conditions of the arid environment. ICARDA has revived, enhanced and promoted an old indigenous practice of collecting (harvesting) the runoff water for subsequent use (Oweis et al., 2001). To retain water, farmers generally use small circular or semi-circular basins or bunds around the trees or the plants. Soil is assembled and raised in such a way as to make a barrier to hold the water, which is therefore collected and made available for agricultural or domestic uses. Water harvesting (WH) proved effective for replenishing the soil water reserve and for the establishment and maintenance of vegetation cover, trees, shrubs or other crops for various uses. Larger catchments are similarly arranged to harvest water and exploited in arid areas by sheep herders to sustain rangeland species. Water harvesting not only provides a much needed additional source of water for drinking or growing plants for feed and food, but it also raises soil moisture, reduces soil erosion and contributes to C sequestration and improved soil quality. In more favorable, semi-arid or wetter regions, and where topography allows, large sloping areas of a few hundred hectares may be targeted for catchments to collect large amounts of water into large ponds or hill reservoirs (or lakes), with a capacity of up to hundreds of thousands cubic meters, requiring more solid, locally-made structures to retain the water (Ben Mechlia et al., 2008). In Tunisia alone, there are about 1,000 hill lakes across the country, contributing to the shrinking water resources. Such large hill lakes are managed with the participation of local communities or organizations for an equitable water distribution among farmers. Although priority is given by governments to strategic crops like wheat, farmers still prefer irrigating summer vegetables instead, for their higher return, although they consume more water. In the semi-arid areas of North Africa, field crops such as wheat and barley are traditionally grown under rainfed conditions, where average yields vary between 1 and 2 t ha⁻¹ (Table 3), although in good years, yields can reach up to 3-4 t ha⁻¹ and more. The highly variable rainfall and the increased frequency of very dry years in semi-arid regions (Bahri, 2006) induced farmers into irrigating once or twice their winter-grown crops to reduce risk and secure a harvest. Such a practice, referred to as supplemental irrigation (SI) augments the rainwater with some additional water applied to the crop at a critical time during the growing season, when rain fails to come and plants are most vulnerable to water stress (Oweis, 1997).

| Crop | North African country | | |
|--------|-----------------------|---------|---------|
| | Algeria | Morocco | Tunisia |
| Wheat | 1.22 | 1.24 | 1.59 |
| Barley | 1.23 | 0.85 | 0.91 |

Table 3. Average grain yield (t ha⁻¹) for wheat and barley under rainfed conditions of North Africa (1998-2000).

Our experience shows that candidate critical periods of rain deficiency occur at planting, at stem elongation, and at anthesis, generally not always occurring together in the same season. Supplemental irrigation of wheat in semiarid and subhumid environments of Tunisia resulted in increases of yield and WUE reaching up to 100% and 73%, respectively (Rezgui, et al., 2005). Similarly, a single 60 mm irrigation of winter sown chickpea in Morocco, resulted in lengthened green area duration and associated yield gain (Boutfirass, 1997). Supplemental irrigation of barley during 3 years in coastal areas of Libya with an annual rainfall of 200-300 mm resulted in 50-400% yield increase, depending on rainfall, with larger increases occurring in drier seasons. As compared to rainfed cropping, supplemental irrigation in semiarid Tunisia yielded a net return of 60-170% for cereal crops and up to over 400% for vegetables (Ben Mechlia et al., 2008).

Research conducted in North Africa and similar semi-arid regions shows that SI not only improves and stabilizes grain yield, but it also gives “more crop per drop”, i.e. it has a good water return or high water-use efficiency (WUE) or, equivalently, high water productivity (WP), both terms referring to crop return, such as grain yield or value, per unit of consumed water (Oweis, 2010). Unlike land productivity that refers to crop return per unit of land (e.g. “x” Kg ha⁻¹), WP relates the crop return to consumed water, as water is the most important limiting factor, especially in dry regions. In cereal-based cropping systems of semi-arid areas, WP of wheat is generally around 0.35-1 kg grain/m³ water, but may reach up to over 2.5 kg grain/m³ water under SI (Oweis, 2010). Therefore SI is a water saving procedure that effectively reduces the impact of drought on farmer’s livelihood. However, certain farmers tend to over-irrigate and waste valuable water resources, thinking “the more water, the better”. In fact, results of wheat research show that WP is maximum for an optimum level of SI, beyond which it starts decreasing; the optimum SI level is about 1/3-2/3 the level of full irrigation (FI), the latter being equal to the full crop water requirement. Full irrigation is not as efficient as supplemental irrigation in using the water resources (Oweis & Hachum, 2006; Shideed et al., 2005). In fact, in wheat WP for FI is 1 kg/m³ but it is 2.5 kg/m³ for SI. In scarce-water conditions, it is therefore more rewarding for the farmer to use SI to optimize WP rather than maximize yield. This approach saves water to grow the crop on a larger area and the farmer ends up with a larger total output, while using water sustainably (Oweis & Hachum, 2006). Also, water productivity can be further improved through proper crop management, including early planting, weed control, fertilizer application, and irrigation at critical times to avoid or minimize detrimental water stress, e.g. at flowering time and fruit or grain formation. For example, supplemental irrigation of wheat, combined with early planting in the Tadla region of Morocco hastened maturity, enabled the crop to escape terminal drought and heat stress, and doubled grain yield and WP (Karrou & Oweis, 2008). The beneficial effect of SI is further enhanced when SI is combined with the use of adapted varieties (Karrou & Boutfirass, 2007).

While water harvesting and supplemental irrigation are effective technologies for augmenting and enhancing the value of fresh water resources, these resources are still too limited to cope with the increasing rural and urban user demands that are further exacerbated by unabating climate change. However, there is a potential for other avenues that could be explored for additional water sources, including brackish water, saline water and treated wastewater. Brackish water and saline water have been used in irrigation with disappointing results in all three countries (ICID, 2003) primarily because of very high evaporative demand in desert or arid regions, and the lack of fresh water and adequate drainage for leaching the salts away. The dry environments in such areas preclude the normal growing of regular crops, but special-purpose, halophytic crop species may be grown successfully, to provide essential oils, folk medicine, biofuel, fodder, shade for animals, or to retain soil and arrest desertification (Neffati et al., 2007; Qadir, 2008). In more favorable semiarid or subhumid areas, brackish water may be successfully used to grow tolerant plants (such as barley) where both fresh water and drainage facilities are more readily available. The use of treated wastewater, although feasible, has been limited so far to less than 20,000 hectares in North Africa, due primarily to unreliable delivery, regulatory exclusion of vegetables growing, and social unacceptance. However, the increasing water scarcity will ultimately make it a *de facto* alternative for fodder, grains and tree cultivation, especially as suitable regulatory frameworks are established and promoted (Qadir, 2008). Despite all the newly adopted and proposed technologies that make the best use of available water resources, including water harvesting, supplemental irrigation, and utilization of non-conventional water resources, the fact remains that North Africa is a water-deficient region, and will be more so in the future. A more sustainable long-term solution that will not only provide enough fresh water for generations to come, but will also enable reclaiming salinity-degraded land resources, lies in seawater desalination using solar power from the Sahara desert. The Sahara is 9 million km² large and North Africa sea coast extends over 4000 km. These two virtually limitless resources for clean energy from the Sahara desert and bountiful fresh water from the sea will make of North Africa a sustainable water-rich region.

