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Cactus (*Opuntia* spp.) as forage

FAO PLANT PRODUCTION AND PROTECTION PAPER

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Food and Agriculture Organization of the United Nations

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FOREWORD

The cactus *Opuntia* has been used in Mexico from pre-Hispanic times, and along with maize (*Zea mays*) and agave (*Agave* spp.), played a major role in the agricultural economy of the Aztec civilization.

In recent years there has been increased interest in *Opuntia* species for the important role they play – and are likely to play – in the success of sustainable agricultural systems in marginal areas of arid and semi-arid zones.

Opuntias are well-adapted to arid zones characterized by droughty conditions, erratic rainfall and poor soils subject to erosion, having developed phenological, physiological and structural adaptations to sustain their development in these adverse environments. Notable adaptations are their asynchronous reproduction, and their Crassulacean Acid Metabolism, enabling them to grow with very high efficiency under conditions of limited water.

While opuntias may particularly contribute in times of drought, serving as a life saving crop to both humans and animals, they also regularly provide livestock forage in arid and semi-arid areas. They provide highly digestible energy, water and minerals, and when combined with a source of protein, they constitute a complete feed.

In 1995 FAO published a book on *Agro-ecology, cultivation and uses of cactus pear*, prepared through CACTUSNET, the international cactus network, with only one chapter devoted to the use of opuntia as feed. The present publication, also prepared through CACTUSNET, focuses primarily on the use of opuntia as forage and presents many recent research and development findings.

The preparation of this book was coordinated by Enrique Arias and Stephen Reynolds of the Horticulture and Grassland and the Pasture Crops Groups of the Plant Production and Protection Division, and by Manuel Sanchez of the Feed Resources Group of the Animal Production and Health Division.

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PREFACE

Towards the end of 1990, encouraged by the Mexican Embassy in Rome, a Mexican delegation consisting of researchers, technicians and officials from the federal agricultural sector, visited the island of Sicily, Italy, with the aim of initiating agreements to exchange information between the two countries concerning the cultivation and utilization of opuntia. When the delegation arrived on the island, the spectacular development of opuntia was noted. It was surprising to realize that formal cultivation of opuntia started only in the 19th century.

One year later, an *International Symposium on Opuntia*, with participants from Chile, Italy, Mexico and USA, was organized in Lagos de Moreno (Jalisco, Mexico), with the purpose of encouraging producers and researchers to increase cooperation among the participating countries and to diffuse information on the importance of opuntia.

As a follow-up to this meeting, it was proposed to create an International Technical Cooperation Network on Cactus Pear (CACTUSNET). The proposal was presented in a special session of the *Second International Congress on Opuntia*, which was held in Santiago, Chile, in 1992. CACTUSNET was established under the auspices of the Food and Agriculture Organization of the United Nations (FAO) in a specific meeting organized by the University of Guadalajara, Mexico, in August 1993, with the participation of ten countries from the Americas, Asia and Europe. Subsequently, several African countries have also joined the Network.

Subsequently, thanks to the voluntary cooperation of CACTUSNET members residing in countries with an arid environment, it was possible to start a database on countries of production, opuntia uses, and cultivated areas. At the end of the 20th century, the area under cultivated opuntia for forage was reported to be 900 000 ha, greatly surpassing the reported area for fruit (100 000 ha). For farmers in arid zones, opuntia planting is one solution to the problem of recurrent droughts. The succulence and nutritive value of opuntia make it a valuable emergency crop, permitting livestock farmers in Brazil, Mexico, South Africa and USA to survive prolonged and severe droughts.

It is worth mentioning that most authors of this book are technicians and scientists with wide experience in their own country of cultivation and use of opuntia as forage. The publication strengthens the written information on opuntia, since most of the existing publications have emphasized its use as a fruit.

Finally, I would like to mention that the diffusion of information on species like opuntia can allow assessment of its value for tackling drought in the short term, while in the medium term opuntia can constitute an important alternative to counteract global climate change and desertification. Other benefits from opuntia are soil and water conservation, and protection of local fauna in arid and semi-arid lands.

The publication of this book is, therefore, opportune, reflecting one of the basic objectives of the CACTUSNET, namely the diffusion of technical and scientific knowledge on opuntia

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INTRODUCTION

Stephen G. Reynolds and Enrique Arias

GENERAL BACKGROUND ON OPUNTIA

The utilization by man of the cactus *Opuntia* was recorded in Mexico in pre-Hispanic times, where it played a major role in the agricultural economy of the Aztec empire; with maize (*Zea mays*) and agave (*Agave* spp.), opuntias are the oldest cultivated plants in Mexico. There are three crucial steps in the transition from the use of wild plants to planned cultivation, namely:

* the gathering of wild plants;
* cultivation of (wild) plants near human settlements, and
* cultivation of varieties, altered by selective propagation methods, in intensive farming for the purpose of marketing.

Opuntias are now part of the natural landscape and the agricultural systems of many regions of the world. Typically, there are three main production systems: wild cactus communities; family orchards; and intensive commercial plantations. Opuntias have adapted perfectly to arid zones characterized by droughty conditions, erratic rainfall and poor soils subject to erosion. They thus contribute in times of drought, serving as life saving crops for both humans and animals. Some species are even naturalized weeds in countries such as South Africa and Australia, where the environmental conditions are particularly favourable.

In recent years, plantations for fruit or forage production, as well as for vegetable or nopalitos and cochineal, have been developed in many countries of Africa, America, Asia and Europe. There is increasing interest in opuntias, and *O. ficus-indica* in particular, and the important role they play and are likely to play in the success of sustainable agricultural systems in arid and semi-arid zones, where farmers and shepherds must look to those few species that can profitably survive and produce. Thus opuntias have become an endless source of products and functions, initially as a wild plant and, later, as a crop for both subsistence and market-oriented agriculture, contributing to the food security of populations in agriculturally marginalized areas.

BOTANY

There are almost 300 species of the genus *Opuntia* (Scheinvar, 1995). In Mexico alone, Bravo (1978) recorded 104 species and varieties.

According to Scheinvar (1995), the name “Opuntia” comes from an ancient Greek village in the region of Leocrid, Beocia: Opus or Opuntia, where Tournefort found a spiny plant which reminded him of the American opuntias. Opuntia includes 11 subgenera: *Opuntia*, *Consolea*, *Austrocylindropuntia*, *Brasiliopuntia*, *Corynopuntia*, *Cylindropuntia*, *Grusonia*, *Marenopuntia*, *Nopalea*, *Stenopuntia* and *Tephrocactus*.

The taxonomy is difficult for a number of reasons: their phenotypes, which vary greatly according to ecological conditions; their polyploidy, with a great number of populations that reproduce vegetatively and sexually; and the existence of numerous hybrids, as almost all species blossom during the same period of

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the year and there are no biological barriers separating them. Scheinvar (1995) mentions nine wild species of *Opuntia* (*O. hyptiacantha* Web; *O. joconostle* Web; *O. lindheimeri* (Griff. and Haare) Bens.; *O. matudae* Scheinv.; *O. robusta* Wendl. var. *robusta*; *O. sarca* Griff. ex Scheinv.; *O. streptacantha* Lem.; *O. tomentosa* SD. var. *tomentosa* and var. *herrerae* Scheinv.) and three cultivated species (*O. albicarpa sp. nov.; O. ficus-indica* (L.) Mill.*; O. robusta* Wendl. var. *larreyi* (Web.) Bravo), as well as one cultivated species of the subgenus *Nopalea* (*O. cochenillifera* (L.) Mill.), providing detailed descriptions of each.

The evolution of members of the subgenus *Opuntia* in arid and semi-arid environments has led to the development of adaptive anatomical, morphological and physiological traits, and particular plant structures, as described by Sudzuki Hills (1995).

The species of the *Opuntia* spp. subgenus have developed phenological, physiological and structural adaptations favourable to their development in arid environments, in which water is the main factor limiting the development of most plant species. Notable among these adaptations are asynchronous reproduction, and Crassulacean Acid Metabolism (CAM), which, combined with structural adaptations such as succulence, enables this plant to survive long periods of drought, and to reach acceptable productivity levels even in years of severe drought.

TERMINOLOGY

In this book opuntia is used to refer to the whole genus, of which the most widely known is *Opuntia ficus-indica*. Previously, opuntia was used almost interchangeably with cactus pear and prickly pear. Here, while these terms are occasionally used, the term opuntia is preferred because cactus pear can sometimes refer to the fruit, and also not all opuntias are prickly pears, there being many spineless clones.

Other terms used include the following:

* cactus pear – opuntia plant
* cladode – shoots or stem-like organs
* jarabe – a syrup product from the fruit
* melcocha – jam
* miel de tuna – cactus pear honey
* nocheztli – highly prized red dye obtained from the body of the cochineal insect (*Dactylopius coccus*) living on some opuntias. Called *grana cochinilla* by the early Spanish in Mexico, now called cochineal
* nochtli – opuntia fruit
* nopal – opuntia plant (mainly Mexico)
* nopalitos – young cladodes used as vegetables
* nopalli – opuntia plant in Nahuatl language
* notuatl – the original Mexican word (from Aztec times) for opuntia
* prickly pear – opuntia plant
* queso de tuna – cactus pear cheese
* tenochtli – sacred opuntia in early Mexico
* tun/tunas – Caribbean word for fruit or seed

Opuntia ficus-indica

Common names:

- * Spanish: nopal, cardón de México, chumbera, chumbo, chumbua, higo chumbo, higo de pala, higo México, higuera de pala, nopal de castilla, tuna de España, tuna española, tuna mansa, tuna, higo chimbo, tuna real.
- * Portuguese: palma forrageira, figo da India, figo de pitoira, figueira da India, palmatoria sem espinhos, tabaido.
- * English: Barbary fig, Indian fig, prickly-pear.
- * French: chardon d'Inde, figue de Barbarie, figuier à raquettes, figuier d'Inde, opunce, raquette.
- * Italian: Fichi d'India
- * German: frucht des feigenkactus, Indianische feige.

CACTUSNET

Upon the request of member countries, an international network, CACTUSNET, was established in Guadalajara, Mexico, in 1993, under the auspices of FAO, to increase cooperation among scientists, technicians and growers from different countries, and to facilitate the exchange of information, knowledge and technical cooperation on cactus. Cooperation in the collection, conservation, evaluation and utilization of germplasm, and the promotion of the ecological and social benefits of opuntias are also aims of the network. Twenty-two countries have since joined. The University of Guadalajara, Mexico, and the University of Reggio Calabria/University of Palermo have hosted the general coordination; from October 2000, the coordinating institution became the National Institute for Agricultural Research of Tunisia. Meetings normally take place in conjuction with the International Congress on Cactus Pear and Cochineal, held every fourth year, but additional regional meetings and working group meetings are also held, such as those in Angola, Argentina, Chile, Italy, Mexico, Peru and South Africa on a range of topics, including post-harvest aspects, genetic resources, cochineal, forage, fruit production, etc.

Tangible results of cooperation through CACTUSNET have been the preparation for publication in 1995 of the FAO book *Agro-ecology, cultivation and uses of cactus pear* (which has been translated into Spanish and is being translated into Arabic), the production of a Descriptor List, and the annual CACTUSNET Newsletter. The fifth edition, published in March 2000, focused on the use of opuntia as forage and is available on the website of the FAO Grassland Group:

http://www-data.fao.org/WAICENT/FAOINFO/AGRICULT/AGP/AGPC/doc/publicat/Cactusnt/cactus1.htm

The present publication is also an example of voluntary cooperation of institutions and individuals participating in the CACTUSNET.

OPUNTIA USE AS FORAGE

Felker (1995) has provided an excellent introduction to Opuntia as forage and a synthesis of common recommendations for cactus use and management for livestock feed. He mentions a number of excellent regional reviews covering the uses of cactus for forage in North Africa (Monjauze and Le Houerou, 1965), South Africa (De Kock, 1980; Wessels, 1988), Mexico (e.g. Flores and Aguirre, 1979; Fuentes, 1991), Brazil (Domingues, 1963) and the United States (e.g. Russell and Felker, 1987a, b; Hanselka and Paschal, 1990). Much of the progress stemmed from the work of Griffiths in Texas in the first two decades of the 1900s.

Opuntia is particularly attractive as a feed because of its efficiency in converting water to dry matter, and thus to digestible energy (Nobel, 1995). Cactus is useful not only because it can withstand drought, but also because its conversion efficiency is greater than C_3 grasses and C_4 broadleaves. Biomass generation per unit of water is on average about three times higher than for C_4 plants and five times higher than for C_3 plants. Under optimal conditions, the various types of plants can produce similar amounts of dry matter per surface area, but under arid and semi-arid conditions, CAM plants are superior to C_3 and C_4 plants.

Cacti, and specifically *Opuntia* spp., have been extremely useful livestock forage in times of drought, primarily by providing digestible energy, water and vitamins. Although mainly used for cattle, opuntia has also been used as forage for pigs. However, it must be combined with other foods to complete the daily diet because opuntias are poor in proteins, although rich in carbohydrates and calcium. Since it grows in severely degraded land, its use is important because of its abundance in areas where few crops can grow. It is estimated that, worldwide, 900 000 ha are cultivated with opuntia for forage production.

While spineless types need to be protected against herbivory, the more cold-hardy, slower growing spiny types require no such protection, although it is necessary to burn off the spines before using for livestock feed.

Felker (1995) noted the lack of serious R&D and suggested priority areas for research into the use of cactus for forage.

ENVIRONMENTAL ISSUES

Opuntia spp. are being utilized in programmes to prevent soil erosion and to combat desertification; they have a great capacity for adaptation, growing in severely degraded soils which are inadequate for other crops and are ideal for responding to global environmental changes such as the increase in atmospheric CO_2 levels. Opuntias are also important as cover in arid and semi-arid areas because they can survive and spread under conditions of scarce and erratic rainfall and high temperatures and can play an important role in the protection of local fauna.

However, this capacity for adaptation and rapid spread has caused problems, mainly where introduced *Opuntia* spp. have established and thrived in the absence of natural enemies and appropriate management to become noxious weeds in a number of counties. In the previous FAO publication *Agro-ecology, cultivation and uses of cactus pear*, a chapter by Brutsch and Zimmermann focused on naturalized *Opuntia* spp. which threaten native plant genetic resources, and also on the biological, chemical, mechanical or integrated means of control which have been developed. Biological control has been particularly successful in countries such as Australia and South Africa. However, the problems of developed countries are not necessarily the same as those of less developed countries, and what may be considered a weed in one country may be an important economic source of food in another. Therefore different countries and even areas within countries may view *Opuntia* spp. differently.

This book emphasizes Opuntia as a valuable natural resource, which in many countries is underutilized, and which can provide forage for livestock and enable economic activities to be undertaken and may contribute to the food security of populations in agriculturally marginalized areas.

