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Opuntia ficus-indica productivity and ecosystem services in arid areas

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Produttività ed utilizzo di *Opuntia ficus indica* in aree aride

Riassunto. *Opuntia* sp. pl è coltivata su 2,6 milioni di ettari in tutto il mondo ed utilizzata principalmente per la produzione di foraggio e frutta in agricoltura di sussistenza e orientata al mercato. Nonostante la loro importanza ecologica, economica e sociale, *Opuntia* sp. pl continua a ricevere una limitata attenzione scientifica, politica e dei media.

Le piantagioni ben mantenute generano esternalità positive e beni e servizi ambientali: possono svolgere un ruolo importante, non solo in termini di miglioramento della biodiversità e sequestro del carbonio, ma per quanto riguarda la conservazione del paesaggio e della natura, la mitigazione dell'erosione del suolo, la protezione delle acque. E' una specie facile da impiantare e da mantenere e ha vari utilizzi in grado di migliorare il sostentamento dei poveri delle aree rurali. Produce frutta di buona qualità per mercati locali o internazionali; i giovani cladodi di cactus (nopalitos) sono usati come vegetale e la maggior parte dei cladodi giovani e anziani fornisce foraggio che aiuta anche a ridurre il consumo di acqua del 70%. Una produzione di 50 T ss/ha/anno è possibile in cultura intensiva (80 T di letame, 160.000 piante/ha) in ambienti piovosi nel Nord Est del Brasile.

Nelle regioni aride della Tunisia (200-250 mm di pioggia, senza fertilizzanti), 14,5 T ss /ha/anno, sono sufficienti a coprire il fabbisogno di 15 pecore mentre 2 ha di pascolo consentono di sostenere 1 pecora (35 volte più alta). Una produttività del frutteto di cactus di 20 T ss /ha/anno è sufficiente per sostenere 4-5 bovini adulti all'anno. Nella stessa area sono necessari 15 ettari di pascolo per sostenere un'unità animale (60-75 volte più alta). Coltivata sia per la produzione di foraggio sia per quella del frutto, in condizioni molto difficili, può produrre circa 1,5-2 T ss /ha/anno.

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Introduction

Cacti are cultivated on 2.6 million ha across the world, and mostly used for forage, fodder and fruit production in both subsistence and market oriented agriculture. They can survive with as little as 50 mm rainfall in a given year, but with neither growth nor production. Mean annual rainfall of 100-150 mm is the minimum requirement for the successful establishment of rainfed cactus plantations (Le Houerou, 1984), provided soils are sandy and deep (Le Houerou, 1984a). "Humble", "aggressive", "gold green", "green jewel", "fruit of the poor", "fruit of thorns and delights", "priceless treasure", "treasure under the thorns", "dromedary of the vegetal world", "plant of the future" and "monstrous tree" are just some of the many epithets used to describe the plant and fruit of cactus pear (*Opuntia* spp.).

The controversy over whether it is a helpful or harmful plant depends on the species, where, when and how it is grown, and to whom it applies. Anyhow, there are numerous reasons behind the diffusion of *Opuntia* spp. around the world, particularly of *O. ficus- indica*, including:

- simple cultivation practices required to grow the crop;
- rapid establishment soon after introduction in a new area;
- easy multiplication practices that favour rapid diffusion and exchange of material among users;
- ability to grow in very harsh conditions characterized by high temperature, lack of water and poor soil;
- generation of income from the sale of much-valued and appreciated fruits;
- use of stems in the human diet and as forage for livestock;
- useful deployment of plants for fencing farms;
- nutritional value of juicy fruits;
- long shelf-life of fruit; and production of a wide range of industrial derivatives from fruit.

Despite its ecological, economic and social importance, Opuntia (cactus pear) continues to receive limited scientific, political and media attention. Well-maintained cactus plantations generate positive externalities and environmental goods and services: they can play a major role, not only in terms of biodiversity enhancement and carbon sequestration, but with regard to landscape and nature conservation, mitigation of soil erosion, water protection and cultural heritage. However, these public services do not have a market price, are difficult to disaggregate, are highly interrelated in complex dynamic ways and are difficult to measure.