3.2 Conservation agriculture

Conservation agriculture (CA), referred to under different labeling (direct seeding, NT or no-till, zero tillage) in different countries, is an agricultural technology that combines minimum or no soil disturbance, direct seed-drilling into the soil, cover crop or residue retention and crop diversification through rotation (Kassam et al., 2010). Now practiced on 117 million hectares worldwide, it covers diverse agroecologies and cropping conditions. In North Africa, CA was introduced about 30 years ago in both Morocco and Tunisia where it now covers 6,000 ha and 12,000 ha, respectively. Algeria's work in CA started only 7 years ago and is gaining momentum (Zaghoulane et al., 2006). In addition to the obvious benefits of reduced labor and energy cost, and some yield advantage (generally realized a few years from the start), the most striking effects in semi-arid regions of North Africa is the reduced erosion, especially in sloping areas. CA also presents the advantage of flexibility for the implementation of field crop management that allows timely planting and input application, despite unfavorable field conditions that do prevent such operations in conventional agriculture (e.g. wet soil at planting time). CA prevents soil plowing which has been identified as a major cause for CO₂ emission. Cover crops, residues and crop roots contribute to better soil structure and composition with enhanced build up of organic

matter, while crop residues protect the soil and minimize soil evaporation (Angar et al., 2010; Ben Moussa-Machraoui et al., 2010; Gallali et al., 2010; Mrabet, 2006, 2008). CA therefore contributes both to CC mitigation through reduced GHG emissions and enhanced C sequestration, and to adaptation through soil water retention and infiltration, and increased water use efficiency. Therefore, CA based on the NT system is an effective technology to conserve natural soil and water resources while minimizing the drought effect on crop production and contributing to better food security in North Africa.

A difficulty faced in CA is a compaction in the upper soil caused by excessive animal grazing during the wet season (Angar et al., 2010). Major challenges to adoption of CA technology in North Africa are posed by severe drought of rainfed arid regions and the consequent need for fodder resources during the dry season, both of which threaten the maintenance of crop mulch, a key component of CA. In such a situation, partial stubble grazing could offer a compromise. Results in Tunisia indeed show beneficial effects of CA (improved soil organic matter, better soil infiltration, higher wheat yield) despite the low amount of crop residues (1-2 t residue ha⁻¹). Another solution will be some sort of compensation to farmers for environmental services (Lal, 2010) and sustainability of natural resources that will help farmers secure alternative feed resources for the dry season. Other challenges to CA adoption in North Africa are (a) high weed infestation at the initial stage of CA adoption (Dridi et al., 2010), and (b) the unavailability of suitable CA-ready seed-drills (El Gharras & Idrissi, 2006). In fact, the adoption of NT technology in Tunisia is limited to farms of size ≥ 100 ha, where farmers could afford a high investment for the purchase of NT equipment. ICARDA and collaborating partners are pursuing efforts in North Africa to promote local manufacturing of low-cost NT drills, which will expand CA adoption to small-scale farmers who represent the majority of North African farmers (Requier-Desjardins, 2010). Here is another opportunity for policy makers to encourage farmers reduce the impact of CC, by promoting CA through reduced cost of NT drills.

3.3 Biodiversity and crop variety development

Protracted drought in semiarid regions inevitably leads to disappearance and loss of plant species and varieties in extremely dry or hot years. The likelihood of this happening has increased with climate change. Realizing this risk, researchers around the world make efforts to conserve genetic diversity of plant species in their own environments (*in situ*) where the plants can preserve their specific characteristics while they are living and evolving naturally. Researchers also conserve these indigenous species or varieties under controlled conditions, both in research farms and in genebanks (*ex-situ*). For example, ICARDA maintains over 130,000 accessions of cereals (essentially wheat and barley), legumes (lentil, chickpea, and faba bean) and other species at its Gene bank under cold conditions for medium (up to 30 years) and long-term (100 year) storage, and distributes annually over 30,000 samples to requesting researchers around the world. Seed of requested materials is sent along with associated information on genealogy, special characteristics, and area of origin and adaptation. Such information will assist the user to target the requested genetic resources to specific environments. In return, the user's feedback enriches the information database that gets more valuable as it is accessed by more users.

In addition to the wealth of genetic resources that are characterized and maintained in gene banks, several hundreds of newly-bred crop entries are annually shared with breeders and other researchers around the world through the ICARDA International Nursery Network.

ICARDA and partner breeders use hybridization and selection to develop new germplasm, possessing desirable traits for different purposes and uses in various environments, including tolerance to biotic and abiotic stresses, and good agronomic, nutritional and industrial properties. Breeders work combines the use of both conventional breeding methods based on field and lab manipulations, observations and measurements, and biotechnological tools to speed up germplasm development and identification and transfer of useful traits from varied sources, including alien species. The outcome is a pool of germplasm with a broad genetic base. Of particular interest and relevance to climate change are varieties possessing tolerance to drought and heat, and to major diseases and insect pests prevailing in North Africa. For example, the Moroccan durum wheat varieties INRA-1804 and INRA-1805 are resistant to Hessian fly, a major wheat insect pest, in contrast to the older variety Karim, susceptible to such a level that it yields no grain under heavy infestation, where the resistant varieties yield 1.5 t ha^{-1} under severe drought conditions. In Algeria, the new durum wheat variety Boussalem yields 3.5 t ha^{-1} compared to 2 t ha^{-1} for the widely grown variety Waha, both grown under the same semiarid conditions (El Mourid et al., 2008). In Tunisia, the newly released durum variety Maali is drought tolerant and has an average grain yield of 4 t ha^{-1} compared to 3 t ha^{-1} for the common variety Karim. New barley and wheat varieties are developed with participation of farmers in selection and evaluation on their own farms. In fact, participatory plant breeding where farmers and breeders make independent selections, contributes to maintaining a good level of genetic variability in breeders and farmers selections, which is purposely maintained through generations of continuous selection within heterogeneous populations (ICARDA, 2008; Ceccarelli et al., 2010). Such heterogeneity assures a certain degree of resilience to climate change and ensuing environment variation. Early maturing cultivars are particularly adapted to semi-arid areas of North Africa, where late-season drought is very common. Such cultivars suffer least in dry environments and contribute to lessen the effect on farmer of drought risk and harvest uncertainty. Early maturity, controlled by photo-thermal response genes, is therefore a prime objective in crop breeding of major field crops in North Africa. However, breeders are also investigating other genetic sources of drought tolerance in land races and wheat synthetics and work to incorporate such genes in useful genetic background (ICARDA, 2007; ICARDA, 2010). Wheat synthetic types are derived from crossing durum wheat (*Triticum turgidum* var. *durum*) with goat grass (*Aegilops tauschii*). Interspecific and intergeneric hybridization generates new genetic variability and contributes to enhancing biodiversity, a valuable asset or 'vaccine' for adaptation and survival and development in erratic environments.