PURPOSE OF THE BOOK

Several publications have dealt with opuntia. Previously, through CACTUSNET, FAO published *Agro-ecology, cultivation and uses of cactus pear*. The present publication focuses solely on the use of opuntia as forage and aims to present much of the recent findings and research in one volume. From chapters dealing with its early use as forage in Mexico and its ecophysiology, the book presents material on germplasm resources and breeding for forage production, then deals at length – through eight chapters – with its use as forage in Mexico, Brazil, USA, Chile, Argentina, Western Asia and North Africa, Ethiopia, and Southern Africa. One chapter focuses on various aspects of opuntia cultivation for fodder. The final chapter deals with hydroponic opuntia production, followed by a comprehensive bibliography and an annex of opuntia-related websites. It is hoped that the book will achieve its purpose of providing readers with an up-to-date reference on the use of Opuntia as forage for livestock, and assembling in one volume past, recent and ongoing work on the subject.

HISTORY OF THE USE OF OPUNTIA AS FORAGE IN MEXICO

Marco Antonio ANAYA-PÉREZ

INTRODUCTION

Opuntia, often called prickly pear, or cactus pear as it is now usually known in commerce, is a plant typical of the Mexican landscape, and a major symbol of identity for the Mexican people. Together with maize and agave, opuntia has been a staple food, instrumental in enabling human settlement and cultural development of the Chichimeca groups of the centre and north of the country.

Complementary to its importance as food were *inter alia* its uses as a beverage, medicine, source of dye, and as an object of magical-religious practices. *Tlacuilos* [the native historians of Pre-Columbian Mexico, who used pictograms to record events], chroniclers, travellers, historians and scientists have left testimony of this. However, the economic importance of opuntia as forage was not perceived during the Spanish Colonial Period, or even after independence.

The few records on the use of opuntia during the colonial and post-independence eras indicate that it was used as animal feed, especially in the northern arid and semi-arid zones. Its use increased from the early 1600s with the introduction of cattle to semi-arid areas and the consequent depletion of grasslands. This situation forced stockmen to cut opuntia pads and burn off the thorns to feed livestock in their pastures, especially during droughts.

In the second half of the twentieth century, the Government of Mexico and some educational institutions began to recognize the importance of opuntia cultivation, particularly for forage. The Colegio de Posgraduados released improved varieties to participate in a programme aimed at stopping overexploitation of wild populations of opuntia, associated with intensive livestock feeding during droughts or as a regular complement to the diet. Opuntia plantations have been promoted as a foundation of reforestation and recovery programmes for extensive degraded areas, aiming to control desertification. There are few studies on the history of opuntia, with the exception of cochineal. This chapter presents a brief account of the utilization of opuntia as forage in Mexico.

ORIGIN

According to Flannery (1985), between the end of the Pleistocene (ca. 100 000 years B.P.) and the beginning of the fifth millennium AD, the prehistoric indigenous group of the semi-arid basins and valleys of the states of Hidalgo, Mexico, Morelos, Guerrero, Puebla and Oaxaca began cultivating a series of native plants, which later became the basic foodstuffs of the ancient middle-American civilizations. For centuries, these native Americans had lived as nomads, learning *inter alia*, which plants to gather and consume, how to roast opuntia and agave to make them edible, and how to extract syrup from the pods of the mesquite (*Prosopis* spp.). The cultivation of beans, squash, *huatli* (*Amaranthus* sp.), chilies, tomatillo, avocado, and, as Flannery (1985) suggests, perhaps opuntia, agave and other semitropical fruits began between 7 500 and 5 000 years BC.

Since the arrival of man in Mexico in the desert and semi-desert zones, about 20 000 years ago, opuntias have been important as food sources, as well as for drink and medicine. Long before horticultural management of the opuntia was known, the ancient Mexicans consumed it abundantly from the wild. Fray

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Bernardino de Sahagún, in his work *Historia General de las Cosas de la Nueva España* – written during the first half of the 16th century – reported that native Americans lived for many years and were "healthy and strong." Their vitality, according to him, was due to the type of diet, which was not cooked with other things. They ate "prickly pear leaves", prickly pear fruits, roots, mesquite pods, and yucca flowers which they called *czotl*, honey and rabbits, hares, deer, snakes and fowl (Sahagún, 1997).

On the use of opuntia "sacred tree" as a beverage to quench thirst, Friar Toribio Motolinia said, "... these Indians whom I refer to, because they are from a land so sterile that at times they lack water, drink the juice of these leaves of *nocpal* ... " The fresh and aromatic opuntia fruit, or *tuna*, was also used for this purpose; they made *nochoctli*, or *pulque* (a fermented drink, generally made from the sap of the century plant. – Translator's note). The word *tuna* originated in Haiti and was introduced by the Spaniards during the Conquest.

The De la Cruz-Badiano Codex of 1552 shows how opuntia was used to treat several ailments of the human body. For example, opuntia was used to cure burns: "The burned part of our body is cured with the juice of the *nopalli* with which it should be rubbed on with honey and egg yolk ..." (Velázquez, 1998).

The genus *Opuntia* spread from Mexico to practically the entire American continent (from Alberta, Canada, to Patagonia, Argentina), and, after the Spanish Conquest, to the rest of the world (Flores and Aguirre, 1979). In 1700, Tournefort named opuntias *Opuntia*, because of their similarity to a thorny plant that grew in the town of Opus, Greece (Velázquez, 1998). In Mexico, several species of the genus *Opuntia* of the Cactaceae family are called *nopal*. All of them are endemic to America, and of the 377 recognized species, 104 are found wild in Mexico, and 60 of these are endemic in Mexico.

There are few studies on the history of opuntia, except in its association with cochineal. Tibón (1993), in his *History of the name and of the foundation of Mexico*, describes the drawing done by the *tlacuilo* of Fray Diego Durán, of the foundation of Mexico *Tenochtitlán*:

> "To the left of the hill, a beautiful bird with its wings extended has just alighted on a prickly pear and sings, as its open beak indicates. A large snake with forked tongue rises in the direction of the plant ...
>
> "Thus, the *tenochtli*, the prickly pear of hard red *tunas*, was, from the beginning, the tree of human hearts. The serpent that emerges from the bowels of the earth is night; the bird that sings over the prickly pear is at once the same eagle-sun ..."

It is of interest that the opuntia where the bird, or eagle, has alighted is known by the scientific name of *Opuntia streptacantha*, which comes from *streptos*, "twisted" and *acantha*, "thorn". The *tuna lapidea*, according to Dr Francisco Hernandez is similar to opuntia in its flowers and fruit, but with long, narrow, twisted branches (Granados and Castañeda, 1991).

Although the sources consulted for the Colonial Period do not mention the use of opuntia, as a forage plant, without doubt during the droughts which affected New Spain, the livestock that spread throughout the country had to consume opuntia, as reported in sources from the 19th and 20th centuries.

DISTRIBUTION

The geographical distribution of the genus *Opuntia* in Mexico, according to recent studies, reflects the abundance of opuntia and its natural incidence in associations, focusing on the most important species (Granados and Castañeda, 1991; Flores and Aguirre, 1979):

O. leucotricha Guanajuato and eastern San Luis Potosí, with irregular distribution and variable densities. Between Santa María del Río and San Luis Potosí, southwest of Villa de Arista. With high areal densities in Fresnillo and Calera.

O. lindheimeri	With a density of up to 1000 plants/ha in General Terán, Salinas, and elsewhere in the state of Nuevo León, and in Tamaulipas, Guerrero and Hidalgo.
O. streptacantha	San Luis Potosí: Zaragoza and north of the capital, north of Bocas and southeast of Moctezuma. Densities of 200 to 600 plants/ha are found in San Luis Potosí. In Zacatecas: Noria de los Angeles, Ojo Caliente, Troncoso and Guadalupe.

This distribution indicates that the region of Mal Paso, southwest of the city of Zacatecas, has the greatest diversity of opuntia species. In contrast, chroniclers and historians of the colonial period recounted the abundance of opuntia practically throughout the country. From the chronicles of travellers or scientific works, the present distribution includes Querétaro, Guanajuato, Jalisco, Nayarit and Coahuila in Mexico, and Texas in the United States.

Pedro de Rivera, in his trip to northern New Spain at the beginning of the 18th century, reported that in the direction of San Juan del Río, Querétaro, he found thick vegetation of mesquite, *guizaches* (*Prosopis* sp.), and opuntia. In the direction of Ojuelos, Jalisco, near San Miguel El Grande, he passed through flat land with scrub vegetation of oak, mesquite and opuntia. On the border between the kingdoms of New Galicia and Nayarit, he went through rough mountains with many rocks and thick brush of mesquite, guamuchiles, guizaches and opuntia (Trabulse, 1992a).

Alexander Von Humboldt reported that Villa de Saltillo, province of Coahuila, is located in an arid plain which descends toward Monclova, the Río Grande, and the province of Texas, where instead of the wheat he might find in a European plain, he found only fields covered by opuntias (Humboldt, 1984).

COLONIAL MEXICO

Description of the opuntia plant

The morphology of opuntia awed the Europeans, who had never seen a plant like it, leading them to describe it the best they could. During the colonial period, study and recording of opuntia began with the work of José Antonio Alzate on cochineal. The *nopalli*, or cactus pear, was known by the Spaniards as *nopal*, and the fruit as *tuna*, although in the 16th century this plant was also called *higuera de indias* (fig of the Indies), *higuera de pala* (shovel fig), *tunal de Castilla*, *nopal de Castilla*, *chumbos*, *tuna chumbera*, *tuna mansa*, and *tunal* (Rojas and Sanders, 1985).

In 1539, Friar Toribio Motolinia, describing his experiences in Michoacán, reported that in this province the *tunales* were abundant:

> "... they are trees that have leaves the thickness of fingers, some thicker and others less, as long as the foot of a man, and as wide as a hand span..." (Motolinia, 1995).

In the mid-16th century, Friar Bernardino de Sahagún wrote:

> "The tree called tuna has large, thick leaves, and green and thorny; this tree gives flowers on the same leaves [and] some are white, others vermilion, others yellow, and others fleshy; produced in this tree are fruits called tunas [that] are very good to eat [and] come out of the same leaves ... "(Trabulse, 1993).

Describing opuntia, Friar Bernardino de Sahagún reported:

> "There are trees in this land they call *nopalli*, which means *tunal*, or tree with tunas; it is a monstrous tree, the trunk is composed of leaves and the branches are made of these same leaves; the leaves are broad and thick, having juice and are viscous; the same leaves have many thorns ... The leaves of this tree are eaten raw and cooked." (Sahagún, 1997).

The Nahuas – a Pre-Columbian tribe that dominated central Mexico – identified several native species whose scientific names, common names and place where identified are the following:

* *Nopalea cochenillifera* (L.) Salm-Dyck (syn. *Cactus cochenillifera* L.; *Opuntia cochenillifera* (L.) Mill), also called *nochez opalli* (Nahuatl), *nopal de San Gabriel* (Oaxaca), *tuna mansa* (Puerto Rico), *tuna nopal* (El Salvador). This plant and *nopal de Castilla* (*Opuntia ficus-indica* L.) are species used in the production of the cochineal insect (*Dactylopious coccus* Costa). *N. cochenillifera* has several varieties; the best known and most used is *nopalnocheztli*, namely cochineal opuntia, which the Spaniards named *nopal de Castilla*. Another variety is known as *nopal de San Gabriel*.
* *Opuntia* Miller (Cactaceae). The most usual name for the cultivated species of this genus is *nopal*, and the fruit is commonly called *tuna*.
* *Opuntia amyclaea* Tenore (syn. *O. ficus-indica* f. *amyclea* (Ten.) Schelle and *O. ficus-indica* var. *amyclea* (Ten.) Berger.)
* *Opuntia ficus-indica* (L.) Mill. (syn. *Cactus ficus-indica* L.). Also known as *nopal de Castilla, tuna de Castilla*, *nochtli*; used in the production of cochineal.
* *Opuntia imbricata* (Haw.) D.C. (syn. *Cereus imbricatus* Haw., *Opuntia rosea* D.C., *O. decipiens* D.C., *O. exuviata* D.C., *O. arborescens* Engelm., *O. magna* Griffiths, *O. spinotecta* Griffiths, *xoconochtle*, *joconochtle* (Jalisco), *xoconochtli*, *joconostle* (Zacatecas), *cardenche* (Durango, Zacatecas), *tasajo* (Chihuahua), *coyonostle* (Nuevo Leon and Coahuila), *coyonoxtle*, *coyonostli* (Nuevo Leon), *tuna joconoxtla* (Jalisco), *tuna huell, velas de coyote, entraña* (New Mexico)). The *xoconochtli* is a cactus with cylindrical stems with long thorns and very sour fruit.
* *Opuntia megacantha* Salm-Dyck (syn. *O. castillae* Griffiths, *O. incarnadilla* Griffiths), the *nopal de Castilla*.
* *Opuntia streptacantha* Lem. Also called *tecolonochtli* or *tecolonochnopalli*; this is the *cardon nopal* or *cardona tuna*. The fruit is an intense red, aromatic and refreshing. It has great importance in the semi-arid and desert zones (Rojas, 1990).

Friar Francisco de Ajofrín, who travelled through New Spain in the 18th century, reported that there were opuntia fruit – *tunas* – almost year-round. Some were white, others yellow, and some were more fleshy (Trabulse, 1992a). Miguel Venegas indicated in the 18th century that in California the red tunas are infrequent, and in New Spain they called them *tunas taponas* (Trabulse, 1992b).

The physician Francisco Hernández, in his monumental work *Historia Natural de la Nueva España*, found seven distinct types of tunas: *iztacnochtli*, this opuntia was known to the Spaniards as the *higuera de las indias* (fig of the Indies) which, according to them, was similar to the fig tree, even when neither the plant nor the fruit had any similarity to a fig tree or a fig (Trabulse, 1992b), *coznochtli, tlatonochtli, tlapalnochtli, tzaponchtli, zacanochtli* (Rojas and Sanders, 1985), and *nopalxochcuezltic* (*Epiphyllum acker* Haw.) (Rojas and Sanders, 1985). The Nahuas classified this last plant in the group of tunas, most certainly because of the similarity of its flowers and fruits to those of the nopal, which belong to the same botanical family. This is a plant with long fleshy, undulating leaves and beautiful red flowers.

Bernardino de Sahagún also made interesting records of opuntia species and the diversity of tunas, very similar to that done by Francisco Hernandez (Sahagún, 1997) and Motolinía (1995).

Propagation

Friar Toribio de Benavente explains how opuntia reproduces:

> "... and one leaf of these plants is planted and they proceed leaf after leaf, and leaves also come out of the sides, and they become a tree. The leaves at the foot thicken greatly, and become so strong that they become the foot or trunk of the tree... In this New Spain the tree is called *nucpai* – *nopalli* – and the fruit is called *nuchtli* ... "(Motolinía, 1995).