The strong links between cactus pear production and the provision of diverse ecosystem goods and services, especially in marginal areas, need to be considered and integrated into a standard evaluation framework for environmental impacts of agricultural production.

Feed resources: major constraints to a sustainable livestock development in arid and semi-arid regions

The scarcity of natural water resources, combined with the highly variable and generally very low rainfall in most of the arid regions explain in part the low agricultural productivity, especially of key crop commodities, and the reliance on food imports to meet growing national demands; this is especially true for North African countries. 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. To lessen their dependence on highly unpredictable cereal harvests, small-scale farmers maintain livestock 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 the in semi-arid zones in contrast to the arid regions where livestock husbandry is the major agricultural activity (Nefzaoui *et al*., 2011a).

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 (Nefzaoui *et al*., 2011a). Livestock production remains the main source of income of rural populations living in drylands. It represents a key component of resilient production systems and an indicator of wealth. However, this sector is facing many challenges including feeding constraints and climate change.

Livestock production systems in arid and semi-arid regions face serious challenges to their sustainability deriving from:

- climatic constraints represented by the low rainfall and the high incidence of drought, affecting the productivity of rangeland ecosystems and the livelihood of the population;
- the desertification spiral which accelerated during the last decades;
- technical constraints underpinned by shortages in improved technologies to restore the ecological integrity, function and services of the degraded rangeland ecosystems;
- socio economic limitations, including the high poverty and vulnerability rates of the population which are exacerbated by unstable feed and animal market conditions and limited diversification of income sources;
- institutional obstacles linked mainly to continued cross-lawful inefficiencies (Nefzaoui *et al*., 2011b).

What are the main feed sources for livestock in arid and semi-arid regions, with focus to the Near East and North Africa (NENA)?

Rangeland and fallow grazing, standing barley (green or whole dry crop), cereal stubble, crop residues, cereal and legume straws, barley, wheat bran, olive cake, olive tree leaves and twigs, cactus and shrubs are the main feed resources for livestock in the NENA region. Their contribution varies greatly between years according to rainfall and drought occurrence. In any case, the contribution of rangelands to cover livestock feed requirements is dramatically decreasing (10-30%) while concentrate feeds (barley and bran) represent more than 50% of animal needs (Nefzaoui *et al*., 2011a and b).

On the other hand, the integration of crops and livestock is rather a fading illusion. Indeed, forage crops areas remained constantly low during the last three decades and its contribution is less than 10% in average in animal needs (Nefzaoui *et al*., 2014).

This trend is becoming alarming with the recent increase of cereal prices, particularly barley. The future of livestock production in the NENA region appears uncertain. These countries will have to face an increased pressure on rangelands which requires an innovative approach to their effective management and complementation with better use of local natural resources with an emphasis on water harvesting and better use of adapted indigenous plant species, such as cactus and fodder shrubs, and better use of crop residues (Papanastasis and Nefzaoui, 2000).

There are many advantages of promoting cactus crop and other shrubs like *Atriplex nummularia* and/or *halimus*, *Acacia cyanophylla* or *Salsola vermiculata*, because of their wider adaptability to harsh agro-climatic conditions and ability to produce for a longer period. As trees require little care after the establishment, the cost of production will be low. Preferred species are those which can withstand harsh conditions prevailing in the dry areas and improve farmers' income. Unfortunately, the list of these shrubs and trees is too short in the Mediterranean basin. Cactus is a promising shrub species and its plantation is welcomed mainly by farmers from the southern Mediterranean region. In Tunisia for example, most farmers opted for growing cactus in their wastelands. This preference is not only based on the profitability, but also on market demand (Nefzaoui *et al*., 2011a). Cactus plantations are available and expending at high speed in North Africa but also in many countries in Africa (Ethiopia, Mauritania, South Africa, etc.), Asia (India, Iran, Jordan, Pakistan, etc.) and America (Argentina, Brazil, Mexico, etc.). The popularity of cactus lies in its low demand for water, its high water use efficiency, tolerance to high temperature, rapid growth, high biomass, and the high content of its cladodes in water and energy. Additionally, it represents a source of income through selling its fruits and cladodes. Benefits from the integration of cactus cladodes in the diet of sheep and goats are well documented (Nefzaoui and Ben Salem, 2002).