Breeding has been also an effective tool in combating diseases and insect pests and reducing their negative impact on crop productivity and resilience. Genes for resistance to pathogens and pests of wheat, barley, chickpea, faba bean and lentil crops were identified in various crops and wild species and successfully incorporated into commercial cultivars (ICARDA, 2006, 2007, 2008, 2009, 2010). However, there is indication that climate change, with trends of increasing temperature and decreasing rainfall, is favoring the appearance of new pathogen and pest types. Examples include the recent appearance of yellow rust (also called stripe rust) on wheat in relatively warm areas where it was not a problem in the past, as the causal pathogen, the fungus *Puccinia striiformis*, was known to be favored by moderately low temperature; the appearance of the disease in warm areas is likely the result of the appearance of a new race of the pathogen. Similarly, chickpea varieties that were tolerant to

the fungal disease *Ascochyta* blight during the period 1979-2000, started showing signs of susceptibility during the period 2001-2007, the two periods differing quite well in rainfall and temperature pattern (Abang & Malhotra, 2008). While researchers pursue exploiting the genetic sources of resistance to diseases and pests, they are also investigating other avenues for an integrated pest management approach that include also crop management techniques and biological control to minimize the recourse to the use of agrichemicals (ICARDA, 2009). The successful development of new improved varieties does not bear fruit unless the new varieties are effectively adopted and grown by farmers. Experience through a durum wheat project in Algeria, Morocco and Tunisia (El Mourid et al., 2008), shows that small-scale farmers in semi-arid areas do not have easy access to new varieties. This is attributed to high prices of certified seed, and inefficient seed multiplication that inhibits its wide distribution across the country's regions. Informal seed production of those varieties through trained community farmers led to rapid seed multiplication and dissemination within the communities and in nearby areas. Although the seed was not certified, it was of very good quality and free of diseases or pests, and could be bought at an affordable price. Such an informal seed production system was especially successful in remote semiarid areas of all three countries, where the new varieties were available to growers within 3 years only. Similar successful examples of village-based seed enterprises in other regions (ICARDA, 2009) confirm the importance of farmer participation in solving local issues and its relevance to food security and community welfare in remote rural areas. The availability of a number of different varieties of various species gives farmers the opportunity to choose. In fact, most farmers choose more than one variety, to increase their odds against poor or no harvest. By so doing, they also contribute to enhancing biodiversity, a powerful tool to adapt to changing climate and associated changes in agro-ecosystems.

3.4 Integrated crop-livestock-rangeland production systems

Although the dominant production systems in North Africa are based on livestock and crops, livestock is still the main source of income of rural populations in the North African countries. Sheep and goat make up the major portion of livestock in North Africa with 30 million and 10 million heads, respectively (Table 4). Several factors including climate change threaten the sustainability of the production systems. There are considerable gaps in our knowledge of how climate change will affect livestock systems and the livelihoods of these populations. Management of the production risk caused by the fluctuation of feed availability is the main problem hampering the development of livestock production in North Africa. Under the framework of Research-for-development project, the Mashreq/Maghreb project, NARS and ICARDA developed over a decade sound technical, institutional and policy options targeting better crop/livestock integration, community development and improvement of the livelihoods of agropastoral communities in 8 countries (Algeria, Iraq, Jordan, Lebanon, Libya, Morocco, Syria, and Tunisia). These options include (i) organization of local institutions to facilitate both collective and individual adaptation and response to climate change, (ii) an innovative approach to their sustainable improvement and management including institutional solutions for access to communal/collective rangelands, (iii) better use of local natural resources with an emphasis on water harvesting and appropriate use of adapted indigenous plant species, such as cactus and fodder shrubs, and (iv) efficient animal feeding involving cost-effective alternative feeds including feed blocks, and (v) nutrition and health monitoring.

| Country | Sheep | Goat |
|---------|-------|------|
| Algeria | 17.3 | 3.2 |
| Morocco | 16.7 | 5.2 |
| Tunisia | 6.9 | 1.4 |
| Total | 30.9 | 9.8 |

Table 4. Number (million heads) of sheep and goat in three African countries (adapted from Iniguez, L., 2005a)

Two critical trends prevail in the current production context. The first trend involves a crisis in the feed supply reflecting water scarcity, exacerbated by the progressive decline of rangelands’ productivity due to overgrazing, cultivation encroachment, or the disruption of institutional arrangements for resource utilization. Moreover, very low ratio of cultivated forages prevails in the cropping systems.

The second trend involves the expansion of market demand for livestock products leading to opportunities for productivity and income improvement.

3.4.1 Participatory collective rangeland management

The pastoral and agropastoral societies in North Africa went through deep mutation during the past few decades. In the mid-20th century, the mobility pattern of the pastoralists was dictated by accessibility and availability of forage and water. With the mechanization of water transportation and the reliance on supplemental feed, animals can be kept continuously on the range, which disturbs the natural balance and intensifies range degradation (Nefzaoui, 2002, 2004). Mechanization profoundly modified rangelands’ management in the steppes of North Africa. Water, supplements and other services are brought by trucks to flocks. As a result, families settle close to cities for easier access to education, health, and other services, with only sheepherders moving flocks to target grazing areas (transhumance).

Production systems are intensifying and it is nowadays possible to find in the steppe a continuum between intensive fattening units that are developing in peri-urban areas and along the main transportation routes, mixed grazing-fattening systems, and purely intensive systems based on hand feeding only to provide feed supplements to animals.

Agropastoral societies have developed their own strategies for coping with drought and climate fluctuation. These strategies include (Hazell, 2007; Alary et al. 2007):

- mobile or transhumant grazing practices that reduce the risk of having insufficient forage in any location;
- feed storage during favorable years or seasons;
- reciprocal grazing arrangements with more distant communities for access to their resources in drought years;
- adjustment of flock sizes and stocking rates as the rainy season unfolds, to best match available grazing resources;
- keeping extra animals that can be easily sacrificed in drought conditions, either for food or cash;
- investment in water availability (wells, cisterns, and water harvesting);
- diversification of crops and livestock (agropastoralism), especially in proximity to settlements, and storage of surplus grain, straw and forage as a reserve in good rainfall years;

- diversification among animal species (sheep, goats, cattle, camels, donkeys) and different breeds within species;
- income diversification into non-agricultural occupations, particularly seasonal migration for off-farm employment in urban areas.

However, recent infrastructural and demographic changes as a result of urbanization have made such strategies less effective.

In a recent study conducted within the Mashreq/Maghreb project in Chenini agropastoral community, in Southern Tunisia, perception of drought and livelihood strategies to mitigate drought has been investigated using a “sustainable livelihood approach”. Figure 1 translates the perception of agropastoralists of drought and climate change during the past decades, as well as the tools used to adapt to or mitigate climate fluctuation. Indeed, while in the thirties, there was a self reliance on drought coping mainly through transhumance, food and feed storage and goat husbandry, these options shifted gradually towards a significant reliance on government intervention mainly through subsidizing feeds and facilitating feed transport from the North to Southern arid areas.