> "Wherever a leaf falls from this tree, another similar tree is soon formed; and what is admirable is that, after some time, stuck on the leaves appears a gum called *alquitira*, for which many conifers are used." (Cervantes, 1991).

Livestock raising

The livestock brought from the West Indies (Cosio, 1987) by the Spaniards caused a revolution in the economy of New Spain, and immense areas previously unused by agriculture were brought into use. The livestock came from Cuba, Santo Domingo and San Juan, Puerto Rico. Hernán Cortés brought the horses (11 horses and 5 mares), and Gregorio Villalobos brought cattle from Santo Domingo (Cosio, 1987). Livestock gave agriculture a boost, providing animal traction, transport and manure. No less important was its contribution to the development of mining; animals were used as driving power and transport. In addition, livestock was used as a basic source of food. For these reasons and because of the immense virgin grasslands that existed, livestock multiplied and spread from the central high plateau to the rest of New Spain during the 16th century. Although it decreased, notably in the 17th century, the numbers were so great that in many regions many wild herds were formed.

The Spanish *Mesta* concept – a formal organization of livestock producers– also came to New Spain, where it was composed of owners of livestock ranches (Chevalier, 1982). Extensive grazing of sheep and goats began, moving livestock from place to place for summer and winter grazing. The routes crossed New Spain in every direction. The *Cabildo* (government) of Mexico City founded the first Mesta in New Spain on July 31, 1527. Later, Puebla (1541), Oaxaca (1543) and Michoacán (1563) followed (Chevalier, 1982).

Contemporary sources indicate the extent of the changes:

* As of 1579, no fewer than 200 000 sheep from Querétaro moved 300 to 400 km during the month of September, to find fresh pastures near Lake Chapala and western Michoacan, returning to their ranches in May.
* The livestock from Tepeaca, Puebla, and some from the Central Plateau, wintered in pastures of Veracruz on the Gulf of Mexico.
* From the Huasteca, livestock went to graze on the shores of Río Verde, in San Luis Potosí.
* In 1648, more than 300 000 sheep from the mountains of New Spain were taken to the extensive plains of the Kingdom of Nuevo Leon, where they grazed for more than six months. In 1685, it is said that 555 000 head of cattle arrived (Chevalier, 1982; Humboldt, 1984).
* At the end of the 16th century, in the High and Low Mixtec regions, the indigenous people came to own 250 000 head goats and sheep. In Tlaxcala and Puebla, the communities had more than 400 000 head of sheep and goats, and the communities of Zimatlan, Oaxaca and Jilotepec, State of Mexico, together had more than 350 000 head (Rojas, 1990).

The migrating livestock damaged the crops of the indigenous people, in spite of the ordinances of 1574, which obliged the ranch owners to open up roads reserved for livestock to go from one place to the other, but most never obeyed. The irrigated, cultivated areas of the towns were what interested the ranchers, much more than the plains covered with opuntia or the bald mountains they crossed.

Forage

Livestock feeding was mostly provided from natural sources, and that included opuntia. Reproduction of livestock was spontaneous, and often the owners themselves were ignorant of how many beasts they possessed. Sheep and goats were husbanded under nomadic grazing; cattle, only on a small scale, were raised on ranches and specialized haciendas. The harsh environmental conditions affected the animals, and – coupled with losses from robbery, pests, disease, frosts, hail and severe drought – decimated the livestock, especially because a large proportion of the animals was raised in the arid regions.

A drought meant lack of drinking water and grass, followed by hunger, malnutrition, disease and finally death. This situation obliged the owners to leave the animals free to forage for themselves. The historian François Chavalier reported that in the years of drought animals died by the thousands (Chevalier, 1982).

Sources from the 16th, 17th, and 18th centuries state that the livestock ate grasses, stubble, maize and opuntia, among other things. In 1585, Juan González de Mendoza wrote that in the entire Kingdom of New Spain, the livestock fed on green plants and maize, which was the wheat of the Indians (Trabulse, 1993).

Chevalier (1982) reports that at the end of the 16th century, the "encomenderos" (landlords) fattened their animals with maize, which they had, in abundance, thanks to tributes. The quality of the meat was linked to the quality of the maize or the grasses (Trabulse, 1993). As to the usefulness of stubble, in the 18th century, José Antonio Alzate wrote:

> "For some years I saw a subject who obtained an ear of *Meztitlan*, he sowed it in a small garden: the stalks grew to six or seven feet and produced three, four or more ears of large size. This excessive vegetation was not the effect of any preparation neither of the seed, nor of the fertility of the soil, because if he sowed another species of maize, the product corresponded to its nature. This experiment foresees great profits for ranch owners who would benefit if they sowed *Meztitlan* maize, besides the abundance of the fruit, *tlazole*, or straw, increases, which is so necessary for the livestock (Trabulse, 1992b).

As to the opuntia cactus used as forage, the newspaper *El Nacional*, of Mexico City, reported that during the colonial period there were *mestizo* farmers who planted opuntia in half of their farm plots to feed the animals, and in the other half they sowed maize and beans:

> "... and when they judged the land to be worn out, they cut half the cactus pear as forage for the animals, especially the cattle, and the rest was planted in the agricultural land, which after two years was again used for ordinary crops, repeating the same operation of leaving the land to rest by planting cactus pear, which maintains the ground moist and magnificent grasses grow at the same time, preventing erosion of the land and providing abundant, moist, fresh grass for the livestock almost year-round (Anon., 1962).

INDEPENDENT MEXICO

When Mexico won its independence in 1821, the national territory consisted of a little more than 4 million km^2, which included the territories of Texas, New Mexico, Arizona and California, which passed to the USA in 1848. In these territories, opuntia was used as forage; once chopped up or singed, it was given to cattle (Flores and Aguirre, 1979), a practice also common in the Mexican states bordering the USA. This was confirmed by a study in Mexico at the end of the 19th century by the German Karl Kaerger (1896), whose objective was to investigate agricultural aspects in which Germany could invest, especially considering the facilities given by the government of Porfirio Diaz to foreigners.

Livestock husbandry

Cattle raising developed in Mexico mostly in the northern part of the country. Enormous ranches were established and land was concentrated to such a degree that the Terrazas family owned almost the entire state of Chihuahua.

At the end of the 19th century, massive sheep raising was conducted in the northeast of the country, especially in the states of Zacatecas, Tamaulipas and Chihuahua, where there were haciendas with 70 000 to 80 000 head of cattle head (Kaerger, 1986). Goats were abundant in Puebla, Zacatecas, Aguascalientes, Tamaulipas and San Luis Potosí, while cattle were raised basically in the north of Mexico and the coastal region of Veracruz, where improvement of the national breed with the introduction of Durham and Hereford bulls had begun. Outstanding among the pastures used for fattening were those located in the Huasteca, the northern coastal zone of Veracruz, and the southern coastal region of Tamaulipas (most of the state of Tamaulipas was dedicated to sheep and goat raising).

The forage

In the northern part of the country, the cowboys, besides riding horseback every day over a given area of the hacienda to guard the cattle from possible rustling, had the task of getting additional feed for the animals during the dry season. The feed was obtained by cutting agave plants, known as *sotol*, and chopping their leaves, and, more important, cutting opuntia pads and burning off the thorns so that the livestock could eat the pads, although often the plants were eaten where they were standing. The greatest opuntia populations were found in San Luis Potosí, Tamaulipas and Nuevo Leon, where the farmers could distinguish the following varieties:

* *Nopal rastrero* (creeping prickly pear): a cactus with a lateral growth form and consumed mostly by goats.
* *Nopal cuyo*: a thin cactus with few thorns; relished by cattle.
* *Nopal cardón* (*O. streptacantha*): a fruit species with broad pads. Its fruit is used to prepare a fermented drink, mixing it with maize grains, apples and cane alcohol. Cattle can eat it only during the dry season since in the rainy season it swells too much (Bazant, 1980).
* *Nopal cegador* (blinding prickly pear): Well eaten by cattle, although it can cause blindness if the thorns get into their eyes.
* *Cardenche* or *joconostle*: It has large cylindrical stems (trunk) and is preferred by livestock.
* *Tasajillo*: similar to the *cardenche* type, but the stems are smaller and of lower quality. Goats eat its fruit (Kaerger, 1986).

A newspaper article appearing in the early 20th century reported the enormous amounts of tunas of all kinds that were produced in San Luis Potosí. It points out that opuntia grew in the poorest land, in hard, cracked, alkaline soil, where there was no other sign of vegetation, far from fresh water springs, where there were more hills than flat land; this hilly land promoted cactus growth, and gave the landowner splendid profits, since they needed neither care nor expenditures of any kind.

> "[The parts] of the prickly pear used are: the pads for feeding cattle, when they are fresh, and when they are dry they are magnificent fuel, and the tunas, from which a delicious fermented drink is made called *colonche*; also, an exquisite tuna syrup is made, as well as jams and taffy, and a liquor is also extracted from the tuna ... " (Márquez, 1986)

Animals also ate other plants covered with thorns without singeing, such as mesquite (*Prosopis* spp), lechuguilla (*Agave lecheguilla*) (the northeastern agave, which is used to produce fibre), and *huapile*, a bromeliad which covers large areas. The lechuguilla is very nutritious, although it has the disadvantage of inducing the animals to become wild, as they need not drink water because of the juiciness of the leaves (Kaerger, 1986).

RECENT DEVELOPMENTS OF OPUNTIA IN MEXICO

Forage

The importance of opuntia as a forage plant in the 19th century was the outcome of the need to feed livestock in the arid zones of the country, where the dry seasons are very long. Opuntia is an excellent feed for livestock (Flores and Aguirre, 1979).

Government interest in development of the arid zones, which accounted for 40% of the national territory, led to creation of the National Commission for Arid Zones (CONAZA) in 1970. This institution provided support to arid zones where it was not possible to obtain profitable grain harvests unless they were irrigated. CONAZA proposed a programme to grow and use wild plants such as opuntia, candelilla (*Euphorbia antisiphylitica*), lechuguilla (*Agave lecheguilla*), fibre yucca (*Yucca filifera*), and mesquite (*Prosopis juliflora*). According to a preliminary study of the 1970 census, over 50% of the cattle and sheep and almost 80% of the goats existing in the country were in arid zones. In these zones, opuntia became vital, because it provided some food and water for the animals (Villarreal, 1958).

Although during the first half of the 20th century there were numerous species of wild opuntia, they began to disappear, mostly because of the excessive removal by merchants to supply foreign markets. Laws were passed to prohibit its export, but today the commerce in opuntia continues in different forms, with the consequent disappearance of some species (Granados and Castañeda, 1991).

The people of Northern Mexico have used opuntia as forage for many decades. At present the dairy industry in the arid zones of the north still use opuntia as forage. In 1966, 600 tonne of opuntia were used daily in feeding stabled dairy cattle in Monterrey, Nuevo León, and 100 tonne daily in Saltillo, Coahuila (Granados and Castañeda, 1991). Cattle and, above all, grazing goats and sheep, consume opuntia almost all year. The shepherd burns off the thorns from the pads that he selects, although sometimes the standing plants are singed (Flores and Aguirre, 1979).

The Ministry of Agriculture promoted opuntia plantations for forage in many regions. The gathering of opuntia for forage was banned in the states of Coahuila, Chihuahua, Nuevo Leon and Tamaulipas, and industrialization promoted. Cattlemen were barred from singeing opuntia thickets to ship them to market (Anon., 1961). The government of Zacatecas began a campaign to industrialize opuntia, especially the cardon type, abundant in the state (Anon., 1963a).

Reduction of the opuntia populations obliged the Ministry of Agriculture to set up a Programme for Genetic Improvement of Prickly Pear in 1961, at the Graduate College of the National School of Agriculture. The goal was to increase fruit production and improve cattle feeding in the semi-arid zones of the country, which largely depend on opuntia during droughts. The main objective was to obtain improved varieties, which would, besides producing high quality fruits, be spineless in order to use the pads to feed cattle (Anon., 1963b). By 1975, Mexican geneticists had produced several useful varieties (including cvs. CPF1, Pabellón and CPV1).

Opuntia production

Opuntia is not considered a regular forage crop and statistics on planted area and production were not reported until 1984, and then with little accuracy. Although the cultivated area has been growing steadily, the figures are low: 22 ha in 1984, rising to 422 ha in 1997 (SARH, 1984 to 1989; SAGAR, 1990 to 1997). Forage production has been reported in the northern and central part of the country, as well as Southern Baja California. Opuntia used for forage production is not directly assessable compared to traditional crops because of the wide utilization of wild stocks.

ECOPHYSIOLOGY OF *OPUNTIA FICUS-INDICA*

Park S. Nobel

INTRODUCTION

The physiological basis of the ecological success and agricultural usefulness of opuntias as a forage in large measure reflects their daily pattern of stomatal opening (stomata are fine pores in the leaf or stem surface that regulate the exchange of gases between a plant and its environment). Most plants have daytime stomatal opening so that CO_2 uptake occurs concomitantly with photosynthesis, which uses the energy of light to incorporate CO_2 from the atmosphere into a carbohydrate. Plants like *Opuntia ficus-indica*, however, have nocturnal stomatal opening, so net CO_2 uptake and water loss occur during the cooler part of the 24-hour cycle. This gas exchange pattern is referred to as Crassulacean Acid Metabolism (CAM) because it was studied extensively in the Crassulaceae, although apparently first recognized in the Cactaceae (Ting, 1985; Nobel, 1988). CAM plants are native to arid and semi-arid regions, as well as to periodically dry microhabitats such as those occupied by epiphytes (most of the 20 000 species of CAM plants are epiphytes growing on trees in tropical forests (Winter, 1985; Nobel, 1991a).

DAILY GAS EXCHANGE

As just indicated, *O. ficus-indica* takes up CO_2 primarily at night (Figure 1A). Under wet conditions and moderate temperatures, net CO_2 uptake becomes positive in the late afternoon, when daytime temperatures have decreased substantially, and reaches its maximum value a few hours after dusk. Generally, a small burst of net CO_2 uptake occurs at dawn (Figure 1A), when the availability of light allows for direct incorporation of atmospheric CO_2 into carbohydrates using the C_3 pathway of photosynthesis during the coolest part of the daytime. The daily pattern for water vapour loss via transpiration for *O. ficus-indica* (Figure 1B) is similar to the pattern for net CO_2 uptake, reflecting the requirement of appreciable stomatal opening to get substantial exchange of either gas with the environment.

The CO_2 taken up by a CAM plant at night is bound to a three-carbon compound to form a four-carbon organic acid, such as malate. The accumulating organic acids are stored overnight in large vacuoles within cells of the chlorenchyma (the greenish chlorophyll-containing region), so the tissue becomes progressively more acidic during the course of the night. CO_2 is released from the organic acids during the next daytime, causing the tissue acidity to decrease. This released CO_2, which is prevented from leaving a CAM plant by daytime stomatal closure, is then incorporated into photosynthetic products in the chlorenchyma cells in the presence of light. The daily oscillations of acidity, which is characteristic of CAM plants, requires large vacuoles for the sequestering and short-term storage of the organic acids.