As an example, Tunisia adopted this strategy since 1940 and Le Houérou (2002) reported that fodder plantations were systematically developed, following the visit of Griffith to Tunisia in 1932. The development of cactus for fodder was strongly supported by the government. The leadership authorized conditional land allotments in Central Tunisia under the condition that the contracting beneficiaries planted 10 % of the allocated land with spineless cactus. This was to serve as an emergency standing fodder crop reserve, which would stand as a buffer in times of fodder shortages. This was a strategic move as the country faced 3 years of severe droughts from 1946-48, where livestock were decimated by 70-75 %. Livestock losses were lower for those who had cactus plantations (Le Houérou, 2002).

Different cactus plantation options in arid and semi-arid regions

Fences and copses

This is a very common practice in all North Africa countries where most of farms are protected by biological fences using thorny cactus. Besides their efficient defensive role, these hedges played in the past an important role in the landscape organization and in the local socio-economy as evidence of land rights and land ownership in countries or regions where collective land ownership is prevalent. These hedges play also an important role in erosion control, particularly when established along contours (Le Houérou, 2002). Thorny cacti *O. ficus-indica* var. *amyclaea* (Ten.) A. Berger and var. elongata Shelle are often used as defensive hedges. Moreover, hedges are a physical obstacle to runoff, favoring temporary local runoff accumulation and silting, thus preventing regressive erosion. Some badlands, developed in outcrops of shale and stony/rocky slopes, have been cheaply rehabilitated in Tunisia and Algeria by contour planting of cacti. In arid lands subject to wind erosion, cactus hedges are an easy, cheap and efficient way to prevent and control topsoil loss and aid accumulation of wind-borne deposits (Le Houérou, 2000; Nefzaoui and El Mourid, 2009; Nefzaoui and El Mourid, 2010).

The other important traditional cactus plantation is in the form of copse around the rural houses. This "close-by" plantation is a source of feed for the family livestock, source of fruit for self-consumption and a shelter for the family poultry.

Rangelands

Rangeland improvement using spineless cactus is practiced mainly in North Africa and started since early 1930-40 (Le Houérou, 2002). From the agronomic view point, planting strategy to rehabilitate and/or improve rangeland, shrubland, bushland or poor farming areas wherever the soil is too shallow, too stony, too steep, too sandy or the climate is too dry for practical farming, is planting at a density of 1000-2000 single or double cladodes per ha, with a spacing of 5-7 m between rows and 1-2 m along the rows. Generally, no special treatments such as fertilizers application, pruning or treatment against pests and diseases are applied. Sometimes but not systematically, if the first year is too dry, supplemental irrigation is applied during establishment. Plantations are exploitable after 3-4 years and fully grown after 7-10 years and when rationally managed they can remain productive for more than 50 years (Louhaichi *et al*., 2017.

The productivity of a rangeland planted with cactus can be increased by a factor as much as 1 to 10 when rangeland is too degraded and 1 to 5 when the rangeland is in a good condition (Le Houérou, 2002). Similar results were reported by Nefzaoui and El Mourid (2009) and where impressive results are obtained with fast growing shrubs (Acacia cyanophylla) or cactus (Opuntia ficus indica) planting in Central Tunisia (tab. 1).

Few plant species are able to increase land productivity in the magnitude mentioned above, particularly when marginal lands are concerned. This is due to the rain-use efficiency (RUE) of cacti. Indeed, degraded Mediterranean rangelands have a RUE of 1 to 3 kg DM/ha/year/mm whilst rangelands in good condition exhibit a RUE of 4 to 6, desert rangelands, in turn, may have a RUE factor as low as 0.1-0.5 (Le Houérou, 1984). Rangeland rehabilitated with Opuntia ficus indica exhibits a RUE of 10 to 20 kg of above ground DM/ha/year/mm in arid areas where rainfall ranges between 200 to 400 mm per year.