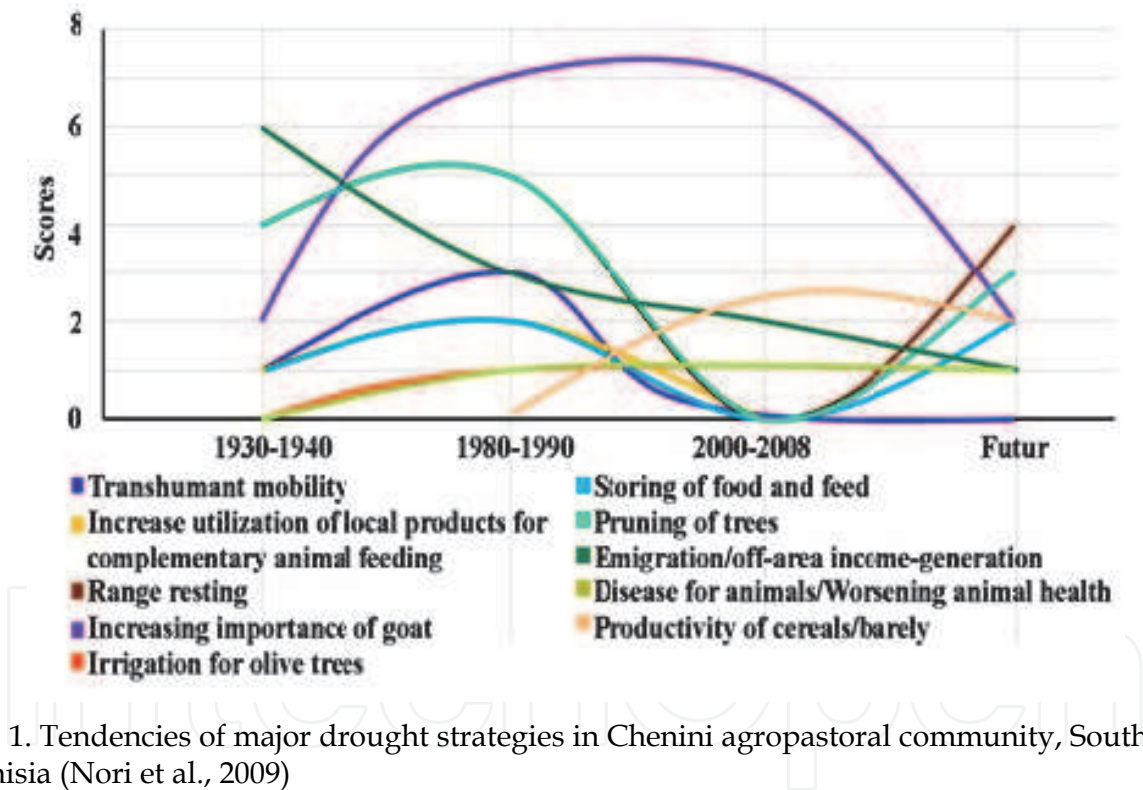


Fig. 1. Tendencies of major drought strategies in Chenini agropastoral community, Southern Tunisia (Nori et al., 2009)

However, science and technology, including climatic adaptation and dissemination of new knowledge in rangeland ecology and a holistic understanding of pastoral resource management are still lacking. Successful adaptation depends on the quality of both scientific and local knowledge, local social capital and willingness to act. Communities should have key roles in determining what adaptation strategies they support if these have to succeed. The integration of new technologies into the research and technology transfer systems potentially offers many opportunities to further contribute to the development of climate change adaptation strategies. Geospatial information, spatial analysis tools, and other decision support tools will continuously play a crucial role in improving our understanding

of how climate change will affect livelihoods of pastoral communities. Climate change also offers the opportunity to promote payment to pastoralists for environmental services, as in the case of some livestock keepers in Europe. These services could include watershed management, safeguarding biodiversity, landscape management and carbon sequestration (MacOpiyo et al., 2008).

3.4.2 Matching small ruminant breeds to environments

It is widely recognized that pastoralists and their communities play an important role in conserving domestic animals diversity. In North Africa, seven of the sixteen sheep breeds of the arid regions are at high risk of disappearance (Table 5), either because animals are totally replaced by exotic species or because they are crossbred with more productive breeds. Most of these local breeds (Table 5) are well adapted to harsh environments and their genetic makeup is attracting many western countries that are preparing for similar climate change in Europe. ICARDA has been documenting the status of the diversity and phenotypic characteristics of sheep and goat breeds in the West Asia and North Africa (WANA) region jointly with NARS partners. Many breeds are shared across the region and have important adaptive traits to dryland conditions (Iñiguez, 2005).

| Breeds | Average rainfall | Country* | Risk to genetic erosion | Primary purpose |
|-----------------------|--------------------|----------|-------------------------|--------------------|
| Atlas Mountain breed | 500 (mountain) | M | High | Meat + wool + skin |
| Barbarine | 75-500 | MATL | High/low | Meat, milk |
| Barki | 150-300 | EL | None | Meat, wool |
| Beni Guil | 100-250 | M | High | Meat, wool |
| Berber | 450-500 (mountain) | A | High | Meat, milk |
| Boujaad | 300 | M | None | Meat, wool |
| D'man | 100 (oasis) | MAT | High | Meat, manure |
| Farafra | 100 (oasis) | E | None | Meat, wool |
| Hamra | 200-250 | A | High | Meat, fleece, milk |
| Ouled Djellal | 200-500 | AT | none | Meat, fleece, milk |
| Queue Fine de l'Ouest | 200-400 | T | None | Meat |
| Rembi | 300 | A | Moderate | Meat, fleece, milk |
| Sardi | 300 | M | None | Meat |
| Taadmit | | A | Extreme | |
| Tergui-Sidaou | 50 | A | Low | Meat |
| Timahdite | 500 (mountain) | M | None | Meat, wool |

Table 5. Sheep breeds of non-sedentary (pastoral and semi-pastoral) production systems in North Africa (Dutilly-Diane, 2007). (*) A: Algeria, E: Egypt, L: Libya, M: Morocco, T: Tunisia.

3.4.3 Efficient animal feeding using cost-effective alternative feeds

Managing the production risk caused by the variability of feed availability is the central issue in the small ruminant (SR) production system of the WANA region. Desertification, increased drought frequency and duration, greenhouse emissions, and decreased livestock

performance, justify the need for a serious understanding on the readjustment and or the establishment of new feeding strategies targeting the improvement of animal production without detrimental effects on the environment. Moreover, the development of simple and cost-effective techniques such as feed blocks, pellets, and silage (Ben Salem and Nefzaoui, 2003) to valorize local feed resources (e.g. agroindustrial byproducts) help smallholders to better manage livestock feeding throughout the year. Main benefits from these options for the animal, the environment and their impact on farmers’ livelihoods are reported in Table 6. Overall, the interesting results on the positive effect on animals of tanniniferous (e.g. in situ protection of dietary proteins, defaunation, reduced emission of methane, anthelmintic activity) and/or saponin (e.g. increased absorption rate of nutrients, defaunation, decreased production of methane) containing forages to improve feed efficiency and to control gastrointestinal parasites, and thus improve the productive and reproductive performance of ruminants should promote plants rich in secondary compounds in grazing systems. These options offer promising solutions to reduce the use of chemicals in livestock production systems to enhance livestock productivity and to decrease emission of methane (Nefzaoui et al., 2011).