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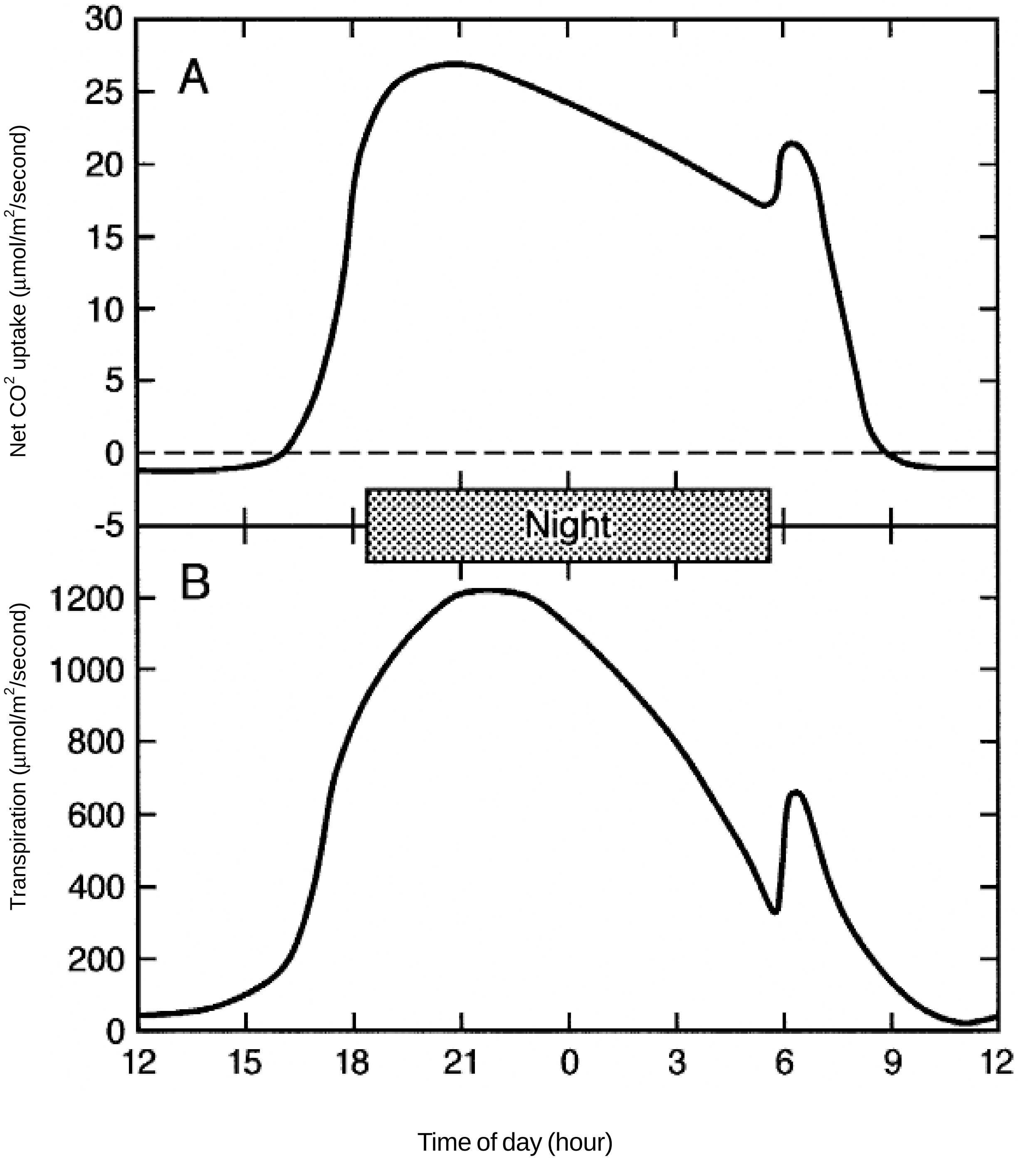
WATER-USE EFFICIENCY

A useful benefit:cost index for gas exchange by plants is the ratio of CO_2 fixed by photosynthesis to water lost by transpiration, which is referred to as the water-use efficiency (WUE). For the gas exchange data presented in Figure 1, net CO_2 uptake integrated over the 24-hour period is 1.14 mol/m^2/day and the water loss is 51.3 mol/m^2/day. Thus the WUE is 0.022 mol CO_2 fixed per mol H_2O lost for this CAM plant. This WUE is about triple that found for highly productive C_4 plants (such as maize or sugar cane) under similar environmental conditions. C_4 plants have daytime net CO_2 uptake initially into four-carbon organic acids, and 5-fold higher than for highly productive C_3 plants (such as alfalfa, cotton, or wheat), which also have daytime net CO_2 uptake but whose initial photosynthetic product is a three-carbon compound (Nobel, 1995).

Figure 1. Net CO_2 uptake (A) and transpiration (B) for *Opuntia ficus-indica* over a 24-hour period under conditions of wet soil, moderate temperatures, and high light levels (Source: Nobel, 1988, 1995)



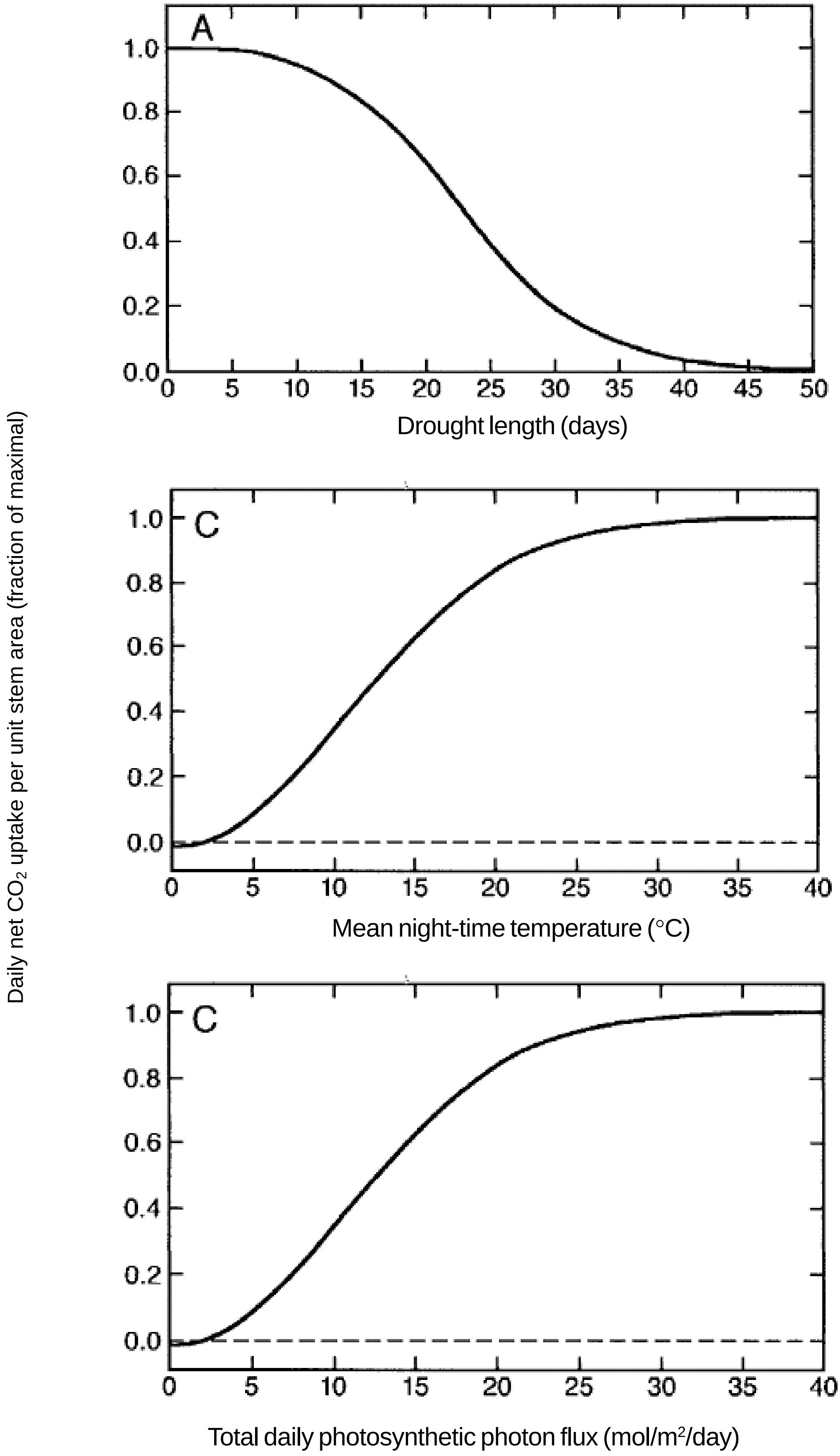
The much higher WUE for CAM plants relates to the reduced difference in water vapour concentration between the plant and the atmosphere during the period of substantial stomatal opening. In particular, the water vapour content in leaves and stems is within 1% of the saturation value in air at the tissue temperature (Nobel, 1999); tissue temperatures tend to be much lower at night, and the water vapour saturation value of air increases nearly exponentially with temperature. For instance, the water vapour content for saturated air is 0.52 mol/m^3 at 10°C, 0.96 mol/m^3 at 20°C, and 1.69 mol/m^3 at 30°C. If the water vapour content of the air is 0.38 mol/m^3 (40% relative humidity at 20°C), then the drop in water vapour concentration from the plant to the atmosphere, which represents the driving force for water loss from a plant, is the difference between 0.52 and 0.38, or 0.14 mol/m^3 at 10°C; 0.96 - 0.38, or 0.58 mol/m^3 at 20°C; and 1.69 - 0.38, or 1.31 mol/m^3 at 30°C. For the same degree of stomatal opening, the driving force for water loss then is 0.58/0.14, or 4.1-fold higher at 20°C than at 10°C, and 1.31/0.58 or 2.3-fold higher at 30°C than at 20°C. Because tissue temperatures typically average at least 10°C lower at night than during the daytime in many locations, CAM plants tend to lose only 20 to 35% as much water as do C_3 or C_4 plants for a given degree of stomatal opening. This is a key feature in their utility as forage crops in arid and semi-arid regions.

WATER RELATIONS

Besides using CAM, with its inherently high WUE, *O. ficus-indica* has other adaptations that lead to water conservation. For instance, the waxy cuticle on its stems is relatively thick, generally 5 to 30 µm (Conde, 1975; Pimienta-BarRíos *et al*., 1992, 1993; North *et al*., 1995). This helps prevent water loss from the plants to the environment. In addition, the stomatal frequency is usually low for opuntias, generally 20 to 30 per square millimetre (Conde, 1975; Pimienta-BarRíos *et al*., 1992). Consequently, the fraction of the surface area of the stems through which water vapour can move from the plants to the atmosphere is relatively low. Moreover, the stems contain a large volume of whitish water-storage parenchyma, which acts as a water reservoir for the chlorenchyma, where the initial CO_2 fixation at night via CAM and the daytime photosynthesis take place. For instance, during a drought lasting three months, the chlorenchyma in the stems of *O. ficus-indica* decreases in thickness by 13%, while the water-storage parenchyma decreases in thickness by 50%, indicating a greater water loss from the latter tissue (Goldstein *et al*., 1991). As another adaptation, the roots of *O. ficus-indica* tend to be shallow with mean depths near 15 cm, facilitating a quick response to light rainfall. For instance, it can form new roots within 24 hours of wetting of a dry soil (Kausch, 1965). Its various water-conserving strategies lead to a need for a small root system; indeed, roots compose only about 12% of the total plant biomass for *O. ficus-indica* (Nobel, 1988).

Drought, which physiologically commences when the plants can no longer take up water from the soil (because the soil water potential is then less than the plant water potential), leads to a decrease in the ability of the stems to take up CO_2 from the atmosphere (Figure 2A). Little change in net CO_2 uptake ability occurs during the first week of drought for *O. ficus-indica*, reflecting water storage in the stem and the inherently low water requirement for CAM. Also, the waxy cuticle and low stomatal frequency allow 20% of the maximal net CO_2 uptake to be present even one month after the plants are under drought conditions (Figure 2A). After the initial week of drought, the net CO_2 uptake over the next month averages about half of the maximal value (Figure 2A); after about two months, a small daily net CO_2 loss occurs, as respiration becomes greater than net photosynthesis, whereas most C_3 and C_4 crops begin having a net loss of CO_2 within one week of the commencement of drought. Thus the net CO_2 uptake ability of *O. ficus-indica* and certain other CAM plants is extremely well suited to arid and semi-arid regions. Nevertheless, soil water is the major limiting factor for net CO_2 uptake by *O. ficus-indica* in such regions, where irrigation may not be economically feasible.

Figure 2. Influence of drought length (A), night-time temperature (B), and light (C) on net CO_2 uptake over 24-hour periods for *O. ficus-indica*. Except as indicated, plants were well watered, maintained at night-time temperatures near 15°C, and had a PPF of about 25 mol/m²/day incident on the cladode surfaces (Source: Nobel and Hartsock, 1983, 1984; Israel and Nobel, 1995)



TEMPERATURE RELATIONS

Temperature not only influences metabolic processes and hence daily net CO_2 uptake but extreme temperatures can also lead to injury and even death of plants. In this regard, *O. ficus-indica* is extremely tolerant of high air temperatures, but not of air temperatures substantially below freezing. When plants are acclimatized to high day/night air temperatures of 50°C/40°C, their chlorenchyma cells are not seriously injured by 1 hour at 60°C, and most cells survive 1 hour at 65°C (Nobel, 1988). Indeed, high-temperature damage for *O. ficus-indica* in the field is generally only observed near the soil surface, where temperatures in deserts can reach 70°C; young plants or newly planted cladodes are especially vulnerable to injury. In contrast, cell injury in the field occurs at freezing temperatures of -5°C to -10°C. Damage varies with the cultivar (Russell and Felker, 1987b), with the rapidity of the onset of freezing and hence the time for low-temperature acclimatizion or "hardening" (Nobel, 1988), and with the stem water content, as a lower water content leads to better tolerance of lower air and stem temperatures (Cui and Nobel, 1994a; Nobel *et al*., 1995).

