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Changes in North Africa production systems to meet climate uncertainty and new socio-economic scenarios with a focus on dryland areas

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Abstract. Production systems in North Africa are typically marked by the scarcity of water resources throughout the region. This scarcity is expected to worsen and to negatively affect food security under the grim scenarios of climate change with a predicted 20% reduction of precipitation by the end of the century and 0.2°C temperature increase per decade in the coming 2 decades. Most affected areas are those of the pastoral and agro-pastoral systems where rainfall is both low and highly variable, and productivity is continuously threatened and indeed negatively by the unfavorable changing climate. A clear change is being witnessed through the evolving livelihood pattern, marked by a more sedentary living of local populations and a strong preference for more remunerating and less-labor intensive activities, including high value animal and plant products, such as niche products, honey, aromatic and medicinal plants, and off-farm derived income including handicraft and eco-tourism. In areas less affected by drought, lowland cereal-based systems including integration of intensive livestock production are dominant. In those areas farmers are more benefiting from technological advances including mechanized farming operations, supplemental irrigation of cereal and forage crops and occasional full irrigation of high value commodities, including fruits, vegetables, and highly nutritious forage crops for animal fattening and intensive dairy production. Mountainous regions have been traditionally neglected despite their rich biodiversity and more abundant water resources. Nonetheless, local populations in all regions are more and more proactively involved in deciding on the strategies to address the dilemma of securing better livelihood and conserving natural resources in a global environment marked by a relentless climate change.

Keywords. Production systems – Agropastoral system – Cereal based system – Ruminant feeds – Climate variability.

Changement des systèmes de production face aux incertitudes climatiques et aux mutations socio-économiques des zones arides de l'Afrique du Nord

Résumé. *Les systèmes de production en Afrique du Nord sont marqués par la rareté des ressources hydriques qui est appelée à s'aggraver et à affecter négativement la sécurité alimentaire de l'ensemble de la région. Les différents scenarii de changement climatique prévoient une réduction de la pluviométrie de 20 % et un réchauffement moyen de 0.2 °C par décade. Les systèmes pastoraux et agropastoraux sont les plus touchés à case de la rareté et la variabilité de la pluviosité et les maigres opportunités de diversification des sources de revenus. La productivité de ces systèmes diminue significativement par l'effet des changements climatiques. Les systèmes pastoraux et agropastoraux vivent de véritables mutations aussi bien sur le plan sociologiques qu'économiques. Les populations essayent de développer d'autres activités plus rémunératrice, telle que le commerce transfrontalier ou des activités à caractère sédentaire (produits de terroirs, plantes médicinales, miel, écotourisme, activité non agricole, etc.). Dans les zones plus favorables où le système de production céréale-élevage domine, les agriculteurs bénéficient des avancées technologiques (mécanisation, irrigation complémentaire des céréales, production fourragère, élevage intensif, etc.). Dans les zones montagneuses du Nord où la pluviométrie est élevée et où les conditions de production sont plus difficiles à cause de la fragilité du milieu, l'activité de l'élevage extensif dans les clairières forestières demeure la principale source de revenu des populations démunies.*

Mots-clés. *Système agropastoral – Système céréale-élevage – Alimentation des ruminants – Fluctuations climatiques – Afrique du Nord.*

I – Introduction

North Africa typically is a dry region, comprising the countries of Algeria, Morocco and Tunisia, 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 (Nefzaoui *et al.*, 2012)

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 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) (Nefzaoui *et al.*, 2012)

Table 1. Selected agricultural characteristics for three North African countries

Characteristic	Algeria	Morocco	Tunisia
Population (million)	34.4	31.6	10.2
Total area (million ha)	238.1	71.0	16.4
Cultivated area (million ha)	8.4	9.0	5.0
Contribution of agriculture to GDP (%)	8.0	17.0	10.0
Rural population (% total population)	35.0	44.0	33.0
Employment in agriculture (% total employment)	14.0	45.0	18.0
Irrigated area (% cultivated area)	6.9	16.6	8.0
Total annual renewable water resources (km^3)	11.7	29.0	4.6
Annual per capita renewable water resources (m^3)	339.5	917.5	451.9
Wheat self-sufficiency (%)	29.0	58.0	50.0

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 (Nefzaoui *et al.*, 2012). 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.