| Options | Impact on the animal | Impact on the environment | Impact on farmers livelihoods |
|-------------------------------|--|--|--|
| Feed blocks | <ul style="list-style-type: none">- Improved digestion of low quality diets and increased growth and milk production- Improved health conditions due to decreased parasitic load (use of medicated FBs) | <ul style="list-style-type: none">- Decreased pollution with perishable AGIBs (olive cake, tomato pulp, etc.)- Decreased pressure on rangelands- Better quality manure | <ul style="list-style-type: none">- Decreased feeding cost, increased animal performance and hence higher income- Diversification of farmers’ income (sale of FBs)- Employment generation through mechanized unit for FBs making |
| Cactus (<i>Opuntia</i> spp.) | <ul style="list-style-type: none">- Improved digestion of low quality forages- Improved animal performance | <ul style="list-style-type: none">- Improved soil condition- Decreased pressure on primary resources (water and rangelands) | <ul style="list-style-type: none">- Added value cash crop (fruit and cladodes sale), and increased animal performance result in increased income |
| Shrub mixing | <ul style="list-style-type: none">- Complementarities between shrub species (nutrients and secondary compounds) increased animal performances | <ul style="list-style-type: none">- Combat desertification- Soil protection | <ul style="list-style-type: none">- Reduced budget allocated for feedstuffs purchasing |
| Rangelands resting | <ul style="list-style-type: none">- Increased feed intake and digestion- Increased productive and reproductive performances | <ul style="list-style-type: none">- reduces degradation risk- Protection of plant and animal biodiversity (domestic and wildlife animals) | <ul style="list-style-type: none">- reduced feeding cost and increased performances resulting in increased income |

Table 6. Productive, environmental and social benefits of some alternative feeding options (Nefzaoui et al., 2011).

Feed blocks (FBs) technology

Cold-processed feed blocks are made of a mixture of one or more agro-industrial by-products (e.g. olive cake, tomato pulp, etc.), a binder (e.g. quicklime, cement and clay), water and common salt, as well as urea with or without molasses. The technique of FB making is well described in the literature (e.g. Ben Salem and Nefzaoui, 2003; Ben Salem *et al.*, 2005a). Some variations in the blocks include the incorporation of polyethylene glycol as a tannin-inactivating agent, which has increased the utilization of tanniniferous browse foliage in ruminant feeding (Ben Salem *et al.*, 2007). Mineral enriched FBs (e.g. with phosphorus, copper, etc.) are fed to animals to mitigate deficiency and improve reproduction in ruminants. Benefits from the integration of FBs in the diet of sheep and goats are reflected by data compiled in Table 7. It is clear that depending on the formula, FBs can partially or totally replace concentrate feeds, thus reducing feeding costs without detrimental effects on livestock performances.

| Basal diet | Supplement* | Animals | Growth rate (g/day) | Feeding cost variation | Country |
|---------------------------|-----------------------|---------|---------------------|------------------------|---------|
| Stubble grazing | Concentrate (250 g/d) | Lambs | 95 | | Algeria |
| Stubble grazing | Conc. (150 g/d) + FB1 | Lambs | 136 | -81% | Algeria |
| Wheat straw <i>ad lib</i> | Conc. (500 g/d) | Lambs | 63 | | Tunisia |
| Wheat straw <i>ad lib</i> | Conc. (125 g/d) + FB2 | Lambs | 66 | -11% | Tunisia |
| Acacia leaves | FB4 | Lambs | 14 | | Tunisia |
| Acacia leaves | FB5 enriched with PEG | Lambs | 61 | | Tunisia |
| Rangeland grazing | Conc. (300 g/d) | Kids | 25 | | Tunisia |
| Rangeland grazing | FB4 | Kids | 40 | | Tunisia |

Table 7. Compiled data on the potential use of feed blocks as alternative feed supplements for sheep and goats in the Mediterranean area (Ben Salem *et al.*, 2005a). (*) FB1: wheat bran (10%), olive cake (40%), poultry litter (25%), bentonite (20%), salt (5%); FB2: wheat bran (25%), wheat flour (15%), olive cake (30%), rapeseed meal (10%), urea (4%), quicklime (8%), salt (5%), minerals (1%); FB4: wheat bran (28%), olive cake (38%), wheat flour (11%), quicklime (12%), salt (5%), minerals (1%), urea (5%); FB5: wheat bran (23%), olive cake (31.2%), wheat flour (9%), quicklime (9.9%), salt (4.1%), minerals (0.8%), urea (4.1%), PEG (18%).

Fodder shrubs and trees (FST) in the smallholders farming systems

Trees and shrubs are part of the Mediterranean ecosystem. They are present in most natural grazing lands of the North Africa region. Some species are high in essential nutrients and low in anti-nutritional factors (e.g. *Morus alba*), some others are low in nutrients but high in secondary compounds (e.g. *Pistacia lentiscus*) while some shrubs are high in both nutrients and secondary compounds (e.g. *Acacia cyanophylla*, *Atriplex* spp.). Such characteristics enable

the plants to withstand grazing and to provide ground for selective grazing. In arid and semi-arid North Africa regions where available forage species cannot grow without irrigation, FST could be used as feed supplements. Saltbushes (*Atriplex nummularia*, *Atriplex halimus* and *Salsola vermiculata*) are planted in dry zones in North Africa and have many advantages because of their wide adaptability to harsh agro-climatic conditions and ability to grow over a longer period. As trees require little care after establishment, the production cost is low (Nefzaoui et al., 2011).

Alley-cropping

This technique consists of cultivating herbaceous crops of both gramineae and legume species between rows of trees or shrub species. Among the reasons for the low adoption of pure shrubs planting are the technical design of plantation, mismanagement, and competition for land often dedicated to cereal crops. Alley cropping overcomes some of these disadvantages because it (1) improves soil; (2) increases crop yield; (3) reduces weeds and (4) improves animal performance. Properly managed alley-cropping allows diversification to benefit from several markets. It also promotes sustainability in both crop and livestock production. Benefits from cactus-barley alley cropping system were evaluated in Tunisia (Alary et al., 2007; Shideed et al., 2007). Compared to barley alone, the total biomass (straw plus grain) of barley cultivated between the rows of spineless cactus increased from 4.24 to 6.65 tones/ha and the grain from 0.82 to 2.32 tons ha⁻¹. These results are due to the change of the micro-environment created by alley-cropping with cactus, which creates a beneficial 'wind breaking' role that reduces water loss and increases soil moisture. The barley crop stimulated an increase in the number of cactus cladodes and fruits, while the cactus increased the amount of root material contributing to the soil organic matter. The alley-cropping system with *Atriplex nummularia* proved efficient in the semi arid regions of Morocco (annual rainfall 200-350 mm). Barley was cropped (seeding rate 160 Kg ha⁻¹) between *Atriplex* (333 plants ha⁻¹) rows. Compared to farmers' mono-cropping system, dry matter consumable biomass yield of *Atriplex* was significantly higher in the alley-cropping system. The latter system was more profitable than mono-cropping. Indeed, Laamari et al. (2005) determined the net benefit from *Atriplex* monocropping and barley-*atriplex* alley cropping over 15 years. The cumulative net benefit was 732.18 \$ ha⁻¹ and 3,342.53 \$ ha⁻¹, respectively. The economic and agronomic assessment of alley cropping shows that this technology is economically profitable. Therefore, it should be extended on a large scale in the agro-pastoral areas of the North Africa region.