Because CO_2 uptake for CAM plants occurs primarily at night, night-time temperatures are far more important than are daytime ones for daily net CO_2 uptake by *O. ficus-indica* (Figure 2B). Moreover, the optimal night-time temperature is relatively low, 15°C, and temperatures from 5°C to 20°C all lead to at least 80% of the maximal net CO_2 uptake. Such low temperatures also lead to low rates of transpiration. As night-time temperatures rise, stomata tend to close for *O. ficus-indica*; e.g., at 30°C the stomata are only one-third as open as at 20°C (Nobel and Hartsock, 1984), which helps reduce net CO_2 uptake at the higher temperature (Figure 2B). Except for night-time temperatures substantially below freezing or above 30°C, temperature is generally not a major limiting factor for net CO_2 uptake by *O. ficus-indica*, especially in seasons when water from rainfall is available, which is fortunate, because manipulation of air temperatures in the field is expensive.

LIGHT RELATIONS

Another environmental parameter affecting net CO_2 uptake is light; the light incident on individual stems can be readily manipulated by the spacing of plants, although tradeoffs occur between maximizing net CO_2 per plant versus net CO_2 uptake per unit ground area (García de Cortázar and Nobel, 1991). The stems of *O. ficus-indica* are opaque, contrary to the case for the leaves of most C_3 and C_4 plants, so orientations of both sides must be considered when evaluating light absorption. Also, the light that is relevant is that absorbed by photosynthetic pigments, mainly chlorophyll, which is referred to as the photosynthetic photon flux (PPF; 400 to 700 nm wavelength; also referred to as the photosynthetic photon flux density and the photosynthetically active radiation (PAR); Nobel, 1999).

When the plants are maintained in the dark, only respiration occurs, so there is a slight loss of CO_2 (Figure 2C). As the daily PPF increases, the daily net CO_2 uptake by *O. ficus-indica* increases. Saturation by light is approached at a total daily PPF of about 25 mol/m^2/day (Figure 2C; for comparison, the total daily PPF on a horizontal surface for a clear day during which the sun passes overhead is about 65 mol/m^2/day; Nobel, 1988). Because of the opaque nature of the stems, some of their surfaces are not favourably oriented with respect to interception of sunlight; also interplant shading will reduce daily net CO_2 uptake. Thus net CO_2 uptake per plant is greatest when the plants are far apart and do not shade each other. However, net CO_2 uptake and hence productivity per unit ground area is then minimal. If the plants are very close together, shading is excessive and much of the stem area receives less than 5 mol/m^2/day total daily PPF, for which net CO_2 uptake is substantially reduced (Figure 2C). Indeed, net CO_2 uptake per unit ground area for *O. ficus-indica* is maximal when the total area of the stem (including both sides of their flattened stem segments, or cladodes) is 4 to 6 times the ground area (García de Cortázar and Nobel, 1991). When the ratio of total stem area to ground area, termed the stem area index (SAI), is 1, 2 and 3, the net CO_2 per unit ground area for *O. ficus-indica* is 35%, 62%, and 85% of maximal, respectively (Nobel, 1991a).

NUTRIENT RELATIONS

Net CO_2 uptake, growth and productivity for *O. ficus-indica* are influenced by macronutrients and micronutrients in the soil, as well as by salinity and soil texture (Nobel, 1988; Hatzmann *et al*., 1991). For instance, growth in sandy loam is about 25% of maximal at a nitrogen content of 0.03% by dry mass, 50% of maximal at 0.07% N, 75% of maximal at 0.15% N, and approaches maximal near 0.3% N (Nobel, 1989a). Because the N content in native sandy soils in arid and semi-arid regions is generally below 0.07%, nitrogen fertilization usually increases the growth of *O. ficus-indica* and other opuntias in such areas (Nobel *et al*., 1987). The protocol for nitrogen fertilization of *O. ficus-indica* has followed traditional practices developed for other crops (Barbera *et al*., 1992; Nerd *et al*., 1993), where the main form taken up from the soil is nitrate (Nerd and Nobel, 1995). Although N is generally the major limiting nutrient, growth of opuntias usually is also stimulated by phosphorus and potassium fertilization (Nobel, 1989b). A soil level of only 5 parts per million by dry mass (ppm) P leads to half-maximal growth for *O. ficus-indica* (Nobel, 1989b), but the stems produced are below the nutritional needs of cattle for phosphorus. Indeed, stems of most opuntias contain about 1% N by dry mass in nutrient-poor native soils, which is below the nutritional need of cattle for nitrogen, but about 2% when grown on periodically fertilized agricultural land (Nobel, 1988).

As for most cacti, *O. ficus-indica* is sensitive to soil salinity. Inhibition of growth is often linear with sodium content, with 150 ppm Na leading to approximately 50% inhibition of biomass accumulation by *O. ficus-indica* (Nobel, 1989b). Its roots are more affected by salinity than are its shoots; e.g. watering with 60 millimolar (mM) NaCl (about 12% of the salinity of seawater) for six months reduces root growth by 84% and shoot growth by 50% (Berry and Nobel, 1985). Exposing the entire root system of *O. ficus-indica* to 100 mM NaCl for 10 weeks reduces root growth by 38% (Nerd *et al*., 1991) but after only 4 weeks, growth of a single root exposed to 100 mM NaCl can be reduced by 93% (Gersani *et al*., 1993). Also, Na is not readily transferred from the roots to the shoot or from basal cladodes to new daughter cladodes (Berry and Nobel, 1985). As is the case for nearly all plant parts, the Na content of the cladodes of *O. ficus-indica* does not meet the nutritional needs of cattle for this element.

ATMOSPHERIC CO_2

The atmospheric CO_2 level is currently increasing by about 2 ppm by volume annually, which can lead to an increase in daily net CO_2 uptake by *O. ficus-indica*. For instance, a doubling of the current atmospheric CO_2 level causes net CO_2 uptake by two-month-old cladodes to increase by 49% and their WUE to increase by 55% compared with the current atmospheric CO_2 level (about 360 ppm; Cui *et al*., 1993). The aboveground-dry-mass productivity by *O. ficus-indica* in the field is 37-40% higher for a doubled CO_2 level versus the current CO_2 level (Nobel and Israel, 1994). Although the nitrogen content of older cladodes remains near 1% of the dry mass, the N content of three-month-old cladodes averages 1.47% of the dry mass at current ambient atmospheric CO_2 levels but 1.26% at doubled atmospheric CO_2 levels (Cui and Nobel, 1994b); the lower N content at the higher atmospheric CO_2 level reflects a lower amount of photosynthetic enzymes, as is also found for other species.

PREDICTED PRODUCTIVITIES

The responses of daily net CO_2 uptake to environmental factors over 24-hour periods under controlled conditions can lead to predictions for plant productivity in the field, as CO_2 uptake leads to growth and hence to an increase in plant biomass (Nobel, 1988, 1991b; García de Cortázar and Nobel, 1991). Such responses, especially with regard to plant spacing leading to a high-planting density that maximizes productivity per unit ground area, have been used to predict maximal productivity. This has led to experimental cultivation of *O. ficus-indica* near Santiago, Chile, and Saltillo, Coahuila, Mexico, under wet soil conditions (generated by year-round irrigation), moderate temperatures close to those optimal for net CO_2 uptake, SAIs of 4 to 6, and non-limiting soil nutrients (Nobel, 1991a; García de Cortázar and Nobel, 1991, 1992; Nobel *et al*., 1992). For these ideal conditions, the measured dry mass productivity is 50 t/ha/yr. Considerably lower productivity is expected, however, under more typical (non-ideal) field conditions, productivities that can be predicted using Figure 2 to obtain relative net CO_2 uptake responses.

A high-planting density with an SAI of 4 to 6 causes the root systems of individual plants to overlap. Thus a more typical field situation might be an SAI of 2, which also allows for the pathways in the field necessary for plant maintenance and the harvesting of cladodes. The weather may not lead to ideal temperatures, which are essentially controllable only by changing the location of the fields. Instead of year-round irrigation, two lesser water availability situations will be considered, which are more typical of Mediterranean climates or regions where encroaching desertification favour the use of *O. ficus-indica* as a forage, namely, where the seasonal rainfall leads to wet soil conditions for nearly two months in the winter and where the rainfall leads to two wet periods of nearly one month each. Using an SAI of 2 leads to 62% of the maximal CO_2 uptake per unit ground area based on PPF interception (Figure 2C) and the field temperatures may lead to 80% of the maximal daily net CO_2 uptake (Figure 2B). For the single winter wet period and using the response of *O. ficus-indica* to drought (Figure 2A), the plants would have a maximal net CO_2 uptake for two months, plus half of the maximal for a month more during drought or (2.5/12)(100%) or 21% of the maximal net CO_2 uptake that would be obtained under year-round wet conditions. Because responses to these three environmental factors are multiplicative (Nobel, 1984, 1988, 1991a), the predicted productivity is $0.62 \times 0.80 \times 0.21 \times 50$ t/ha/yr = 5.2 t/ha/yr. For the two wet periods per year plus the daily net CO_2 uptake responses of *O. ficus-indica* to drought (Figure 2A), water limitations would lead to $[(1.5 + 1.5)/12] \times 100 = 25\%$ of the maximal annual net CO_2 uptake, so the predicted productivity is $(0.62) \times (0.80) \times (0.25) \times (50$ t/ha/yr) = 6.2 t/ha/yr. A more precise estimate can be obtained by using monthly or even daily values for the limitations caused by water, temperature and light on daily net CO_2 uptake (Figure 2). In any case, environmental conditions in the field can be used to predict productivity for *O. ficus-indica* using responses of daily net CO_2 uptake to soil water, air temperature and PPF determined under controlled conditions in the laboratory.

COMPARISONS WITH OTHER SPECIES

Although most ecophysiological studies on opuntias have been done with *O. ficus-indica*, similar results occur for other opuntias and other CAM plants (Nobel, 1988, 1994). For instance, *Opuntia amyclea* can have a high annual biomass productivity of 45 t dry mass/ha/yr at an optimal SAI and under irrigation in Saltillo, Coahuila, Mexico (Nobel *et al*., 1992; actually, species status for *O. amyclea* is uncertain but it is morphologically distinct from *O. ficus-indica*). Among other CAM plants, certain agaves used commercially in Mexico, namely, *Agave mapisaga* and *A. salmiana*, have high biomass productivities, averaging 40 t/ha/yr (Nobel *et al*., 1992). In comparison, the four highest-yielding C_3 crops have an average productivity of 38 t/ha/yr, the four fastest-growing C_3 trees average 41 t/ha/yr, and the four highest-yielding C_4 crops average 56 t/ha/yr (Nobel, 1991a). Of greater importance for forage considerations in arid and semi-arid regions is the biomass productivity when rainfall is severely limiting. Under such circumstances the advantages of CAM become apparent for water conservation, as agaves and opuntias have a higher WUE, leading to a higher biomass productivity per unit ground area than do C_3 or C_4 plants under the same conditions (Nobel, 1994).

Agaves and other cacti also have other ecophysiological responses similar to those for *O. ficus-indica* (Nobel, 1988, 1994). For instance, net CO_2 uptake, growth and biomass productivity respond favourably to N fertilization, and generally also to P and K fertilization, and nearly all species are inhibited by increasing soil salinity (Nobel, 1989b). As for *O. ficus-indica,* increasing the atmospheric CO_2 level also increases the biomass productivity for agaves. A doubling of the current CO_2 level leads to about 50% more biomass for *Agave salmiana* over 4.5 months (Nobel *et al*., 1996) and nearly 90% more biomass for *Agave deserti* over 17 months (Graham and Nobel, 1996). Doubling the atmospheric CO_2 level for *A. deserti* increases daily net CO_2 uptake per unit leaf area by 49% while reducing daily transpiration by 24%, leading to a 110% higher WUE. As for *O. ficus-indica,* other commercial CAM plants are also sensitive to freezing temperatures, but highly tolerant of high temperatures (Nobel, 1988). For instance, -8°C for 1 hour had similar deleterious effects on chlorenchyma cells of *A. salmiana* and *O. ficus-indica* (Nobel, 1996). Thus the extent of cultivation of both species can increase because of the rising air temperatures that are predicted to accompany global climate change, and the increasing atmospheric CO_2 levels will increase their biomass productivity.

CONCLUSIONS

Clearly, *O. ficus-indica* and certain other commercial CAM species are well suited for forage crops in arid and semi-arid regions, generally as a result of their nocturnal stomatal opening that leads to nocturnal net CO_2 uptake. The responses of their daily net CO_2 uptake to soil water content, air temperature and PPF are known or can be measured, allowing predictions of their biomass productivity in various regions. Although extremely high (50 t dry mass/ha/yr) productivity is possible for *O. ficus-indica*, predicted productivity of 5 to 6 t/ha/yr under water-limited conditions can still surpass productivity of C_3 and C_4 species used for forage. Specifically, *O. ficus-indica* can have a WUE that is 3 to 5 times higher than for C_3 and C_4 species. In addition, a low stomatal frequency and a thick cuticle reduce water loss, while its massive photosynthetic stems act as a water reservoir, extending the period during drought that daily net CO_2 uptake can occur. *Opuntia ficus-indica* is sensitive to freezing temperatures but extremely tolerant of high temperatures; its net CO_2 uptake and growth are generally enhanced by N fertilization and increasing atmospheric CO_2 levels but inhibited by soil salinity. In any case, based on the suite of its ecophysiological characteristics, *O. ficus-indica* has great promise for increased usage as a forage crop in arid and semi-arid regions, as well as for combating desertification.

GERMPLASM RESOURCES AND BREEDING OPUNTIA FOR FODDER PRODUCTION

Candelario MONDRAGÓN-JACOBO and Salvador PÉREZ-GONZÁLEZ

INTRODUCTION

The *nopal* or opuntia is generally recognized as a fruit crop for semi-arid subtropical conditions around the world, although it is grown commercially for this purpose only in five countries: Chile, Italy, Mexico, South Africa and USA. However, it is more important as a forage and fodder plant, considering the extent of wild and cultivated areas in countries where it is a native plant, as well as where opuntia has become naturalized. Statistics on worldwide estimated area range from >687 000 ha (Nobel, 1994) to 2.3 million ha (De la Cruz, 1994), the latter figure includes low-density populations scattered across northern Mexico. It has been estimated that 92% of these resources are potentially useful as stock feed.

Two anatomical features of the plant imply that acceptance of opuntia fruit in the international market could be slow and perhaps limited: the actual fruit quality (i.e. seediness) and the peel glochids. The presence of thorns on the most productive and high quality fruit cultivars discourages new growers in non-traditional growing areas. For vegetable use, the mucilage seems to be the most important limiting factor for new consumers. Utilization as a fodder or forage, however, seems to be more feasible. Opuntia can provide a continuous, valuable supply of fresh fodder during the dry season, given its succulent non-deciduous vegetative structure, a feature rarely found in other forage species. The fodder will in turn be transformed into more prized commodities: milk, meat, leather and wool.