The best example is the one of Tunisia where a total of 140,000 ha of private rangelands have been improved by spineless cactus since the launching of the national strategy of rangeland improvement in 1990. This figure is quite impressive if we consider the small size of the country. From 1990 to 2005 the surface area planted is about 6,000 to 7,000 per year and then the planting rhythm is slowing down during the last decade reaching a “plateau” (Gouhis *et al*., 2019 under press). Rangeland improvement by cactus planting increases the herbaceous biomass as well as the total biomass produced per acreage (tab. 2). The herbaceous biomass increased from 350-450 kg dry matter per ha to about 3000 kg DM per ha; while the total biomass reached 7000 kg DM and 14500 kg DM per ha respectively for a planting density of 2000 pads/ha and 8000 pads per ha (Gouhis *et al*., 2019, under press).

Alley cropping

Alley cropping is an agroforestry practice where perennial crops are simultaneously grown with an arable crop (e.g. barley, oat, etc.). The practice is such that cactus is grown in wide rows (e.g. 10-15 m) with a crop in the inter-space. Cactus may serve in this system as windbreak, resulting to improved grass/cereal yields. Wide alley may allow animals to graze biomass strata or cereal stubbles in summer time. In the latter case, cactus cladodes may be harvested shopped and given directly to grazing animals as energy supplement of low quality stubbles (Nefzaoui *et al*., 2014).

Properly managed alley-cropping allows diversification to benefit from several markets. It also promotes sustainability in both crop and livestock production by increasing land productivity and reducing weather risks compared to annual crops only. 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 tons/ha and the grain from 0.82 to 2.32 tons/ha (tab. 3). These results reflect the impact of the micro-environment created by alley-cropping with cactus, mainly through the beneficial ‘wind breaking’ role that reduces water loss and increases soil moisture.

Tab. 1- Productivity of natural and improved rangelands in Tunisia (Nefzaoui and El Mourid, 2009).
Tab. 1- Produttività di pascoli naturali e coltivati in Tunisia (Nefzaoui e El Mourid, 2009).

Rangeland type	Productivity (forage unit per hectare and per year)*
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 *Acacia cyanophylla*, Guettis, Tunisia (200 mm rainfall)	400-500

* One forage unit is equivalent to 1 kg barley grain metabolizable energy (12.4 MJ/kg DM)

Tab. 2 - Improvement of rangeland productivity (biomass) due to cactus planting.
Tab. 2 - Miglioramento della produttività del pascolo (biomassa) a causa della piantagione di cactus.

	Non improved	Improved	
		2000 pads/ha	8000 pads/ha
Herbaceous, kg DM/ha	340-450	3000	3000
Cactus, kg DM/ha		4000	11500
Total biomass, kg DM/ha	340-450	7000	14500

Tab. 3 - Total biomass changes and barley crop yields in Sidi Bouzid (Tunisia)*.
Tab. 3 - Variazioni totali della biomassa e rese delle colture di orzo a Sidi Bouzid (Tunisia).*

Treatment	Natural rangeland	Barley crop (alone)	Cactus crop (alone)	Alley cropping (cactus + barley)
Above ground biomass (t/ha)	0.51	0.53	1.87	7.11
Underground biomass (t/ha)	0.33	0.11	1.8	1.98
Barley grain yield, (t/ha)		0.82		2.32
Barley grain + straw + weeds (t/ha)		4.24		6.65

* Average rainfall in Sidi Bouzid is 250 mm/year. No fertilizers were applied to all treatments. Source: Alary *et al.* (2007)

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.

Tree legumes are also an option to include in alley cropping with cactus. Tree legumes add N to the system, providing protein and fiber to cactus-based livestock diets. In Brazil, *Gliricidia sepium* or *Leucacena leucocephala* were used with cactus and compared to cactus planted in monoculture. Adding the legumes did not change the total biomass, but it did provide a diversified feed source (tab. 4). Cactus and legumes can be grown locally in semiarid areas, reducing the dependency on foreign grain, increasing food security (Saraiva, 2014).

Intensive system

Intensive system for cactus fodder production is prevalent mainly in the North East of Brazil and in few areas in Mexico. The extreme example of intensification is met in Mexico where a dairy cattle farm grow cactus under drip irrigation and fertigation.