Shrub mixing technique

Most Mediterranean fodder shrubs and trees are either low in essential nutrients (energy and/or digestible nitrogen) or high in some secondary compounds (e.g. saponins, tannins, oxalates). These characteristics explain the low nutritive value of these fodder resources and the low performance of animals. For example, *Acacia cyanophylla* foliage is high in condensed tannins but low in digestible nitrogen. *Atriplex* spp. are low in energy and true protein although they contain high levels of crude protein, fibre and oxalates. Cactus cladodes are considered an energy source and are high in water but they are low in nitrogen and fibre. Moreover, they are remarkably high in oxalates. A wealth of information on the complementary nutritional role of these shrub species and the benefit of shrub mixing diets for ruminants, mainly sheep and goats are reported in the literature (Ben Salem et al., 2002, 2004, 2005b). This technique permits to balance the diet for nutrients and to reduce the adverse effects of secondary compounds and excess of minerals including salt. The

association cactus-atriplex is a typical example of shrub mixing benefits. The high salinity and the low energy content of atriplex foliage are overcome by cactus. Some examples of the effects of shrub mixed diets on sheep and goats performance are reported in Table 8. In summary, diversification of shrub plantations should be encouraged to improve livestock production in the dry areas of North Africa.

| Basal diet ¹ | Supplement ² | Animal | Daily gain (g) |
|--------------------------|---|--------|----------------|
| Acacia (417 g/d) | Atriplex (345 g/d); Barley (280 g/d) | Lambs | 54 |
| Cactus (437 g/d) | Atriplex (310 g/d); Acacia (265 g/d) | Lambs | 28 |
| Cactus (499 g/d) | Straw (207 g/d); Atriplex (356 g/d) | Lambs | 81 |
| Atriplex grazing | Cactus (290 g/d) | Lambs | 20 |
| Native shrubland grazing | Cactus (100 g/d); Atriplex (100 g/d) | Kids | 60 |

Table 8. Effect of shrub mixed diets on sheep and goat growth (adapted from Nefzaoui et al., 2011). (1) Acacia: *Acacia cyanophylla*; Cactus: *Opuntia ficus indica* f. *inermis* (cladodes); Atriplex: *Atriplex nummularia*. (2) Values between parentheses are daily dry matter intake

3.5 Cactus

The Cactaceae family includes about 1600 species, native to America, but worldwide disseminated. *Opuntia* is the most widely known genus of this family. The species *Opuntia ficus indica* is cultivated in more than 20 countries. Around 900,000 ha of cactus have been planted in North Africa including 600,000 ha in Tunisia. The total area of cactus is estimated at 5 million ha of which 3 million are wild and located in Mexico. Cacti have been consumed by humans for over 9000 years. From underused crop, cacti received an increasing attention during the last few years. Thus, from 1998 to 2000 more than 600 researchers published over 1100 articles on Cacti.

Specific *Opuntia species* have developed phenological, physiological and structural adaptations for growth and survival in arid environments in which severe water stress hinders the survival of other plant species. Among these adaptations stand out the asynchronous reproduction and CAM metabolism of cacti, which combined with structural adaptations such as succulence allow them to continue the assimilation of carbon dioxide during long periods of drought, reaching acceptable productivity levels even in years of severe drought.

3.5.1 Cacti: The perfect candidate to mitigate climate changes in arid zones

CAM plants (Agaves and Cacti) can use water much more efficiently with regard to CO2 uptake and productivity than do C3 and C4 plants (Nobel, 2009). Biomass generation per unit of water is on an average 5 to 10 times greater than C4 and C3 plants (Table 9). In contrast to C3 and C4 plants, CAM plants net CO2 uptake occurs predominantly at night (Nobel, 2009). As stated by Nobel (2009), the key for the consequences between nocturnal gas exchange by CAM plants and C3 and C4 plants is temperature. Temperatures are lower at night, which reduces the internal water vapor concentrations in CAM plants, and results

in better water use efficiency. This is the key reason that makes CAM species the most suited plants for arid and semi-arid habitats.

| | C3 | C4 | CAM |
|------|--------------|--------------|-------------|
| WUE* | 0.0013-0.005 | 0.0025-0.010 | 0.013-0.040 |
| TR** | 200-800 | 100-400 | 25-80 |

Table 9. Comparative water use efficiency (WUE) and transpiration rate (TR) for C3, C4, and CAM plants (adapted from P.S. Nobel, 2009). (*) Water-Use Efficiency (WUE): ratio of the CO₂ fixed in photosynthesis to water lost via transpiration. (**) Transpiration rate (TR): amount of water lost through transpiration over the CO₂ fixed in photosynthesis.

C3 and C4 plants suffer irreparable damage once they lose 30 % of their water content. On the other hand, many cacti can survive an 80 to 90 % loss of their water content and still survive. This is due to the ability of CAM plants to store a lot of water, to shift water around among cells to keep crucial metabolism active, and to tolerate extreme cellular dehydration (Nobel, 2009).

These three abilities stem from the cacti characteristics including the extra thickness of the cuticles providing efficient barrier to water loss, the presence of mucilage and the daytime stomatal closing. In addition, cacti have an asynchronous development of various plant organs, so that even under the worst conditions some part of the plant is not affected. It is well known that cacti grow in desert where temperatures are extremely high. It has been reported by many authors (i.e. Nobel, 2009) that many agaves and cacti can tolerate high temperatures of up to 60 and 70 °C.

A full chapter has been devoted to this aspect by Park Nobel (2009) in his recent book “Desert Wisdom Agaves and Cacti CO₂, Water, Climate Change”. In view of the specific phenological, physiological and structural adaptations of cacti described above, it can be assessed that they are well positioned to cope with future global climate change. *Opuntia ficus indica*, for example, can generate a carbon sequestration of 20 tons of dry matter (equivalent to 30 tons of CO₂) per ha and per year under sub-optimal growing conditions similar to those in North Africa arid regions. In this regard and as stated by Drennan and Nobel (2000) and Nobel (2009), agaves and cacti with their substantial biomass productivity and their high WUE should be considered for the terrestrial sequestration of atmospheric CO₂ in underexploited arid and semi-arid regions. Such regions, which occupy 30 % of the Earth’s land area, are poorly suited to C3 and C4 crops without irrigation.

3.5.2 How cacti can help adapting to climate change in dry areas?

Soil and water conservation

Several methods like water harvesting strips, contour ridges, gully check structures, biological control of rills and small gullies by planting cactus have been tested and have given good results. The contour ridges consisting of parallel stone ridges are built 5 to 10 m apart to stop runoff water (and the soil it carries) from damaging downstream areas. Each ridge collects runoff water from the area immediately upstream, and the water is channeled to a small plantation of fodder shrubs or cactus. Indeed with a suitable combination of well designed ridges and cactus, farmers are able to meet a large proportion of their fodder requirements.