Animal husbandry on a limited scale is a common survival strategy in semi-arid lands. In many countries, domestic animals also represent social status, because they are an asset that can be readily utilized. Pastoral societies are present in all arid and semi-arid undeveloped regions of the world, making intensive use of native grasslands. As a result, depletion of grasslands is a widespread problem around the semi-arid belt of the world, contributing to desertification. The search for plants that can withstand climatic constraints and help stem land deterioration is continuous. In this context, opuntia has interesting potential, as already shown in its centres of diversity and many other areas of the world that, for historical reasons, have benefited from opuntia introduction and dispersal.

Systematic collection and characterization of germplasm from native as well as naturalized populations, and continued efforts at breeding, are needed to find new selections and to develop new cultivars for desertified areas, areas that currently are running out of options to recover their biological productivity.

Attempts to breed opuntia date back to the early 1900s, when Luther Burbank in California envisioned the development of spineless varieties for fodder (Dreyer, 1985) that could be cultivated around the globe

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and make productive vast tracts of barren land. It is noteworthy that opuntia entered the international scene as a fodder crop, contrasting with its traditional utilization as a fruit and vegetable plant in Mexico.

In this chapter we review the importance of the germplasm base of fodder and forage opuntia, the extent of its variability and utilization, and the need for long-term conservation efforts. The techniques, research progress, breeding constraints and goals associated with developing fodder varieties are also discussed.

BIOLOGICAL BASIS OF BREEDING

Natural hybridization of opuntia is common. It is related to polyploidy and appears to be one of the major causes of diversity. Asexual reproduction is an adaptive answer to the low germination rates and seed predation found in this group (Del Castillo, 1999). Hybridization in natural populations of Southern California was elucidated by Walkington (1966, cited by Gibson and Nobel, 1986) based on morphological and chemical studies. These findings indicated that plants of *Opuntia occidentalis* came from a cross between two native platyopuntias: O. *ficus-indica* and *O. megacantha*. The hybrid was reported as having features of both parents. Scheinvar (1995) reported that in wild populations of opuntias, plants located in the periphery of the population show greater variability than those growing in the middle, probably due to a greater exposure to genetic exchange with other species and genotypes.

Partial as well as total cross-pollination is found in cultivated accessions; thus cultivated types are likely the result of cross-pollination. All Mexican cultivars are reported as products of hybridization of *O. ficus-indica* with different wild opuntia forms (Pimienta-BarRíos and Muñoz-Urias, 1995).

Opuntia flowers are also capable of self-pollination, and bagged flowers are able to set fruit (Nerd and Mizrahi, 1994). Self-pollination was confirmed by Wang *et al.* (1997) with a hybridization trial involving six *Opuntia* species. The success of self-pollination is also confirmed in commercial orchards, where large blocks of a single cultivar set fruits and seeds without the apparent need for special pollinating varieties, as reported by Damigella (cited by Nerd and Mizrahi, 1995, and Mondragón, 1999).

OPUNTIA BREEDING TECHNIQUES

Opuntia flowers are hermaphrodite, but they can be emasculated and isolated with some difficulty to perform controlled crosses. Opuntia breeding principles and techniques were described by Mondragón and Bordelon (1998) and Mondragón (1999), some refinements to the techniques were added by Bunch (1997). The following steps are taken when emasculating opuntia flowers: (1) brush the glochids from the exterior of the buds to allow easy handling; (2) excise the corolla, using as few strokes as possible, thereby avoiding wounds and mechanical damage to the style; (3) carefully remove the stamens and anthers, cutting close to the base; (4) rinse thoroughly with clean water to get rid of residual pollen and anthers; (5) clean the wounded surface with a paper towel; (6) allow 15-20 minutes to promote drying of the wounded tissues; (7) cover the flower with a glassine or paper bag, and seal it with a rubber band; and (8) label.

The seeds are extracted from ripe fruits, then washed and sun-dried. Disinfection with diluted (10%) commercial bleach is recommended before planting. Germination is enhanced by scarification, i.e. immersed in hot water at 80°C and allowed to cool off at room temperature, followed by overnight soaking. The seeds can be planted in standard germination media. High temperatures (30-35°C) and regular irrigation are needed to attain good germination rates (Mondragón, 1999). Germination starts after a week, but can continue for up to two months, depending on seed condition, cultivar and species.

Once the first cladode attains 5-10 cm they can be transplanted to small plastic bags or pots and placed in a nursery. Plant growth in the nursery can be accelerated by providing long-day illumination and fertigation. Plants having a second cladode (25-40 cm total height) are mature enough to tolerate field conditions, but still they are sensitive to frosts, therefore they should be planted after any risk of chilling temperatures is over.

LIMITATIONS TO BREEDING

The ability to generate apomictic seedlings derived from the nucellar tissue of the seed and the length of juvenility are the most important constraints for opuntia breeding. Apomixis has been reported in several species of *Opuntia,* including *O. aurantiaca* Lindl., *O. dillenii* Haw., *O. glaucophyla* Wendl., *O. leucantha* Link., *O. rafinesquii* Engelm., *O. tortispina* Engelm., and *O. ficus-indica* (L.) Mill. (Tisserat *et al.*, 1979). Within cultivated opuntias, apomixis is also a widespread phenomenon. Mondragón (1999), working with 17 breeding populations of Mexican origin grown under greenhouse conditions, found that all entries produced maternal seedlings, though at different rates. An exploratory trial of apomicts identification with phenotypic and molecular markers was also conducted. Seedlings emerging late were found to be associated with a random amplified polymorphic DNA (RAPD) banding pattern similar to that of the maternal entry, providing a tool for early screening of apomictic seedlings.

Another effective approach to separate sexual seedlings has been used by the Italian breeding programme. Assuming that the largest embryo present in the seed is of sexual origin, they are rescued from the seeds and grown in nutrient media (Chessa and Nieddu, 1999) thereby increasing the number of zygotic individuals for field evaluation.

Opuntia can reach the reproductive stage after the second to fifth year of planting when started from cuttings, according to cultivar and growing conditions. Plants derived from seeds of a cross between cv. Cristalina and cv. Reyna (both of which set fruit after the third year when propagated from cuttings) under optimum conditions in northern Guanajuato, Mexico, also started bearing fruits at the third year (Mondragón and Fernandez, unpub. observation). However, some important traits that qualify a fodder cultivar – including nutritional value, digestibility and lack of spines – can be evaluated after the second year of planting. To evaluate plant productivity, fully-grown cuttings can be obtained at the end of the second year (Mondragón, personal observation).

GERMPLASM RESOURCES

Wild stock

Numerous opuntia species are utilized as forage in northern Mexico. Fuentes (1991) and Flores and Aranda (1997) reported the use of 10-18 species, 15 of which are platyopuntias. *O. streptacantha*, *O. megacantha*, *O. leucotricha*, *O. robusta*, *O. rastrera*, *O. lindheimeri*, *O. engelmannii*, *O. cantabrigiensis*, *O. macrocentra* and *O. phaeacantha* are the most important regarding abundance, distribution and preference by ranchers. The most frequently used are *O. engelmannii* and *O. lindheimeri* (De la Cruz, 1994). All the above-mentioned species are thorny and have to be processed for more efficient use. *O. robusta* presents spiny and spineless types, but individuals with smooth pads are predated by rodents during the juvenile phase and are not usually found in the wild. *O. ellisiana* is valued in South Texas and used *in situ* after burning off the spines (Felker, 1995).

Even some obnoxious species harmful to livestock, like *O. mycrodasys* (or blinding prickly pear, named after the damage caused by the numerous glochids) are consumed when other species become scarce (De la Cruz, 1994). Varieties of all species can be found close to the original stock, originated by chance seedlings of sexual origin. Most of the wild accessions have been reported as having low ploidy levels (4x and 6x), although *O. streptacantha* cv. Cardona presents 2n = 2x = 88, as observed by Muñoz-Urias *et al.* (1995).

The utilization of whole plants to feed cattle is endangering wild populations of opuntia in northern Mexico. Too often, they are completely uprooted to increase the collected volume and monetary income, severely diminishing the chances for recovery. The problem cannot be solved easily because the plants are harvested to be utilized in suburban dairy operations, far away from the native locations and benefiting other users, besides the landlords. The germplasm available in these areas has been barely evaluated and the risk of loss of valuable individuals is a real threat. The effects on opuntia variability can be disastrous and permanent. An initiative to enforce rational utilization and *in situ* conservation of wild opuntia is needed, along with intensive efforts to rescue useful germplasm.

Backyard sources

Backyard orchards containing opuntia are commonly seen in semi-arid central Mexico. They represent an intermediate stage in opuntia domestication, and were also the source of propagules for the earlier commercial orchards (Pimienta-Barrios, 1990). Fruit clones are important in these sites, but clones for multiple use – fruit and vegetable, fodder and vegetable, etc. – are also present in these domestic collections. Mixed stocks of spiny and spineless genotypes are widely available. Plants in the yard represent feedstuff readily available for domestic livestock during the dry season. Spineless genotypes are preferred for easier handling.

The family orchards are the best sites to find individuals of sexual as well as clonal origin growing in close vicinity. Opuntia is capable of cross-pollination, allowing the possibility of chance seedlings derived from natural crosses. In these places, seedling predation may be lower and growing conditions are improved by waste water and manure of domestic animals. Collection efforts in Mexico have been focused mainly in backyards, but a complete evaluation of suitability as fodder and productivity under cultivation is lacking.

EARLY ATTEMPTS AT BREEDING OPUNTIA FOR FODDER

Hybridization in opuntia was first claimed by Luther Burbank in the early 1900s, which led to the development of the so-called 'spineless' cactus. Burbank saw it as having immense potential for cattle forage in desert areas. Several cultivars were developed, and Burbank aggressively marketed five of them (Dreyer, 1985). They were said to be the product of extensive crossing and selection among accessions shipped from Mexico and other countries. Today, four of these cultivars still remain in the South African collection.

Disregarding the obvious importance of opuntia as a valuable resource for Mexico, the plant remained nearly forgotten by the Mexican scientific community for more than half a century. Formal breeding was initiated in Mexico in the 1960s. The Universidad Autónoma Agraria Antonio Narro initiated research, selecting for cold-hardy *Opuntia* (Martinez, 1968, Borrego *et al.*, 1990). During the same decade, the late Dr F. Barrientos of the Colegio de Postgraduados de Chapingo pioneered the first hybridizations of opuntia in Mexico.

The improved Mexican cultivars

The COPENA series of cultivars were developed by the Colegio de Postgraduados of the Escuela Nacional de Agricultura. Cvs CPF1, CPF2 and CPF3 were selected for fodder production, and cv. CPV1 for vegetable use (Barrientos, 1965a, b), but all belong to *O. ficus-indica*. The mature pads of CPV1 are useful as fodder. Currently, only CPF1 and CPV1 can be found, planted in small plots in central Mexico.

COPENA F1 or cv. CPF1 produces long, thin, green pads, excellent for human consumption when tender. The fruits of this cultivar are light green, with thin pericarp and a slight blush. Under rainfed conditions, at least one flush of pads per growing season is produced. Cv. CPV1 is a vegetable cultivar whose mature pads can also be used for fodder.

Cv. Pabellón has ovoid, thick, dark green pads; adult plants produce red tasty fruits similar to the fruits obtained from cv. Roja Lisa, a fruit cultivar. It is probably a selection from Aguascalientes, Mexico. Both entries are now available in most of the germplasm banks recently formed.

Cvs ANF1 and ANV1 are cultivars developed during the 1960s by the Universidad Autónoma Agraria Antonio Narro (UAAAN). Described as spineless and suitable for fodder production, plantations were promoted primarily in northern Mexico, but with limited success, probably due to the lack of interest in opuntia cultivation for fodder production as a result of the abundance of the wild resource. They are only available at the source.

The 'Palmas of Brazil'

Northeast Brazil is the most important growing area for fodder opuntia in the world. Cvs ′Palma Gigante′ and ′Palma Redonda′ (both *O. ficus-indica* Mill.) are widely cultivated in dry areas. Together with cv. ′Palma Miuda′ (*Nopalea cochinellifera* Salm-Dick), which tolerates more humid conditions, they are the mainstay of commercial production of this crop.

These cultivars have small and sweet fruit without commercial importance. They were introduced to Brazil by the Portuguese during the colonial era. ′IPA-Clone 20′ was selected from open pollinated seeds of Palma Gigante (*O. ficus-indica* Mill.). In field trials, IPA-Clone 20 produced 50% more fodder than the maternal entry (Arruda and Warumby, 1999).

The spineless Burbank selections in South Africa

O. ficus-indica is believed to have been introduced to South Africa at least 250 years ago (Zimmerman and Moran, 1991), giving this country the oldest record of opuntia introduced as a fodder crop. Modern introduction started in 1914, including 22 entries: 19 green "leafed" and three blue "leafed" accessions, by way of "true-to-type seed". From this initial collection, and assuming cross-pollination, numerous crossbred cultivars have been found. These selections were obtained by Luther Burbank in California from material collected in Central America (Wessels, 1988).

The selections Robusta, Monterey and Chico, described as blue-leafed spineless cultivars (probably *O. robusta*, based on the bluish hue of the cladode and the red fruit and flesh) were imported to South Africa as seed from Burbank Nurseries, to be cultivated as stock fodder (Wessels, 1988). Robusta and Monterrey are highly productive, while Chico presents some cold resistance. All spineless or 'Burbank' opuntias bear tiny bristles (glochids) around areoles and on the fruit surface (Brutsch and Zimmerman, 1990).

ACTIVE BREEDING PROGRAMMES

The early efforts in selection and genetic improvement were unsustained. A fresh start at breeding is underway in Italy, Mexico, South Africa and USA, based on the utilization of local germplasm. This renewed interest, encouraged by the Food and Agriculture Organization of the United Nations (FAO), has resulted in the collection of wild and semi-domesticated accessions, publication of information on crop management practices, and development of new uses for opuntia (Barbera, 1995).

D'Arrigo Brothers, a produce company based in California, USA, supports a private breeding programme aimed at improving fruit quality of their spineless commercial cultivar Andy Boy (similar to cv. Rossa, which is grown and marketed in Italy). Even though they are involved in neither the development of fodder nor vegetable varieties, the programme is selecting only spineless cultivars, which could be evaluated by other parties.

Texas A&M University, Kingsville, (TAMUK) has been involved since 1982 in collection and introduction of opuntia to the USA, as well as agronomic research and extension. The programme focuses on the development of freeze-tolerant cultivars, as chill damage is a common problem in the region (Wang *et al.*, 1997). In 1996, the first round of crosses marked the beginning of a long-term breeding programme. In 1998, the genetic material was transferred to Universidad Nacional Santiago del Estero, Argentina, where the work continued vigorously. TAMUK is also responsible for the popularization of the vegetable opuntia and opuntia products in Texas. Cv. Spineless 1308 (an accession originally collected in the humid tropical region of Tamazunchale, Mexico) has been extremely successful among growers and consumers.