II – Climate change 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 the 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 greenhouse 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 CO_2 equivalents (TE-CO_2) and the climate change impacts in North Africaare 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).

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

GHG emissions	Algeria	Morocco	Tunisia
Total emissions (million TE-CO_2)	103.1	63.3	20.8
Annual per capita emissions (TE-CO_2)	3.0	2.0	2.1
Emission composition (%):			
Carbon dioxide (CO_2)	64.5	67.0	72.0
Methane (CH_4)	29.7	18.0	14.0
Nitrous dioxide (N_2O)	5.9	14.0	14.0
Agriculture contribution to total emissions (%)	5.9	25.0	20.0

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 (CO_2), methane (CH_4) and nitrous oxide (N_2O) (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 Houérou, 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.

III – Constraints and opportunities in North Africa major production systems

Major production systems may be clustered under two main agro-ecologies, i.e. vulnerable agro-ecology and favorable agro-ecology with two important production systems per agro-ecology (Table 3).

1. Vulnerable agro-ecologies

Vulnerable agro-ecologies correspond to the driest areas of North Africa and embrace more than 60 % of the arable land in the region. They include two predominant production systems, the pastoral system and the agropastoral system. These vulnerable areas are characterized by a high population growth rate, large and rapidly increasing food and feed deficits, low and highly variable income levels, and limited natural resources, especially water. In addition to being the main locus of rural poverty, they are severely degraded. The rural livelihoods are based on production systems in which small ruminants represent the principal economic output. These systems are in transition and vary both within and between countries, from nomadic or semi-nomadic rangeland-based (pastoral system) to mixed crop-livestock smallholder systems (agropastoral system).

Rural populations in these fragile environments are often forced to pursue production strategies that, while meeting short-term requirements, are in the long-term destructive and unsustainable. Inappropriate policies of land use, incentives and the absence of secured property rights have exacerbated the problem. In most countries of the region, the traditional local institutions governing access to grazing lands have been disrupted, resulting in a system of "open access", without a regulatory mechanism to control the extent and intensity of grazing.

More frequent and prolonged droughts associated with global warming have worsened the vulnerability of agropastoral societies which forced governments in the region to intervene with various forms of drought assistance. Most of these interventions have encouraged farming practices that could increase both the extent of future drought losses and the dependence of local people on government assistance. However, empirical studies have revealed that although the rural poor may have limited resources, they still have considerable capacity to adapt to environmental degradation and to rehabilitate degraded resources (Nefzaoui *et al.*, 2012).

Experience showed that neither technical interventions nor policy adjustments alone will solve the problems. An innovative program of research for development integrating policy and institutional alternatives with research on technologies and management practices is capable of enhancing the resilience of the production systems and livelihoods in these regions (Nefzaoui *et al.*, 2012).

2. Favorable agro-ecologies

Two major production systems are located within these favorable agro-ecologies, the cereal-based production system and the mountain production system. The cereal-based system, generally concentrated in lowland plains, is often rainfed and is suitable to sustainable intensification for more productive, profitable and diversified dryland agriculture. Wheat is the dominant crop that could generate income if competitively produced. Farm size varies considerably with large farms well exceeding 100 ha and others not reaching 1/10th of this. The small farms cannot benefit from economies of scale such as effective mechanization, and lack opportunities of capitalization and access to input markets. These small farms offer bleak prospects for future generations of farmers. Youngsters are increasingly looking for alternative opportunities in the cities where employment is getting scarce. The result is unbridled urbanization with slums and social unrest.

North Africa countries are increasingly aware of this rural dilemma and are seeking ways to support the development opportunities in these rural areas in a two-pronged approach: aggregate the smaller units while retaining the work force on the farms or develop alternative production systems that can be competitive on a world market through high-value crops or animal products.