In the countries of North Africa, particularly Tunisia, cactus is successfully associated with water harvesting structures. Planted according to contour lines, cactus hedges play a major

role in erosion control. Soil physical properties are considerably improved under these hedges and in immediate adjacent areas, with an improvement in organic matter and nitrogen as compared to non-treated fields. About 40 to 200% increase in organic matter and nitrogen have been reported. Top-soil structural stability is enhanced, susceptibility to surface crusting, runoff and erosion are reduced, while permeability and water storage capability are increased (Nefzaoui and El Mourid, 2009).

Comparing different cultivation systems, such as downhill planting, contour planting, reduced weeding, and intercropping with contour hedges, it was found that soil losses (0.13 to 0.26 t ha⁻¹ y⁻¹) are the lowest with the last technique. Cactus planting in contour hedges may help retaining up to 100 t ha⁻¹ soil annually (Margolis et al., 1985). Experiments conducted in Brazil and Tunisia show clearly that planting cactus in agroforestry system is more efficient for soil and water conservation than conventional land use (Table 10).

| Crop type | Soil preparation phase | Cultivation phase | Harvest until next growing season | Total Soil losses | C factor |
|----------------------|------------------------|-------------------|-----------------------------------|-------------------|----------|
| Bare soil | 7.19 | 8.20 | 13.71 | 29.10 | 1.000 |
| Cotton | 2.42 | 1.77 | 6.72 | 10.91 | 0.392 |
| Maize | 1.51 | 0.68 | 3.75 | 5.94 | 0.199 |
| Maize + beans | 1.36 | 0.55 | 2.02 | 3.93 | 0.119 |
| Opuntia ficus-indica | 0.48 | 0.02 | 1.48 | 1.98 | 0.072 |
| Perennial grass | 0.00 | 0.02 | 0.01 | 0.03 | 0.001 |

Table 10. Comparison of soil losses (tons per ha per year) under different crops in semi-arid Northeastern Brazil (Margolis et al., 1985)

Cactus to rehabilitate degraded rangelands

Cacti and Opuntia in particular are some of the best plants for the reforestation of arid and semi-arid lands because they can survive under scarce and erratic rainfall and high temperature. Impressive results are obtained with fast growing shrubs (*Acacia cyanophylla*, *Atriplex nummularia*) or cactus (*Opuntia ficus indica*) planting in Central Tunisia where average annual rainfall is 200-300 mm (Table 11).

| Rangeland type | Productivity (forage unit per hectare)* |
|---|---|
| Natural rangeland in Dhahar Tataouine, Tunisia (100 mm rainfall) | 35 -100 |
| Private rangeland improved by cactus crop in Ouled Farhane, Tunisia (250 mm rainfall) | 800-1000 |
| Cooperative rangeland improved through <i>Acacia cyanophylla</i> , Guettis, Tunisia (200 mm rainfall) | 400-500 |

Table 11. Productivity (forage units per hectare) of natural and improved rangelands in Tunisia (Nefzaoui and El Mourid, 2009) (*): One forage unit is equivalent to 1 kg barley grain metabolizable energy

3.5.3 Cacti: A multipurpose crop and a source of income for the rural poor

Cactus crop is easy to establish and to maintain and has various utilizations. It produces good quality fruits for local or international markets; it is an excellent fodder; cactus young cladodes (nopalitos) are used as vegetable; it produces the “perfect red dye” from a cochineal that lives only on a specific type of cactus; and recent research revealed the vast interesting areas of its medicinal and cosmetic uses.

Fruit production: Cactus pear is cultivated for fruit production since the Aztec time. Main producers today include Mexico, Italy, South Africa, Tunisia, Morocco, Peru, and others. Yields are extremely high and reach 25 tons fruits per ha. Harvest and post-harvest techniques are well developed in producing countries (Inglese et al., 2002). The fruit quality is quite similar to orange or papaya. Recent findings show that cactus fruit has a high content of anti-oxidants and other nutraceuticals.

Use of cactus as forage: Cacti present high palatability, digestibility, and reduce the water needs to animals; however, they must be combined with other feedstuff to complete the daily diet, as they are poor in proteins, although rich in carbohydrates and calcium (Nefzaoui and Ben Salem, 2002). Animals can consume large amounts of cladodes. For instance, cattle may consume 50 to 70 kg fresh cladodes per day, and sheep 6 to 8 kg per day. The energy content of cladodes is 3,500 to 4,000 kcal kg⁻¹ dry matter, just over half of which is digestible, coming mainly from carbohydrates. In arid and semi-arid regions of North Africa, cereal crop residues and natural pastures generally do not meet the nutrient requirements of small ruminants for meat production. Cladodes can provide a cost-effective supplementation, for raising sheep and goats on rangelands. When cladodes are supplied to grazing goats that have access to alfalfa hay, the milk yield is increased by 45% (to 436 g day⁻¹). When cladodes are associated with a protein-rich feedstuff, they may replace barley grains or maize silage without affecting body weight gains of sheep and cattle. For instance, milk yield for lactating goats supplied with 2.2 kg alfalfa hay day⁻¹ is actually slightly higher (1.080 g day⁻¹) when 0.7 kg cladodes replaces an equal mass of alfalfa. Water scarcity can depress feed intake, digestion, and therefore weight gains of sheep and goats. Thus, supplying livestock with water during the summer and during drought periods is crucial in hot arid regions. Animals consume considerable energy to reach water points. Therefore, the high water content of cladodes is a solution to animal raising in dry areas. In fact, animals given abundant supplies of cladodes require little or no additional water (Nefzaoui and Ben Salem, 2002).

Use of cactus as vegetable and other valuable products: It is feasible to industrialize cladodes, fruit, and nopalitos. This potential market deals mainly with concentrated foods, juices, liquors, semi-processed and processed vegetables, food supplements and the cosmetic industry; it is feasible, but it requires sustained effort and investment to develop the market (Saenz, 2002 – 2006). Many brands of jellies, marmalades and dried sweets are prepared and sold in Latin America, South and North Africa. Juice obtained from the strained pulp is considered a good source of natural sweetener and colorants. Pads are widely used as a dietary supplement to increase fiber content in the human diet and for other beneficial purposes such as weight reduction, decrease in blood sugar and the prevention of colon cancer. The world market for pills made from powdered cactus is growing at a fast pace and small-scale producers could well benefit from this trend (Saenz, 2006).

Medicinal uses: There is some experimental research with promising results on the use of “nopalitos” for gastritis; for diabetes due to the reduction of glucose in blood and insulin;

for hypercholesterolemia due to reduction of total cholesterol, LDL cholesterol and triglycerides serum levels; and for obesity (Nefzaoui et al., 2007).

Economic profiles have been developed for the main exploitation alternatives and reveal that these are indeed viable and with adequate investment returns. These projects bring additional benefits, such as the generation of employment, environmental improvement, etc., which do not represent income for investors, but do contribute to humanity.