Another active breeding programme is located in Sassari, Italy, involved mainly in improving fruit quality. Their interest also focuses on spineless cultivars. Additionally, the programme is working with other opuntias of ornamental value.

Opuntia breeding started in Brazil in 1985, with 85 clones obtained from seeds derived from open pollination of cv. Palma Redonda, plus 17 other clones from several Brazilian locations. Continuous introduction of genetic material from Algeria, Mexico, South Africa and USA has increased the number of entries to 1400 clones at the Instituto Pernambucano do Pesquisa Agropecuaria, (Cordeiro and Alburquerque, this volume), making it the highest number of fodder clones in evaluation anywhere in the world. Higher productivity and better nutritional value, as well as adaptation to more humid and warmer environments, are the goals of this programme.

BREEDING GOALS

Cold tolerance

Hybridization of cold-tolerant native species with highly productive but cold-sensitive commercial species should be a major objective of breeding programmes to expand the cultivation of opuntia (Gregory *et al.*, 1993; Mizrahi *et al*., 1997). The most important opuntia cultivars are generally irreversibly injured at temperatures of -5 to -10°C (Russell and Felker, 1987b; Nobel and Loik, 1993). Certain wild *Opuntia* species, such as *O. fragilis* (Nutt.) Haworth and *O. humifusa* (Rafinesque), both native to Canada, can tolerate temperatures below -20°C when properly acclimatized (Nobel and Loik, 1993). Cold tolerance is an important feature for opuntia production (fruit as well as forage) in the southern USA, where freezing temperatures occur occasionally (Parish and Felker, 1997). Susceptibility to freezing is the primary factor limiting the expansion of opuntia as fodder and forage in cattle-producing areas of the USA. Russell and Felker (1987b) reported that *O. ellisiana* in Texas endured -9°C without apparent damage, while fruit and fodder accessions from Brazil, Chile, Mexico and South Africa presented different degrees of frost damage. The South African spineless fodder cultivars were the least affected.

In the early 1900s, Uphoff (1916) reported that species of cacti having relatively thick integuments (cuticle, epidermis, crystal-bearing layers, and several layers of thick walled cells) were more resistant to low temperature than those with thinner integuments. According to Goldstein and Nobel (1991), reduced water content and accumulation of organic solutes and mucilage may be partially responsible for cold acclimatization.

A key issue in cold hardiness is the length of the onset period of freezing temperatures, as noted by Gregory *et al.* (1993). In *Opuntia*, the lack of freeze hardiness is probably not due to the lack of tolerance to cold temperatures *per se*, but the range of day to night temperatures, from 28°C down to -12°C in a single day in Texas, which does not allow the plant to properly acclimatize and express cold tolerance.

Borrego *et al.* (1990) reported that selection for cold-hardy genotypes was initiated in the Universidad Antonio Narro in northern Mexico by Dr Lorenzo Medina in 1963, taking advantage of an unusual -16°C frost event. The best 31 individuals were selected, together with outstanding fruit and vegetable regional genotypes that also survived the frost, collected from backyards. Some of these clones were later introduced to southern Texas by P. Felker.

Parish and Felker (1997) found several promising clones in their experimental orchard at Kingsville, Texas, an area with recurrent frost and low temperatures of about -12°C. Clone 1436, obtained from Saltillo, Mexico, was found to have high yield and good fruit quality. Two other clones, 1452 and 1458, collected in northern Mexico from areas in the highlands exposed to late frosts and light snow cover, are also promising. These findings indicate the existence of genes for cold tolerance and the possibility of opuntia cultivation in colder regions.

Development of hybrids with improved cold hardiness was undertaken at Kingsville, Texas, using the spiny *O. lindheimeri* as a source of cold-tolerance genes (*O. lindheimeri* and *O. ellisiana* have been observed to tolerate -20°C) and spineless accessions of good fruit quality from Mexico (Wang *et al.*, 1997). Any spineless segregant has potential to be used in cultivated conditions as a fruit or fodder cultivar.

O. robusta typically does not tolerate frost, as observed in Texas with cvs ′Robusta,′ ′Monterey′ and ′Chico,′ none of which tolerated a -12 C frost registered in 1989 (Felker, 1995).

Spineless pads

The presence of spines on the pads is a serious impediment to widespread utilization of opuntia. Spineless pads are thought to be the result of domestication by man, because plants with smooth pads do not prosper in the wild. The inheritance mode of this trait has not been identified, but reversal of spineless back to spiny forms has been reported in South Africa. Zimmerman and Moran (1991) reported that there is evidences that only spineless forms were introduced to South Africa more than 250 years ago, and they reverted back to the original spiny form over a period of nearly 200 years. Spiny plants are more aggressive and better adapted to spread. These clues suggest the existence of recessive genes associated with spininess, and confirm the ability of opuntia to reproduce from seed. All breeding programmes aim to produce spineless forms.

Plant productivity

Striking differences in plant vigour have been observed within seedling populations derived from selfing and crossing, suggesting that these differences are probably derived from the plant's own capacity to photosynthesize as well to absorb nutrients and water. This might be expressed as a higher bud density and capacity to budbreak in spring, resulting in more cladodes per plant or larger size. It is an important selection trait, particularly if associated with spineless pads, digestibility or nutritional value.

Given that fodder production involves partial or total utilization of the vegetative structure, the capacity to produce new cladodes and to recover quickly from pruning are the more important features to be manipulated through breeding. The size of the cladodes is determined by the genotype (Mondragón, 1999), and to a lesser extent by the planting layout and soil fertility. For higher biomass yield in cultivated stands, it is preferable to have cultivars with medium-sized cladodes suitable for close planting.

High protein content

Protein content varies significantly according to cladode age, with mature pads having higher percentages. The differences persist among varieties and species. Crude protein varied widely when Fuentes (1991) compared six opuntias from northern Mexico. The lowest value was observed in *O. rastrera* (2.8%) compared to 5.1% recorded in *O. ficus-indica*. The latter sample most probably was obtained from a backyard or from a commercial plantation. According to Murillo *et al.* (1994), differences have been observed between *O. lindheimeri* var. *tricolor* (2.81%), which has higher protein content than *O. lindheimeri* var. *lindheimeri* (4.0%). The genetic component of this trait is difficult to separate because it is strongly influenced by soil fertility and crop management. Therefore, selection for cultivars with high protein content must be conducted under carefully controlled conditions. It is doubtful that the genetic gain of protein content associated with selection can surpass the effects of efficient management of soil fertility.

Pest and disease tolerance

There are a number of pests that affect opuntia, and variations in susceptibility to pests have been observed but not thoroughly studied. Wild cochineal (*Dactilopius coccus* Costa) and stinky bugs (*Chelinidae tabulata*) seem to prefer some spiny cultivars (Mondragón, pers. observation). Soft black rot (*Erwinia* sp.) is a serious disease affecting forage and vegetable plantations in Italy, Mexico and other countries, and there are no reports of tolerance among commercial varieties. Even though there are options for chemical control, tolerant cultivars would offer a safer and more economical alternative for growers.

IMPROVED OPUNTIA CULTIVARS BEYOND 2000

Collection of opuntia germplasm is performed on the basis of major use: fruit, vegetable or forage. New hybrids will have to be subjected to a wider evaluation to increase the output of breeding programmes. Breeding for multiple uses is an immediate objective to be pursued by the research programmes. The suitability of tender pads to be used as a vegetable can be judged during the juvenile phase, after the first year planted in the field. Mature pads, needed to evaluate fodder potential, can be obtained after the second year, without hindering the growth or development of the plants. Several combinations can be expected in regard to use: fruit+forage cultivars and vegetable+fodder, as well as the usual single-use cultivars.

Local tastes and preferences for vegetables can slow down the acceptance of tender opuntia in those countries without a tradition of human consumption of *Opuntia*. Therefore, the most important combination for growers – other than Mexicans – will be forage+fruit. Evaluation of protein content and nutritional value should be included as a routine for all new cultivars. There is little information on the usage of fruits as a supplement to mature pads, and the effects on the nutritional value of an opuntia-based diet, an alternative of use in countries without a tradition of fruit consumption.

The new cultivars have to be devoid of thorns to facilitate cultivation, fodder handling and feeding. Modification of cropping systems could allow the introduction of opuntia to new locations; the practice of multiple cropping based on the local staple crops will allow gradual introduction of opuntia to new growers. Outstanding spiny cultivars, which are less affected by wild rodents, can be directed towards ecological applications, such as recovery of degraded lands. Vigorous exchange of spineless genotypes among breeding programmes should be encouraged.

PRODUCTION AND USE OF OPUNTIA AS FORAGE IN NORTHERN MEXICO

Juan José López-García, Jesús Manuel Fuentes-Rodríguez and R.A. Rodríguez

OPUNTIA IN NORTHERN MEXICO

Environmental conditions and physiographic variables have resulted in a wide range of semi-arid ecosystems with a diverse flora and fauna in northern Mexico, where *Opuntia* is abundant and widely distributed in large thickets called *nopaleras*. It is represented by 104 species, 60% located in the Chihuahuan desert. The most important species for forage use are: *Opuntia leucotricha, O. streptacantha, O. robusta, O. cantabrigiensis, O. rastrera,* O. *lindheimeri* and *O. phaeacantha* (Bravo, 1978; Elizondo *et al.*, 1987).

GEOGRAPHICAL DISTRIBUTION OF NOPALERAS

Marroquin *et al.* (1964) recognized three large regions covered with opuntias in northern Mexico alone. A wider approach, including the whole country, was proposed by López and Elizondo (1990), who recognized four regions occupied by opuntiaeras exploited for forage or fruit, or both.

A. ***Central-southern zone***. This includes parts of the states of Puebla, Querétaro and Oaxaca, and is characterized by tree types cultivated in nopaleras and producing tender pads (*nopalitos*), fruits (*tunas*) and forage. Species are mainly *O. ficus-indica* (*nopal de Castilla*), *O. amyclaea* (*nopal alfajayucan*), with several cultivated varieties (Barrientos, 1972), *O. megacantha* (*tuna amarilla*) and *O. tomentosa*.

B. ***High plateau zone***. This lies mainly in the states of Zacatecas and San Luis Potosí, but includes also parts of Aguascalientes, Durango, Guanajuato and Jalisco. It includes tree-type vegetation of *O. leucotricha* (*nopal duraznillo*) and *O. streptacantha* (*nopal cardón*), as well as shrubby plants of *O. robusta* (*nopal tapón*), *O. cantabrigiensis* (*nopal cuijo*), *O. rastrera* (*nopal rastrero*), *O. lindheimeri* (*nopal cacanapo*) *and O. leptocaulis* (*nopal tasajillo*).

C ***North zone*** in the Chihuahuan desert is the largest region, and includes the states of Chihuahua, Durango, Zacatecas and Coahuila. It is represented by shrub vegetation of *O. cantabrigiensis, O. phaeacantha* (*nopal rastrero), O. lindheimeri* and *O. rastrera.*

D. ***Coastal zone of the Gulf of Mexico.*** This covers parts of the states of Coahuila, northern Nuevo Leon and Tamaulipas. Shrubby plants of *O. lindheimeri* are found associated with other forage species: *O. leptocaulis, O. microdasys* (*nopal cegador*), *O. imbricata* and *O. rastrera* to a lesser extent.

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DISTRIBUTION OF THE MAIN FORAGE SPECIES

O. leucotricha (*nopal duraznillo*). The most widely distributed species across region B at altitudes between 1500 and 2500 m with an annual rainfall ranging from 220 to 450 mm. These wild populations have been seriously affected by the continuous increase in the cultivated area of maize and dry beans.

O. streptacantha (*nopal cardón*) is present in large areas of the states of Zacatecas and San Luis Potosí, and to a lesser extent over Aguascalientes, Durango, Jalisco and Guanajuato. This area is threatened by serious desertification.

O. robusta (*nopal tapón*) grows in association with *O. leucotricha* and *O. streptacantha.* It is widely distributed over the states of Zacatecas, San Luis Potosí, Guanajuato, Aguascalientes and Jalisco. The tender cladodes are large and succulent, appreciated for human consumption both fresh and pickled.

O. cantabrigiensis (*nopal cuijo*) is a shrub with a well-defined stem and abundant spines, used mainly to feed goats. It has a wide distribution at altitudes from 1500 to 2200 m with relatively low densities on calcareous soils over the states of Nuevo León, Coahuila, Zacatecas, San Luis Potosí, Hidalgo, Aguascalientes, Durango, Jalisco, Querétaro and Guanajuato.

O. rastrera is a shrub with creeping habit, less than 1 m tall, widely used to feed dairy cattle in the states of Coahuila, Nuevo León, Zacatecas, San Luis Potosí, Durango and Aguascalientes. It grows well in a wide range of soils, from deep to shallow, rocky and calcareous. It is sometimes found in dense thickets.

O. lindheimeri (*nopal cacanapo*) extends over the states of Coahuila, Nuevo León and Tamaulipas at altitudes around 1000 m with an average annual rainfall of 400 mm. The species has four important varieties, all widely appreciated for forage: *aciculata, lindheimeri, subarmata* and *tricolor*.

O. phaeacantha grows wild in Coahuila and the southern parts of Chihuahua and Durango with only 200 mm of annual rainfall at altitudes between 1500 and 1700 m. Five distinct forage varieties have been described: *major, phaeacantha, diskette, spinosibaca* and *Nigerians*. All of them have good forage quality.

O. engelmannii is found in NE Zacatecas and SW Coahuila at altitudes between 1700 and 2200 m in shallow, calcareous soils. It is used mainly to feed goats and sheep.

O. imbricata (nopals *coyonoxtle, xoconoxtle, cardenche* or *cholla*) exhibits great variability and is widely distributed in the states of Coahuila, Zacatecas, San Luis Potosí, Chihuahua, Aguascalientes, Durango, Jalisco and Guanajuato. It grows well in relatively poor soils and is a typical invader plant in poorly managed grasslands. Used to feed goats and sheep after burning off the spines *in situ*.

O. microdasys is a short shrub without true spines but loaded with short bristles or *ahuates*, which are blown by wind and can easily blind animals. It grows on calcareous soils, and is used to feed animals under extreme drought conditions in southern parts of Coahuila, north of San Luis Potosí and Zacatecas.

O. violacea (*morado*) is recognized by its purple-coloured cladodes. A short shrub (< 1 m) that grows on deep clay soils of Chihuahua, NW Coahuila and east Durango – areas with only 200 mm of annual rain, hot summers (up to 45°C) and cold winters (-8°C). Its forage quality is poor.

O. rufida (blinding opuntia) is a shrub growing to about 2 m that grows in calcareous clay soils, in the slopes or in the deep valleys. Its cladodes are larger than *O. microdasys,* and its quality as forage is also poor. It is used only as an emergency feedstuff (Elizondo *et al*., 1987).