Recent experiences in Brazil indicated that drip-irrigating 10 mm per month (2.5 mm/week) using water harvested by in situ water catchment technique has increased productivity and made possible the cultivation of cactus in areas where cactus growth was limited due to warm night temperatures combined with lack of soil moisture (Lima *et al*., 2015).

Dubeux *et al*. (2015) reported that the use of drip-irrigation applying only 10 mm per month resulted in annual dry matter yields up to 19.6 t ha^{-1} in a region where cactus (*Opuntia ficus-indica* Mill.) would not grow well because of the low rainfall and warm night temperatures.

Cactus can reach high productivity in rainfed semiarid agroecosystems. Productivity above 50 tons DM/ha/year has been reported in intensive cultivation systems including the use of high levels of manure (80 tons/ha/year) and high plant population (160,000 plants per ha) in a rainfed system in Northeast Brazil (Silva, 2012). Average productivity often found in small farming systems are lower than the ones reported by Silva (2012) likely due to lower fertilization and lower plant population, as well as lack of weed control. A cactus orchard productivity of 20 t DM ha^{-1} $year^{-1}$ (Santos *et al*., 2000) would be enough to sustain 4 to 5 cows per year. In the same area, 15 ha of rangeland is needed to sustain one animal unit per year, in this case cactus productivity would be 60-75 times higher (Dubeux *et al*., 2017). Therefore, a small area of cactus would provide enough forage to sustain the herds and reduce the pressure on the natural resources of rangelands. Productivity observed in low input systems could be much lower than the results presented here. Farias *et al*. (2000) reported cactus productivity ranging from 2.2 to 3.4 tons DM/ha/year with 5,000 plants per ha intercropped with *Sorghum bicolor* (L.) Moench. Thus, productivity varies with inputs and systems, and producer should take into account land availability and economic value of inputs and outputs to come up with the decision on what system would fit better a particular condition (Dubeux *et al*., 2017).

Tab. 4 - Biomass productivity in alley cropping with Cactus and *Gliricidia sepium* or *Leucaena leucocephala*; Pernambuco, Brazil.
Tab. 4. -Produttività della biomassa nel vicolo che si raccoglie con Cactus e Gliricidia sepium o Leucaena leucocephala; Pernambuco, Brasile

Cropping system	Cactus biomass	Legume biomass	Total biomass
		Ton DM/ha/year	
Cactus + Gliricidia	13.6a	4.2a	17.8a
Cactus + Leucaena	14.0a	2.6b	16.6a
Cactus	16.9a	-	16.9a
S.E.	1.0	0.2	0.8

a,b Means in the same column followed by similar small case letters do not differ by Tukey test at 5%. Source: Saraiva (2014).

Mixed fruit-forage orchards

This is the most common system and also the most spread. It is prevalent almost in all countries where environmental conditions allow cactus growing and cropping cactus is part of the local knowledge and tradition. Two major types of plantations are present, the intensive specialized fruit orchards where the production objective is to produce good quality fruits for the local market or export and orchards with low inputs where fruits are mainly for self-consumption or local market. In both cases, pruning provides large amounts of cladodes that are sold and/or utilized at farm level to feed the livestock.

Cacti and subsistence agriculture

Cacti improve the livelihood of the rural poor directly (feed, food, fruit processing) and indirectly through improving the sustainability and the resilience of the production system (environment conservation, biodiversity conservation)

Cacti as feed for livestock

Opuntia spp. used for animal feeding are abundant, easy and cheap to grow, palatable, and able to withstand prolonged droughts (Shoop *et al*. 1977; Nefzaoui, 2009; Nefzaoui and Ben Salem, 2002; Nefzaoui *et al*., 2011a). Such characteristics make them a potentially important feed supplement for livestock, particularly during periods of drought and seasons of low feed availability. The cladodes constitute the majority of the biomass of an *Opuntia* and can be fed to livestock as fresh forage or stored as silage for later feeding (Abidi *et al*., 2013). In any case, the idea of using cactus to feed livestock is not recent and goes back to the 18th century (Griffith, 1933).