4. Institutional innovations: Empowering local communities

Development projects in the past failed to adequately address real community issues and concerns in agropastoral dry areas in North Africa. Decision-makers and all research and development partners are increasingly aware that “the heart of the rangeland sustainable management” is linked to institutional issues. Indeed, in the past the situation of rangelands was relatively better not only because population pressure and demand for meat were lower, but also because the management of rangelands was more strictly controlled by traditional institutions (*jmaas in Morocco, Myaad in Tunisia*) that enjoyed effective power. Numerous policy and institutional reforms have been carried out in several countries of North Africa. In most cases, policy and institutional reforms weakened pastoral institutions. These institutional reforms can be classified into three main approaches: state appropriation of rangeland resources, strengthening customary tribal claims, and privatization with titling (Ngaido and McCarthy, 2004).

ICARDA and IFAD (International Fund for Agricultural Development) worked together within the framework of the Mashreq/Maghreb Project to develop and implement a new participatory approach aiming at sustainable development of agropastoral communities in dry areas of the North Africa region. More specifically, it aims to develop participatory methodologies and tools that empower local communities and promote sustainable livelihood and conservation of agropastoral resources in those areas.

A methodology is developed through the joint inputs of all stakeholders including community members, agricultural specialists, extension services, researchers, local institutions, and decision makers. The methodology consists of the following steps: characterization of the community, diagnosis, planning and programming, institutional set-up, implementation, and monitoring and evaluation. The pillar of the methodology is an effective communication where all stakeholders negotiate community development plan (CDP) on an equal basis and where all sources of knowledge are explored, encompassing both indigenous and research-based knowledge. So far there is little integration of indigenous knowledge into development planning, thus concerned communities are becoming more powerless. It is suggested that development agencies should use indicators extracted from local know-how of agropastors to prepare relief instead of just relying on satellite imagery.

This participatory approach has been accepted and embraced by communities and development agencies in Tunisia, Algeria, and Morocco. It has been documented and disseminated through different channels including: a field manual in English and Arabic, linkage with Karianet network, and specific websites (www.icarda.org; www.mashreq-maghreb.org).

Key lessons from this experience include: (i) participatory characterisation of communities is essential for cooperation and trust among stakeholders; (ii) recognition of local know-how is an important step for successful diagnosis; (iii) the preparation of annual and long-term

development plan approved by communities is an efficient tool to mobilize resources and ease project implementation; (iv) not to underestimate the ability of communities to identify appropriate technical solutions, to solve internal conflicts particularly relating to property rights and land use, and the importance of additional-income generating activities; (v) the success and the sustainability of the process depends on the promotion of elected community-based organizations that play a key interface role between communities and other actors (government agencies and decision makers, non government agencies, donors, and other communities).

Promoting community-based organizations and empowerment will support adaptation to climate change (Garforth, 2008) through:

- help building strong institutions that can facilitate both collective and individual adaptation and response to climate change and other external pressures, both in the short and long term;
- platforms for managing conflict over natural resources
- creating and intensifying learning opportunities, to broaden the set of information and knowledge available to farmers and support local innovation: Livestock Field Schools are an example of how this can be done;
- supporting local innovation processes;
- helping livestock keepers identify opportunities to enrich the set of options they have when making livelihood choices: re-thinking how advisory services are provided, particularly to small-scale, relatively poor livestock keepers.

Recent experience of communal rangeland management in Southern Tunisia (IFAD PRODESUD Project) is quite successful. The community-based organizations (GDAs) are built up on socio-territorial units that correspond to the traditional tribe boundaries. They are fully participating in the design and implementation of their integrated local development. The approach involves the real participation of agropastoral communities, in a new bottom-up mode, for the establishment of community development plan (CDP) that reflects the real issues and priority needs of the community. This is developed through the joint inputs of all stakeholders including community members, agricultural specialists, extension services, local administration and state representatives. Best-bet options for technical, institutional and policy issues are jointly identified for implementation, monitoring and evaluation. The community is represented by a formal community-based organization (CBO), directly elected by community members and fully recognized by government authorities as their equal partner for implementation of all actions set out in the jointly developed CDP. This includes such crucial issues as management of communal pasture and rangelands (for example more than 50,000 ha of collective rangelands are put under rest and fully controlled by the communities), as well as the procurement of funds and necessary inputs and facilities, and the independent and transparent contact with all stakeholders and similar CBOs in the region for exchange of relevant information and experiences (Nefzaoui et al., 2007).

5. Conclusions

In this chapter we reviewed some of the agricultural achievements realized in three North African countries where agriculture depends primarily on rainfed production systems dominated by cereal crops and small ruminant livestock. Successful adopted technologies under unfavorable climate conditions include drought tolerant and disease resistant crop

cultivars, water harvesting and supplementary irrigation, no-tillage practices, efficient feeding of small ruminants including communal rangeland management, utilization of balanced feed blocks, fodder shrubs and cactus, a marvelous multi-purpose crop, and above all the participation and empowerment of rural communities facing the adverse effects of climate change. Most of these innovations have been outscaled to other countries and regions with similar agro-ecologies. Thus, within the framework of FAO-ICARDA International Technical Cooperation Network on Cactus (FAO-ICARDA Cactusnet), cactus technologies have been disseminated to countries in the Near East (Jordan, Iran, Arabian Peninsula), South East Asia (India, Pakistan), Sub-Saharan Africa (Mauritania, Mozambique), and East Africa (Ethiopia, Eritrea). Within ICARDA Mashreq-Maghreb project (www.mashreq-maghreb.org), technological options such as feed blocks and fodder shrubs and trees have been adopted in countries of the Near East (Lebanon, Jordan, Syria, Iraq) and South East Asia (India, Pakistan). Institutional innovations including the community approach and community development plan have been applied and largely adopted in Jordan, Syria, Lebanon, Pakistan, and Mauritania.

The adoption of the improved technologies and institutional innovations and of further upgrade thereof will enable the North African rural communities cope with climate change. However, the recent IPCC projections point to an alarming increase in temperature, an important sea level rise, a general trend of rainfall reduction, and frequent occurrence of extreme events including severe drought and floods. These projections call for a firmer commitment and investment of North African countries and concerned international institutions in scientific innovations to address the worsening of natural resources status and the ensuing threat to food security. Issues to be addressed include (i) modeling climate change effect on a local level to develop more accurate warning systems for better coping with and adaptation to climate change; (ii) use of new biotechnological tools to increase the level and stability of animal and plant productivity encompassing tolerance to drought and heat stress as well as diseases and pests; (iii) developing new fresh water resources through desalination of bountiful sea water using limitless solar energy (iv) developing and promoting socially-acceptable policies on insurance against climatic risks and on water pricing and property rights; (v) North African countries should strive for a fair share of the post-Kyoto and other arrangements for access to the world carbon market and payment for environmental services.

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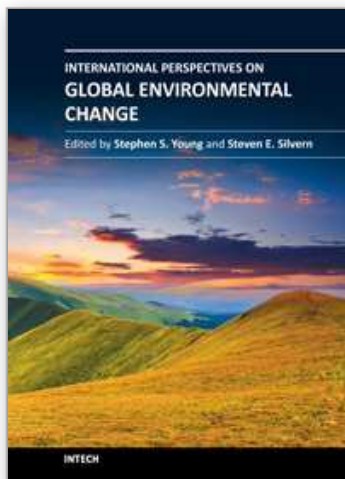
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