The mountains production system hosts the highest poverty rates (more than 40%). Mountain zones cover about 25 million hectares, of which 60%, 32% and 8% are located in Morocco, Algeria, and Tunisia, respectively. These areas have different geographical characteristics (extent, altitude, landscape etc.) and the climate is highly diverse ranging from humid in the north to desert in the south with arid and semi-arid climates in between, but in all cases with high variability in rainfall and prevailing droughts. In this paper, a special focus will be put on humid areas. Mountain zones are endowed with important natural resources and account for 30% of the arable land in Morocco, 12.5% in Algeria and 10% in Tunisia. They are also the main preserve of forestry resources, accounting for 65% of the forested area in Morocco, 31% in Algeria and 60% in Tunisia. Moreover these zones host most of the region's biodiversity and water resources. However, they face severe degradation and a high risk of loss of biodiversity (El Mourid, 2012).

The highlands of the Maghreb countries are well populated. They host 30%, 20% and 10% of the total populations of Morocco, Algeria and Tunisia, with population densities of 46, 150 and 100 inhabitants/km^2, respectively. These densities are higher than the national averages and are variable, ranging from 10 habitants per km^2 in the High Atlas of Morocco to more than 250 inhabitants per km^2 in Kroumirieof Tunisia and in the Rif of Morocco.

The prevailing production systems, consisting mainly of cereals, fruit trees and livestock, contribute significantly to domestic agricultural production in the respective countries. In these zones the average size of farms is generally small and cropped land is fragmented. Farms with less than five hectares of land represent 80% of mountain farms, and make up about 25% of total small farms nationwide.

The economy of mountain areas is poor and fragile. Per capita income represents, on average, half the per capita urban income, and poverty is high in most zones leading to high rates of emigration to other regions of the country and overseas.

When compared to other agro-ecosystems, mountains-based systems have not received adequate attention from research and development, despite their importance and the constraints they are facing. The social and economic development policies that have been implemented in the three countries did not address these zones until the early 1980's when a few integrated development projects were initiated. However, the impact of these projects was very limited, as they did not account for the specificity of these areas in terms of approach and technical and social recommendations.

In fact, the development of the highland areas has been based almost entirely on productivity concerns, relying on the excessive use of external (purchased) inputs and mechanization. This approach has been targeted at relieving constraints impeding the conventional intensification of production systems by the adoption of technologies and crop management practices initially developed for high potential (lowland) areas. It omitted to take into account the mountain context and the distinctive characteristics of the highlands. The appropriateness of this approach to the mountain context has often been questioned because of the resulting pressure on the natural resource base and its limited impact on poverty reduction.

Table 3.Characteristics of major production systems in North Africa

	Vulnerable agro-ecosystems		Favorable agro-ecosystems	
	Pastoral system	**Agropastoral system**	**Cereal-based system**	**Highland system**
Constraints	- Very low and highly variable rainfall, short growing season with high temperature, and a trend of increasing aridity and desertification (CC) - Encroachment of rangelands by barley and olive crops, - Natural resources degradation and overgrazing especially around watering points - Problems of livestock watering, and water points management - Conflicts on grazing lands - Animal health problems - Rejection of pastoral work by youngsters - Scarce opportunities for attractive employment and high poverty rates (outmigration of young people) - Lack of investments - Difficult access to credits	- Low and irregular, rainfall and scarce water resources - Limited available lands for cropping expansion, - Degradation of grazing lands - Land tenure problems - Marginal and variable farm incomes - Low level of exploitation of natural and cultural patrimony - Pressure on natural resources (overexploitation) - High unemployment and poverty rates (outmigration of young people) - Lack of investments and diversification - Difficult access to credits	- Low soil fertility - Monocropping and lack of diversification - Increasing biotic stress favored by CC (new races and strains of diseases and pests) - Low input use: seeds, fertilizers, pesticides - High harvest and post-harvest losses - Low adoption of improved cultivars and production package - Production uncertainty (occasional low-rainfall seasons, or floods, heat, frost) - Increasing production cost (mainly driven by higher fuel cost) - Unfavorable market/add value/ Insurance - Socio-economic constraints to specify) - Lack of economic scale - Land fragmentation	- Harsh environmental conditions, especially in winter - Highest illiteracy and poverty rates - Subject to severe natural resource degradation with a high risk of loss of biodiversity. - Highly populated (above the national average), - Limited arable land, - High rate of soil erosion - Land fragmentation - Fragile economy - High outmigration rate - Low investment for development - Government interventions focusing on productivity concerns with little attention to natural resources conservation and development