The nutritive quality of *Opuntia* cladodes depends on plant type (species, varieties), cladode age, season, and agronomic conditions (e.g., soil type, climate, and growing conditions). Cacti cladodes are an unbalanced feed nutrient wise but a cost-effective source of energy and water. Cladodes are low in crude protein, fiber, phosphorus, and sodium. Therefore, diets containing cactus should be balanced for these nutrients by appropriate supplements. The water content on a fresh weight basis averages nearly 90%. The ash content of cladodes is high, mainly because of the high calcium (Ca) content. Cladodes also have high levels of oxalates (about 13 % of the dry weight and 40 % of it in soluble form). The crude protein is often below 5% but can be up to 10% of the dry weight. The fiber content is also relatively low, about 10% of the dry weight. The nitrogen-free extract, which includes monomeric and polymeric sugars, is about 60% of the dry weight 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. Cladode consumption can have a laxative effect, leading to a more rapid passage of the food through the animal's digestive tract. This leads to poorer digestion, especially when the cladodes constitute more than 60% of the dry matter intake; supplementing with fibrous feed (e.g., straw or hay) can alleviate such laxative effects (Nefzaoui and Ben Salem, 2002).

The energy content of cladodes is 3,500 to 4,000 kcal/kg dry matter, just over half of which is digestible and comes mainly from carbohydrates (tabb. 5 and 6). In arid and semiarid 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, such as for raising sheep and goats on rangelands. For instance, when diets of grazing sheep are supplemented with cladode cakes, the daily weight gain increases nearly 50 % (145 g average daily gain). When cladodes are supplied to grazing goats that have access to alfalfa hay, the milk yield is increased by 45% (to 436 g/day). When cladodes are associated with a protein-rich feedstuff,

Tab. 5 - Effect of supply of spineless cactus (*O. ficus indica* var. *inermis*) on intake and digestibilities by sheep fed straw-based diets in Tunisia (Nefzaoui and Ben Salem, 2002).
*Tab. 5 - Effetto dell'erogazione di cactus senza spina dorsale (*O. ficus indica *var* inermis*) sull'assunzione e la digeribilità da parte di diete alimentate a paglia alimentate a pecora in Tunisia (Nefzaoui e Ben Salem, 2002).*

Parameters	Amounts of cladodes (g dry matter:dy)				
	0	150	300	450	600
Dry matter intake, g/day					
Straw	550	574	523	643	761
Cactus + straw	550	724	823	1093	1278
Total digestibility					
Organic matter	45	50	54	58	59
Crude protein	50	55	54	59	64
Crude fiber	53	51	53	52	47
Digestible intake (% of maintenance requirements)					
Organic matter	93	123	158	193	212
Crude protein	52	52	64	93	111
Protozoa (104 per ml)	3.5	9.3	13.0	17.7	13.1
Degradability of cellulose, %	85	72	57	55	56

Tab. 6 - Intake, digestibility, nitrogen balance, and growth for lambs on straw-based diets supplemented with conventional feeds (barley and soybean meal) and alternative feeds (spineless cactus and *Atriplex nummularia*) (Nefzaoui and Ben Salem, 2002).
Tab. 6 - Assunzione, digeribilità, bilancio dell'azoto e crescita per gli agnelli con diete a base di paglia integrate con mangimi convenzionali (farina di orzo e soia) e mangimi alternativi (spineless cactus e Atriplex nummularia*) (Nefzaoui e Ben Salem, 2002).*

Quantity	Supplements			
	Soybean meal		Atriplex	
	Barley	Opuntia	Barley	Opuntia
Organic matter intake (g per kg metabolic weight ($Kg^{0.75}$)	68	85	81	94
Digestibility %				
Organic matter	70	71	68	75
Protein	73	71	71	73
Fiber	68	69	68	74
Retained nitrogen (g/day)	9.4	9.5	7.5	12.2
Average daily weight gain (g/day)	108	119	59	81

they may replace barley grains or maize silage without affecting sheep and cattle daily weight gains. For instance, milk yield for lactating goats supplied with 2.2 kg alfalfa hay day-l is actually slightly higher (1.080 g/day) when 0.7 kg cladodes replaces an equal mass of alfalfa.

