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Cactus as a Tool to Mitigate Drought and to Combat Desertification

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Abstract: Land degradation occurs in all continents and affects the livelihoods of millions of people, including a large proportion of the poor in the drylands. *Opuntia ficus-indica* (L.) Mill. is a xerophytic cactus species, widely cultivated in arid and semi-arid regions worldwide. As most of species of the *Cactacee* family, *O. ficus-indica* exhibits Crassulacean Acid Metabolism (CAM), with nocturnal stomata opening and CO_2 uptake occurring, typically, from dusk to dawn. Many reasons may account for the great interest devoted to cacti. The multipurpose use of this plant species and their ability to grow in harsh environments are the main reasons. Their root characteristics ameliorate wind and rain eroded soils so their growth in degraded areas should be encouraged. The establishment of sustainable production systems based on cactus may contribute to the food security of populations in agriculturally marginalized areas and to soil improvement. Cacti are some of the best plants for the revegetation of arid and semi-arid areas because they are tolerant of scarce and erratic rainfall and high temperatures. The reasons behind the inclusion of cacti include (i) simple cultivation practices required to grow the crop, (ii) its quick establishment soon after the introduction in a new area, (iii) ability to grow in harsh conditions characterized by high temperature, lack of water and poor soil, (iv) generation of income from the selling of much valued and appreciated fruits, (v) use of its stems in the human diet and as fodder for livestock and (vi) many industrial derivatives are produced from the fruits.

Key Words: Global warming, Land degradation, Livelihood, Poverty alleviation, Soil and water conservation

1. Introduction

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

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

Table 1. Comparative water use efficiency (WUE) and transpiration rate (TR) for C_3, C_4 and CAM plants (adapted from Nobel (2009).

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

* Water-Use Efficiency (WUE): ratio of the CO_2 fixed in photosynthesis to water lost via transpiration.
** Transpiration Ratio (TR): amount of water lost through transpiration over the CO_2 fixed in photosynthesis.

2. Cactus: the Perfect Candidate to Mitigate Climate Changes in Arid Zones

CAM plants (Agaves and Cactus) can use water much more efficiently with regard to CO_2 uptake and productivity than do C_3 and C_4 plants (Nobel, 2009). Biomass generation by CAM plants per unit of water is on average 5 to 10 times greater than C_4 and C_3 plants (**Table 1**). In contrast to C_3 and C_4 plants, CAM plants net CO_2 uptake occurs predominantly at night (Nobel, 2009). Nobel (2009) stated that the key for consequences between nocturnal gas exchange by CAM and C_3 and C_4 plants is temperature. Temperatures are lower at night, which reduces the internal water vapor concentrations in CAM plants, and results in better water use efficiency. This is the key reason CAM species are the most suited plants for arid and semi-arid habitats.

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Table 2. Comparison of soil losses (t ha^{-1} y^{-1}) under different crops in semi-arid north-eastern Brazil (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	8.2	13.71	29.1	1
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	0.02	0.01	0.03	0.001

Table 3. Productivity (forage units per hectare) of natural and improved rangelands in Tunisia (Nefzaoui and El Mourid, 2009).

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

* One forage unit is equivalent to 1 kg barley grain metabolizable energy.

C_3 and C_4 plants suffer irreparable damage once they lose 30% water content. On the other hand, many cacti can survive an 80 to 90% loss of their hydrated water content and still survive. This is due to the ability of CAM plants to store a lot of water, to shift water among cells to keep crucial metabolism active, and to tolerate extreme cellular dehydration (Nobel, 2009). These abilities stem from the cactus characteristics including the extra thickness of the cuticles providing an efficient barrier against water loss, the presence of mucilage, and the daytime stomatal closing. In addition, cacti have an asynchronous development of various plant organs, so that even under the worst conditions some part of the plant is not affected. It is well known that cactus grow in deserts where temperatures are extremely high. It has been reported by many authors (*i.e.* Nobel, 2009) that many agaves and cactus can tolerate high temperatures of up to 60 and 70°C.

A full chapter has been devoted to this aspect by Park Nobel (2009) in his recent book “Desert Wisdom Agaves and Cacti CO_2, Water, Climate Change”. In view of the specific phenological, physiological and structural adaptations of cactus described by Nobel (2009), it can be assessed that they are well positioned to cope with future global climate change. *Opuntia ficus-indica*, for example, can sequester carbon at a rate of 20 t dry matter (equivalent to 30 t of CO_2) per ha each year under sub-optimal growing conditions similar to those in North African arid regions. In this regard and as stated by Drennan and Nobel (2000) and Nobel (2009), agaves and cactus with their substantial biomass productivity and their high WUE should be considered for terrestrial sequestration of atmospheric CO_2 in underexploited arid and semi-arid regions. Such regions, which occupy 30% of the Earth’s land area, are poorly suited to C_3 and C_4 crops without irrigation.