Table 3 (cont.). Characteristics of major production systems in North Africa

	Vulnerable agro-ecosystems		Favorable agro-ecosystems	
	Pastoral system	**Agropastoral system**	**Cereal-based system**	**Highland system**
Opportunities	- Important pastoral reserve for the region - Community-based rangeland management efficient & well accepted - Relatively important pastoral infrastructures - Local know-how for rangeland management and animal breeding	- Important public and private agricultural development programs - Specific agricultural products (sheep and goat meat, dry figs, olive oil, honey, etc.) - Important aromatic and medicinal plants and fruit trees, biodiversity - Well preserved local know-how (agriculture, etc.)	- Availability of improved technologies and associated tools (both locally and thru international market) - Relatively easier access to credit (as opposed to drier, high-risk areas) - Mechanization is possible despite land fragmentation, through service providers-cooperatives de service) - Better opportunities for learning of new technologies, especially through farmer-to-farmer dissemination	- Favorable climate especially with respect to rainfall and water resources - Promising results on pasture and livestock - Endowed with important natural resources - Main preserve of forestry resources - Host most of the region's biodiversity and water resources
Major changes	- Dismantlement of traditional institutions managing natural resources - Drastic reduction of nomadism and development of "mechanized" transhumance - Important increase of use of purchased feeds (supplementation) - Diversification of income sources (eco-tourism, small scale irrigation for high value crops including indigenous herbal aromatic and medicinal species, and , trans-boundary activities)	- Development of irrigated agriculture (vegetables, fruits, cash crops, forages) - Intensification of livestock activity (fattening, dairy cattle) - Privatization and cropping of collective rangelands	- Decrease of fallow practicecrop diversification including the use of improved species/varieties of food legumes in rotation with cereals - Development of supplemental irrigation leading to high cereal yields - Development of forage market with transfer to less favorable areas - Renting cereal stubble for animal grazing (between cereal harvest and soil preparation for the following crop)	- Quasi disappearance of animal traction and its replacement by inappropriate mechanization - Diversification of income sources (ecotourism, niche products, including local honey and high-value plant species) - Advanced land fragmentation

IV – Options to mitigate risk in vulnerable agro-ecologies and to improve sustainable productivity in favorable areas

1. Soil and water conservation and use

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, National Agricultural Research Systems (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 old indigenous practices 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.

2. Irrigation

Although water resources in North Africa do not allow full-scale irrigation of water-demanding crops (food crops, forage crops, vegetables, etc.), research has shown that supplemental irrigation (SI), applied as 1-3 irrigations at dry periods in the season, not only improves and stabilizes grain yield of major food crops, 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). In cereal-based cropping systems of semi-arid areas, WP of wheat is generally around 0.35-1 kg grain/m^3 water, but may reach up to over 2.5 kg grain/m^3 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 and Hachum, 2006; Shideed *et al.*, 2005). In fact, in wheat WP for FI is 1 kg/m^3 but it is 2.5 kg/m^3 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 and Oweis, 2008) The beneficial effect of SI is further enhanced when SI is combined with the use of adapted varieties (Karrou and Boutfirass, 2007).

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.

3. Conservation agriculture

In North Africa, conservation agriculture (CA), based on the no-till system, maintenance of crop residues and crop rotation, 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 (Zaghouane *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 CO_2 emission. Cover crops, residues and crop roots contribute to better soil structure and composition with enhanced buildup of organic matter, while crop residues protect the soil and minimize soil evaporation (Angar *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.

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). 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 (i) high weed infestation at the initial stage of CA adoption (Dridi *et al.*, 2010), and (ii) the unavailability of suitable CA-ready seed-drills. 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. Here is another opportunity for policy makers to encourage farmers reduce the impact of CC, by promoting CA through reduced cost of NT drills.

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. 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 nutrition and health monitoring (Nefzaoui *et al.*, 2012).

Two critical trends prevail in the current production context:

(i) 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.