The dry matter intake of straw steadily increases as the amount of cladodes supplied increases. Because of the low gut fill of cladodes, an increase of cactus in the diet does not necessarily reduce the intake of other components of the ration. This is of great importance for arid zones where livestock is fed mainly with straw or cereal stubble, which are low quality coarse feeds that have poor intakes, resulting in low animal daily weight gains (Ben Salem *et al*., 1996; Ben Salem *et al*., 2004).

The cactus improves rumen fermentation. Sheep rumen fluid pH is not affected by up to 600 g dry matter of cladodes per day, remaining at 6.9. The cladodes are rich in easily fermentable carbohydrates, and their consumption probably enhances salivation. Compared with a cactus-free diet, the highest supply of cladodes doubles the concentration of ammonia nitrogen in the rumen of sheep fed diets based on straw or acacia. This leads to ammonia concentrations near optimal for microbial growth and fiber digestion in the rumen. Adding cladodes to the diet can increase the volatile fatty acids (such as propionic acid) by up to 30%, reflecting the increased intake of soluble carbohydrates Ben Salem *et al*., 1996).

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 beneficial in dry areas. Animals given abundant supplies of cladodes require little or no additional water (Ben Salem *et al*., 1996).

Investigation jointly conducted by INRA Tunisia and the University of Catania (Italy) showed that the consumption of cactus cladodes increases the amount of omega 3 (CLA) in lambs and kids meat. This encouraging result is of high importance and meets the ultimate goal, which is human health concern. Indeed, it is established now that "CLA is the only fatty acid shown unequivocally to inhibit carcinogenesis in experimental animals". Other positive effects of CLA are the reduction of cancer risk, reduction of diabetes and reduction of arteriosclerosis (Ben Salem *et al*., 2002).

The method of utilization of cladodes for livestock will differ according to circumstances, such as available labor, facilities, and quantity of cactus available. Although grazing of cladodes *in situ* is the simplest method, it is not the most recommended and care should be taken so that the animals do not overgraze the plants. The most common method is to cut and feed indoors. Cactus cladodes may be ensiled and used when needed. It is cheapest to store cladodes as parts of living plants instead of ensiling or drying (Abidi *et al*., 2013).

An innovative option of making a better use of cactus in animal feeding is to integrated in available fodder shrubs and trees of arid and semi-arid regions. Indeed, most arid fodder shrubs and trees are either low in essential nutrients 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 performances of animals. For example, *Acacia cyanophylla* foliage is high in CT 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 high in water but they are low in nitrogen and fibre. Wealth information on the complementary nutritional role of these three shrub species and the benefits from shrub mixed diets for ruminants, mainly sheep and goats have been reported (Ben Salem *et al*., 2000, 2002, 2004, 2005a, 2005b). This technique permits to balance the diet for nutrients and to dilute the adverse effects of secondary compounds and the excess of minerals, like salt. The association cactus-atriplex is a typical example of the benefits from shrub mixing. The high salinity and the low energy content of atriplex foliage could be overcome by cactus. Some examples of the effects of shrub mixed diets on sheep and goats performances are reported in table 7.

Managing the production risk caused by the variability of feed availability is the central issue in the livestock in arid and semi-arid regions. 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 feeding techniques based on cacti and other natural resources help smallholders to better manage livestock feeding throughout the year.

Cactus as food and food derivatives for the rural poor

Cactus crop is easy to establish and to maintain and has various utilizations able to improve the livelihoods of rural poor. It produces good quality fruits for local or international markets; 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 revealing the vast interesting areas of its medicinal and cosmetic uses (Feugang *et al*. 2006; Nazareno, 2017).

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 to be 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 (Nazareno, 2017).

Recently, new attractive businesses have been promoted in Tunisia, Morocco and Algeria to extract Opuntia seeds oil and exported for cosmetic uses at very high prices (around 800 $ US per litre). These projects bring additional benefits, such as the generation of employment, environmental improvement, etc.

Cacti and environment 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

Tab. 7 - Compiled data on the effects of shrub mixed diets on sheep and goat growth.
Tab. 7 - Dati sugli effetti delle diete miste di arbusti sulla crescita di pecore e capre.