3. How Can Cactus Help Adapting to Climate Change in Dry Areas?

3.1. Soil and water conservation

In the countries of North Africa, particularly Tunisia, cactus is successfully associated with water harvesting structures. When planted along contour lines, cactus hedges can 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 fields without cactus hedges. Between 40 to 200% increase in organic matter and nitrogen have been reported in fields with cactus hedges. Furthermore, top soil structural stability is enhanced and susceptibility to surface crusting, runoff and erosion are reduced, while permeability and water storage capability are increased (Nefzaoui and El Mourid, 2009).

Cactus planting in contour hedges may help in retaining up to 100 t ha 1 soil annually (Margolis *et al*., 1985). Comparing different cultivation systems, such as downhill planting, contour planting, reduced weeding, and intercropping with contour hedges, it was found that soil losses (0.13 to 0.26 t ha^{-1} y^{-1}) were the lowest with the last technique (Margolis *et al*., 1985). Experiments conducted in Brazil and Tunisia show clearly that planting cactus in agroforestry systems is more efficient for soil and water conservation than conventional land use (**Table 2**).

3.2. Cactus to rehabilitate degraded rangelands

Cactus and Opuntia in particular are some of the best plants for the revegetation of arid and semiarid lands. Impressive results are obtained with fast growing shrubs (*Acacia cyanophylla*, *Atriplex nummularia*) or cactus (*Opuntia* *ficus-indica*) plantings in Central Tunisia where average annual rainfall is 200-300 mm (**Table 3**).

4. Cactus: a Multipurpose Crop and a Source of Income for the Rural Poor

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

Fruit production: Cactus pear has been cultivated for fruit production since the Aztec times. Main producers today include Mexico, Italy, South Africa, Tunisia, Morocco, Peru, and others. Fruit yields are extremely high and reach 25 t ha^{-1}. Harvest and post harvest techniques are well developed in producing countries (Inglese *et al*., 2002). The fruit quality is quite similar to orange or papaya. Recent findings show that cactus fruit has a high content of anti-oxidants and other neutraceuticals (Nefzaoui *et al*., 2008).

Use of cactus as forage: Cactus presents high palatability, digestibility, and reduces the water need to animals. However, cactus must be combined with other feed to complete the daily diet, as they are poor in proteins, although rich in carbohydrates and calcium (Nefzaoui and Ben Salem, 2002). Animals can consume large amounts of cladodes. For instance, cattle may consume 50 to 70 kg fresh cladodes per day, and sheep 6 to 8 kg per day. The energy content of cladodes is 3,500 to 4,000 kcal kg^{-1} dry matter, just over half of which is digestible, coming mainly from carbohydrates. In arid and 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. When cladodes are supplied to grazing goats that have access to alfalfa hay, the milk yield is increased by 45% (to 436 g day^{-1}). When cladodes are associated with a protein rich feedstuff, they may replace barley grains or maize silage without affecting body weight gains of sheep and cattle. For instance, milk yield for lactating goats supplied with 2.2 kg alfalfa hay day l is actually slightly higher (1.080 g day^{-1}) when 0.7 kg cladodes replaces an equal mass of alfalfa. Water scarcity can depress feed intake, digestion, and therefore weight gains of sheep and goats. Thus, supplying livestock with water during the summer and during drought periods is crucial in hot arid regions. Animals consume considerable energy to reach water points. Therefore, the high water content of cladodes is a solution for animal raising in dry areas. In fact, animals given abundant supplies of cladodes require little or no additional water (Nefzaoui and Ben Salem, 2002).

Use of cactus as vegetable and other valuable products: It is feasible to industrialize cladodes, fruit, and nopalitos. This potential market deals mainly with concentrated foods, juices, liquors, semi processed and processed vegetables, food supplements and the cosmetic industry. While this is feasible, it will require 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, and 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 (Nefzaoui *et al*., 2008).

5. Conclusion

Opuntias are now part of the natural landscape and the agricultural systems of many regions of the world. There is increasing interest in opuntias, and *O. ficus-indica* in particular, as they play a strategic role in agricultural and economic development, particularly in disadvantaged areas, in view of its opportunities for income generation, food production and ecosystem conservation. Therefore, opuntias have become an major source of products and functions as a crop for both subsistence and market-oriented agriculture, contributing to the food security of populations in agriculturally marginalized areas and as a tool to mitigate drought and to combat desertification.

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