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

5. Participatory management of communal rangelands

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”.

The perception of pastoralists of drought and climate change during the past decades, as well as the tools used to adapt to or mitigate climate fluctuation has been investigated using a sustainable livelihood approach (Nori *et al.*, 2009). Indeed, while in the thirties, there was 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. 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 on 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).

6. 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 in the North Africa 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 4. 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).

Table 4. Productive, environmental and social benefits from some alternative feeding options (Nefzaoui *et al.*, 2011)

Options	Impact on the animal	Impact on the environment	Impact on farmers livelihoods
Feed blocks	- Improved digestion of low quality diets and increased growth and milk production - Improved health conditions due to decreased parasiticload (use of medicated FBs)	- Decreased pollution with perishable AGIBs (olive cake, tomato pulp, etc.) - Decreased pressure on rangelands - Better quality manure	- 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 (*Opuntia* spp.)	- Improved digestion of low quality forages - Improved animal performance	- Improved soil condition - Decreased pressure on primary resources (water and rangelands)	- Added value cash crop (fruit and cladodes sale), and increased animal performance result in increased income
Shrub mixing	- Complementarities between shrub species (nutrients and secondary compounds) increased animal performances	- Combat desertification - Soil protection	- Reduced budget allocated for feedstuffs purchasing
Rangelands resting	- Increased feed intake and digestion - Increased productive and reproductive performances	- Reduces degradation risk - Protection of plant and animal biodiversity (domestic and wildlife animals)	- Reduced feeding cost and increased performances resulting in increased income

A. 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. phosphorus, copper, etc.) are distributed 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 5. 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.

Table 5. 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)

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 *ad lib*	Conc. (500 g/d)	Lambs	63		Tunisia
Wheat straw *ad lib*	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

†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%).

B. 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 for a longer period. As trees require little care after establishment, the production cost is low (Nefzaoui *et al.*, 2011).

C. Alley-cropping

This technique consists of cultivating herbaceous crops of both graminae and legumes 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 (i) improves soil, (ii) increases crop yield, (iii) reduces weeds, and (iv) 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 tones/ha. 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 at a seeding rate 160 kg/ha, between atriplex (333 plants/ha) 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 and 3,342.53 $/ha, 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.

D. 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 three 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 6. In summary, diversification of shrub plantations should be encouraged to improve livestock production in the dry areas of North Africa.

Table 6. Effect of shrub mixed diets on sheep and goat growth (adapted from Nefzaoui *et al.*, 2011)

Basal diet†	Supplement††	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

†Acacia: *Acacia cyanophylla*; Cactus: *Opuntiaficusindicaf. inermis* (cladodes); Atriplex: *Atriplexnummularia*.
††Values between parentheses are daily dry matter intake.

7. Ley farming

Carter (1974,1978) reviewed the potential for ley farming in Algeria and Tunisia and strongly supported the concept of introducing clovers and medics in place of fallow. He estimated that a potential area of 23 million hectares existed in nine countries and suggested that this should lead to large increases in crop yield and feed supply.

Some of the earliest Australian work on ley farming in the region was in Tunisia (Doolette, 1976) and Algeria (Saunders, 1976). John Doolette worked with Australian cultivars of barrel medic (*Medicago truncatula*) in Tunisia and David Saunders started selecting locally adapted medic ecotypes to suit the cold winter conditions he encountered in Algeria. Although there has been a continuing interest in the use of medics, neither project led to widespread commercial adoption of the system.

The non-adoption of this technique is due to several constraints, including biological/ technical difficulties, land tenure of grazing lands and government policies. Biological constraints include the lack of adapted legume cultivars, the need for inoculation with rhizobia, the need to apply phosphorus and inappropriate sowing methods (Halse, 1989). Technical constraints are well documented (Riveros *et al.*, 1989) and probably the easiest to solve. At the forefront of these constraints is the inability of farmers and technicians of North Africa to master the sensitive techniques of sound pasture establishment and management, which are essential to the self-regeneration of full stands of medics during a good number of years. Seed drills suitable for medic seeds are not readily available to farmers. Another major constraint to the adoption of the ley farming system is management of the medic pastures. Correct management is supposed to regulate the stocking rate so that maximum biomass is produced and grazed by animals, while ensuring sufficient seed production for subsequent regeneration. Farmers, even when they own the grazing livestock, have been unable to adjust stocking rates to plant growth and development.