Basal diet*	Supplement*	Animal	Daily gain (g)	References
Acacia (417 g/d)	Atriplex (345 g/d) Barley (280 g/d)	Lambs	54	Ben Salem et al. (2002)
Cactus (437 g/d)	Atriplex (310 g/d) Acacia (265 g/d)	Lambs	28	Ben Salem et al. (2002)
Cactus (499 g/d)	Straw (207 g/d) Atriplex (356 g/d)	Lambs	81	Ben Salem et al. (2004)
Atriplex grazing	Cactus (290 g/d)	Lambs	20	Ben Salem et al. (2005)
Native shrubland grazing	Cactus (100 g/d) Atriplex (100 g/d)	Kids	60	Ben Salem et al. (2000)

*Acacia (*Acacia cyanophylla*); Cactus cladodes (*Opuntia ficus indica* f. *inermis*); Atriplex (*Atriplex nummularia*). Values between parentheses are daily dry matter intakes.

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 (Nefzaoui *et al*., 2011a).

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 tons/ha/year) are the lowest with the last technique. Cactus planting in contour hedges may help retaining up to 100 tons/ha 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 (tab. 8).

Cacti and biodiversity conservation

Biodiversity constitutes the most important stability factor of ecosystems and agro-ecosystems. Stopping and/or reversing the decline in biodiversity is one of the biggest challenges for the maintenance of biodiversity and wider ecosystem services.

Cacti often act as 'nurse plants' in hot climates, meaning that their shade, and sometimes nutrients associated with their presence, help seedlings of other species to become established, which they may not be able to do when the soil is hot or poor. Cacti can be an attractive source of shelter for wildlife and their shade is very important to animals, but also to other plant species. Cactus species provide significant nest sites for birds, rodents and other animals. Birds perch on their branches to examine their surroundings. Bird droppings often contain seeds of other plants and shade of the cacti can provide a microclimate that promotes other plant life (Louhaichi *et al*., 2017). Cacti provide fruits and flowers to a range of animals including many species of birds, bats and insects including bees.

Conclusion

Livestock agriculture is very sensitive to resource competition. Competition for water, land and feed will increase at the same time as demand is rising. This will increase the risk of insecurity of supply and possibly reduce food safety. The social consequences of this are unknown. Current available information on cactus for fodder production is adequate to implement successful systems in different areas. Further knowledge must be gained in biotechnology, genotype*environment interactions, economic impact

Summary

Cacti are cultivated on 2.6 million ha across the world, and mostly used for forage, fodder and fruit production in both subsistence and market oriented agriculture. Despite their ecological, economic and social importance, *Opuntia* (cactus pear) continues to receive limited scientific, political and media attention. Well-maintained cactus plantations generate positive externalities and environmental goods and services: they can play a major role, not only in terms of biodiversity enhancement and carbon sequestration, but with regard to landscape and nature conser-

Tab. 8 - Comparison of soil losses (tons per ha per year) under different crops in semi-arid Northeastern Brazil (Margolis *et al*., 1985).
Tab. 8 - Confronto delle perdite di suolo (tonnellate per ettaro all'anno) con diverse colture in Brasile nord-orientale semi-arido (Margolis et al.*, 1985)*

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

vation, mitigation of soil erosion, water protection and cultural heritage. Cactus crop is easy to establish and to maintain and has various utilizations able to improve the livelihoods of rural poor. It produces good quality fruits for local or international markets; cactus young cladodes (nopalitos) are used as vegetable and most of young and elder cladode provide forage and fodder which help also in reducing water consumption by 70%. The paper review the us of cactus trees in rangelands. Production of 50 T DM/ha/year are reported in intensive cultivation system (80 T of manure, 160,000 plants/ha) in rainfed conditions in North East of Brazil. In arid regions of Tunisia (200-250 mm rainfall, no fertilizers), 14.5 T DM/ha/year, sufficient to cover the needs of 15 sheep while 2 ha of rangeland are needed to support 1 sheep (35 times higher). A cactus orchard productivity of 20 T DM/ha/year is sufficient to sustain 4-5 cows per year. In the same area, 15 ha of rangeland is needed to sustain one animal unit (60-75 times higher). In fruit-forage orchard and under very harsh conditions, the productivity is around 1.5 to 2 T DM/ha/year.

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