In North African countries, bloat of animals (sheep) grazing on annual medics (native or introduced) was, on many occasions, mentioned by farmers. This problem seems to stem from the intermittent grazing of the annual legume pastures. Reports suggest that animal deaths could occur very rapidly even after a very short (15 minutes) grazing period. Farmers who have suffered animal losses from bloating are not likely to continue with the legume pastures of the ley farming system. Another important drawback to the adoption of the cereal/medic ley farming system is the lack of locally produced, inexpensive medic seed. Some attempts were made by government agencies to produce seed (multiply local ecotypes and introduced ones) in a few countries (e.g.Tunisia and Morocco). However, seed yields were low and land leveling and management of the production fields and harvesting were major limiting factors. The recent trend of more remunerating intensification led to the complete abandon of ley farming in North Africa.

8. Forage crops

Major forage crops in Morocco and Tunisia (Tables 7 and 8) include grass species with a dominance of oats, followed by barley, as a dual purpose grain-forage crop.

Table 7. Importance of forage crops in Morocco (Adapted from Balafrej, 2012)

Species	Cropped area, ha	% irrigated	Yields, t/ha		Use (G, H, S)†	Availability
			Rainfed	Irrigated		
Barley	117800	11	12	36	G	G: March-May)
Lucerne	111580	97	41	62	H, G	G: April-Nov H: All year
Oat	65310	1	23	49	H, G	G: Feb-April H: Oct-Feb
Berseem	63580	99	36	63	G	Rainfed: Jan-March Irrigated: Nov-May
Maize	39302	81	38	47	G, S	G: June-Agust S: All year
Oat-vetch	5800	2	17	27	G, H, S	G: March-April H: All year

†G: Green, H: Hay, S: silage.

Table 8. Importance of forage crops in Tunisia (adapted from Chakroun, 2012)

Species	Cropped area, ha	% irrigated	Use (G, H, S)†	Availability
Oat	190000	7	S, H	S, H: All year
Barley	60000	75	G, S	G: Nov-April; S: all year
Triticale	6000	33	G, S	G: Dec-March; S: all year
Oat-vetch	3500	100	H	All year
Sulla	7000	100	G, S	G: Nov-May; S: all year
Lucerne	7500		H, G	G: 9 months per year; H: all year
Ray-grass	2500	20	H, G	G: Winter/spring; H: all year
Medicago	2000	100	G	Nov-March
Berseem	5500		G	Nov-March
Sorghum	14000		G	July-Nov
Maize	4000		G, S	G: Aug-Sept; S: all year

†G: Green, H: Hay, S: silage.

Oat can produce high forage yield, usually as hay, but suffers from low protein value, which is improved by growing oat in combination with vetch, a legume crop adapted to semiarid conditions. Barley is a fast growing and early maturing species that can provide 3 or more cuts for herbage production plus some grain feed. Other grass forages include Italian ryegrass (*Lolium multiflorum*) particularly adapted to wetter areas where it outyields oats, and maize (*Zea mais*), and sorghum (*Sorghum sudanese*), a summer species grown under irrigation and used mainly as silage for dairy cattle. Alfalfa (*Madicago sativa*), a perennial legume species can grow in semiarid areas (rainfall of 400-500 mm/year), but performs better under irrigated light soil conditions. Berseem (*Trifolium alexandrinum*), a winter legume is also known in North Africa, where it is confined to well-watered or irrigated areas. Forage crops area did not increase in Tunisia during the last 3 decades and remains below 10% of total cropped area. In Morocco, forage crops area has been increasing during the last decade and even though remains around 4% of total cropping area. With the exception of barley, forage production in North Africa is constrained by irrigation water availability and costs and seeds availability. In particular, farmers have to rely on seed imports of species and varieties often bred and tested in environments different from the North African environments. On the other hand, farmers seek more income and prefer using available water to produce high-value cash crops (vegetables, fruit trees) rather than forage crops.

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