PRODUCTION

Wild stands

Forage availability from *Opuntia* in northern Mexico relies mainly on wild populations, formed by the species described above, which are distributed on 283 000 km^2. Unfortunately, these areas have been subjected to heavy use and poor management (Marroquin *et al.*, 1964). Recurrent periods of drought associated with scarcity of other feedstuffs have also increased the demand for opuntia forage. The productivity of such ecosystems is relatively low and unstable, strongly dependant upon climate and management conditions.

Yield ranges from 25 to 125 t/ha, depending upon the species, plant vigour, climate, soil fertility and management system. The yield value assumes that 75-80% of aboveground biomass is usually harvested. The recovery period is strongly dependent on rainfall and intensity of usage.

Cultivated nopaleras

There are several production systems, ranging from replanting wild stands to intensive production systems based on high densities and irrigation. Federal programmes aimed to recuperate highly deteriorated nopaleras have failed due to a lack of understanding of the complexity of the production systems involved. Plantations were usually established on marginal lands and under poor management practices, which contributed to the failure of programmes. However, these federal projects should continue putting emphasis on more efficient use of natural resources, to improve the ecological and socio-economic conditions of the semi-arid regions in northern Mexico (López, 1977; Medina *et al*., 1990).

Well-tended nopaleras planted with 2500 plants per hectare can produce above 100 t/ha after the fifth year of planting. Recorded yield for the seventh year is 160 t/ha. Sustainable production is accomplished by harvesting every other row annually. However, in general, plantations are poorly managed and average yield varies from 5 to 15 t/ha after the fifth year of planting.

Factors important in improving yield include:

* *Site selection.* For intensive production, it is advisable to select the best part of the land in terms of soil conditions. The plantation should be at high density. Extensive plantations are suggested as an aid to recover natural grassland. Planting under these conditions involves a low density of opuntia plants. Extensive plantings are conducted in any type of soil.
* *Variety selection*. A wide range of adaptation to local conditions is needed, expressed as good vigour, health and productivity. They should be suitable for animal feeding either spineless or with a minimum density of spines, palatable with no side effects, of high nutritive value, and have quick recovery after harvest. Tolerance to pests and diseases is also desirable.
* *Propagation*. The source for planting material should be 1-4 years old, collected from healthy and vigorous plants. Cladodes are cut at the joint with a sharp knife, the base disinfected with Bordeaux mixture (1 kg of copper sulphate, 1 kg calcium hydroxide and 100 litre of water) and allowed to air-dry in the shade for a week. Cladode bruising should be avoided. These practices increase transplanting success.

Soil preparation For extensive plantings, cladodes are deposited directly in shallow holes dug in the field without disturbing natural vegetation. Depending upon the slope, it might be necessary to build terraces or individual micro-catchments. Once the plants are well established, surrounding vegetation shading the plants could be eliminated or pruned back. Under intensive planting systems, regular soil preparation practices (ploughing and contour furrowing) should be performed before transplanting the cladodes.

Transplanting Under dry conditions during the spring in the Chihuahuan desert, it is highly recommended to transplant after the first summer rain. However, if additional water for irrigation is available, planting could be performed any time, but late fall seems to be the best time of year to allow plant rooting previous to budbreak.

The best planting material is a cutting with two cladodes, burying 50 to 75% of the basal cladode. If planting material is in short supply, then single-cladode cuttings can be used. Based on the authors' experience, row orientation has not proved to be important for initial plant development in the field.

Planting density Using 2 500 plants/ha it is possible to produce 100 t/ha in the fifth and 160 t/ha in the seventh year of transplanting. If densities are increased up to 40 000 plants/ha under fertile soils and intensive management practices, such as irrigation and fertilization, yields may reach 400 t/ha (Barrientos, 1972). However, actual yields in the arid regions of Coahuila are very low, ranging from 5 to 15 t/ha.

Management practices Care during the first two years involves only the elimination of cladodes growing too close together, which can be used for human consumption (while still tender) or for animal feeding. Although it is not common, in some nopaleras fruit production is allowed to satisfy family needs or demand from local markets. Under these circumstances, a more conservative pruning method is practised, leaving a few more one-year-old cladodes where some fruits will develop during the following season.

HARVESTING SYSTEMS

The use of *Opuntia* as a source of forage to feed cattle, sheep and goats is an old tradition in northern Mexico. Cladode harvesting ranges from direct animal consumption in the field, to various types of harvest systems practised by ranchers.

The variants observed among extensive livestock operations are:

* Direct feeding. Opuntia plants are consumed whole including spines, by cattle, sheep and goats. This practice is inefficient, resulting in serious damage to the animals or even death.
* Removal of cladode edge. The upper portion of the cladodes, where the largest number of thorns is present is removed with a knife, allowing animals to feed on the plant. Its main disadvantage is waste of cladodes.
* Singeing-off of spines of whole plants. The plant is flamed completely, with a propane or kerosene burner, and the animals allowed to consume it down to the base. Usually leading to the complete destruction of the plant. It is combined with grazing in the case of sheep and goats.
* Singeing and chopping *in situ*. The cladodes are harvested and spines burned with firewood or gas torch. Then they are chopped and offered to animals.

A specific case is opuntia harvesting for suburban dairy operations. The plants are harvested whole and transported to stables, where they are burned and chopped. Depending on the size of the operation, chopping is performed manually or with adapted machinery.

Unfortunately, all of these systems are destructive to some degree, as they rely only on wild stands, and should be limited because none of them involve replanting, leading to depletion of the natural resource.

A sound practice consists of extensive cladode cutting and superficial burning to eliminate spines to allow animals to either feed directly in the field, as whole cladodes, or cut into small pieces to facilitate their consumption. Alternative – and more efficient – harvest practices include cladode harvesting from dense stands, which are then transported to the farms, spines burned off, and cut into small pieces to feed the animals.

CONSUMPTION BY ANIMALS

It has been estimated that cattle can consume from 15 to 40 kg of fresh cladodes/day/beast, but under drier conditions they might consume up to 90 kg if cladodes are abundant, while sheep and goats consume between 3 and 9 kg/day. During the rainy season, daily consumption may decrease if other sources of food, such as grasses, are available.

For housed cattle and sheep, opuntia consumption ranges widely (from 15 to 95 kg/day), depending upon the availability of other sources of food. The most common other feed sources include alfalfa (green or as hay), sorghum stover, and cornmeal or cotton meal. Common hay sources are maize or dry bean stover, wheat and oat straw, used to complement opuntia feeding, due to their relatively low nutritive value compared with opuntia. However, due to the high costs of hay, opuntia demand is increasing every year, particularly during periods of drought.

NUTRITIONAL VALUE

The use of *Opuntia* as a source of food for humans, domestic animals and wildlife has been very important in the arid and semi-arid regions of northern Mexico for centuries. Although it has been considered poor in terms of nutrients and fibre, it constitutes the main source of water in traditional production systems, particularly during the dry winter-spring season. *Opuntia* is a key ingredient to supplement the diet of domestic animals due to its:

- *Water content*. Opuntia is one of the main water sources for animals in the semi-arid north. However, the total amount of water stored depends upon species and varieties (Table 1). Water content is strongly influenced by environmental conditions.
- *Dry matter content*. Several factors strongly influence DM, both endogenous (species, genotype and cultivar) and environmental, such as soil, climate and season (Table 2).
- *Bromatological analysis*. There are significant differences among reported data on tissue analysis, associated with variation in species, physiological factors, soil fertility, climate, etc. (Table 2).

Table 1. Water content among species and varieties of *Opuntia* used as forage in Saltillo, Coah., Mexico.

Species	Minimum	Maximum
O. ficus-indica	88	93
O. cantabrigiensis	68	84
O. lindheimeri var. tricolor	72	86
O. lindheimeri var. subarmata	76	87
O. imbricata	70	84

Source: J.J. López-González, unpublished data

Minerals There are few reports on studies aimed to quantify mineral content of opuntia in Mexico. According to Bravo (1978), the main mineral components in opuntia ashes are calcium, potassium, magnesium and sodium, usually found as salts and silica. Iron and aluminium are found in traces.

Digestibility The rate of feed intake by the animal is influenced by species, variety and season (Table 3), cladode age (Table 4), and their corresponding interactions (Revuelta, 1963; Flores and Aguirre, 1992).

Morrison (1956) reported digestibility values as fibre, 40%; crude fat, 72%; protein, 44%; and nitrogen-free extract (NFE), 78%, while Murillo *et al*. (1994) studied the influence on opuntia digestibility of yeast supplemented with two sources of nitrogen. When yeast is added to Opuntia, digestibility was 61.6%; if ammonium sulphate was combined with yeast, digestibility increased to 93.9%. Adding yeast and urea, digestibility reached 76.8%.

Table 2. Nutritional values of *Opuntia* species on a DM basis.

Species	DM	OM	CP	Fat	Fibre	Ash	NFE	Source
Nopalea spp.	10.69	73.79	8.92	1.51	17.21	26.21	50.7	Griffiths and Hare, 1906
O. chrysacantha	15.52	73.45	3.54	1.11	4.32	26.55	64.33	Palomo, 1963
O. tenuispina	12.45	70.21	4.42	1.04	5.14	29.80	59.52	
O. megancantha	10.12	74.51	7.71	1.38	3.75	25.44	68.87	
O. rastera	14.41	59.89	2.78	0.76	6.18	40.11	43.23	
O. azurea	12.55	68.88	4.54	1.35	3.98	30.12	59.84	
O. cantabrigiensis	11.86	68.46	4.79	1.09	3.71	31.54	58.87	
O. engelmannii	15.07	68.41	3.32	1.19	3.58	31.59	60.32	
O. lucens	17.45	69.59	3.67	0.57	2.58	30.43	62.75	
O. lindheimeri	11.57	74.51	4.15	1.03	3.02	25.50	66.25	
O. robusta	10.38	81.41	4.43	1.73	17.63	18.59	57.61	
O. streptacantha	16.01	79.38	3.17	1.99	18.88	20.62	55.34	Griffiths and Hare, 1906
O. leucotricha	14.01	74.01	7.56	2.66	14.01	26.00	49.78	
O. imbricata	17.71	84.25	7.11	1.75	11.51	15.75	63.86	
O. cacanapo	16.95	72.51	5.19	2.06	11.21	27.49	54.04	
O. stenopetala	13.24	77.87	8.84	1.74	9.14	22.13	58.16	
O. duranguensi	10.34	82.94	4.51	1.29	8.23	17.06	68.91	Bauer and Flores, 1969
O. ficus-indica cv. Amarillo oro	11.29	86.93	3.81	1.38	7.62	13.07	74.13	
O. ficus-indica	13.36	81.55	3.66	1.76	9.18	18.45	69.95	
O. spp.	10.01	------	5.71	3.01	8.11	12.01	55.01	Lastra and Pérez, 1978
O. ficus-indica	8.01	------	6.81	1.01	------	8.88	81.25	
O. ficus-indica	7.96	------	4.04	1.43	8.94	19.92	65.67	
O. imbricata	10.41	------	5.01	1.81	7.81	17.30	68.11	

Key: DM = dry matter. OM = organic matter. CP = crude protein. NFE = nitrogen-free extract

Table 3. Variability in nutrient digestibility of spineless *Opuntia.*

Season	Crude protein	Fat	NFE	Cellulose
Winter-Spring	0.2 - 0.3	0.08 - 0.12	3.0 - 5.5	0.4 - 1.0
Summer-Autumn	0.3 - 0.4	0.15 - 0.16	6.5 - 11.0	0.8 - 2.0

Source: Revuelta, 1963.

Table 4. Digestible nutrients of *Opuntia* as influenced by variety and cladode age.

Source	Crude protein	Crude fat	Fibre	NFE
Spiny variety				
1st yr. cladodes	0.24	0.14	5.22	5.22
2nd yr. cladodes	0.21	0.17	0.51	4.73
Spineless variety				
1st yr. cladodes	0.22	0.17	0.49	4.81
2nd yr. cladodes	0.18	0.19	0.63	4.39

OPUNTIA AND ANIMAL PRODUCTION

The information available on use of *Opuntia* to feed livestock in extensive as well as intensive meat and dairy operations supports the importance of *Opuntia* (Fuentes, 1966).

Meat production

Griffiths (1905) reported the first results, stressing the importance of *Opuntia* as a source of food for domestic animals. These preliminary findings, derived from feeding bovines for meat production, were based on a 15-week study, were that:

* cornmeal + opuntia is better than corn [maize] grain + opuntia mixture,
* daily mean consumption per animal was 48.0 kg,
* daily animal gain was 0.85 kg, and
* 55 kg of opuntia combined with 2.5 kg of cornmeal were required to produce 1.0 kg of meat.

Experiences reported from Brazil concluded that 60% of the total energy requirements could be supplied by opuntia. Increasing the protein provision (from cotton meal and *mamona* (*Melicoccus bijugatus*)) or providing molasses did not improve liveweight gain of animals of Zebu, Indobrasil and Guzerat breeds (Viana *et al.*, 1965). Diarrhoea caused by excess opuntia fodder was successfully controlled by providing sorghum stover at the rate of 0.75 to 1.3 kg/animal/day.

In a study conducted by Fuentes (1991) on seven sites in Coahuila, 685 animals grazing freely and supplemented with maize stover, molasses and urea were also fed with 10 to 20 kg/day of burned-chopped opuntia. Daily animal gain ranged from 0.1 to 0.6 kg. Opuntia provided 7.8% of total maintenance energy, 20.6% of the protein, 50% of phosphorous and 100% of the calcium requirements recommended by the NRC (1984).

These results support the importance of including *Opuntia* in the diet of domestic animals, based on experiments combining species, varieties, local conditions and their corresponding interactions.

Milk production

Since the early 1900s, most suburban areas in Northern Mexico provide milk to large cities, and cows are fed with opuntia as a supplement to the regular diet. The belief is that opuntia-based supplement increases not only milk production, but also improves quality of butter in terms of consistency and storage life, as well as adding an attractive “golden” colour to the finished product (Griffiths, 1905; Cottier, 1934; D´Arces, 1941; Aguilar, 1946; Blanco, 1958; Calvino, 1952; González *et al.*, 1998).

However, González *et al.* (1998) reported that milk production in Holstein cows decreased with the rate of *Opuntia* in the diet. Therefore, they recommend using only 20 to 30% (on a dry matter basis) and supplementation with alfalfa hay, oats and sorghum to obtain a good balance between production costs and returns.

Daily *Opuntia* consumption in southern Coahuila (Fuentes, 1991) and Nuevo Leòn (Fuentes, 1992), ranges between 20-30 and 25-40 kg/cow, respectively. It was estimated that in such conditions *Opuntia* provided 4.5% of the total energy required for suckling, 12.2% of the proteins, 46% of crude fibre, 15% of phosphorous and 100% of calcium compared to the recommended requirements (NRC, 1984).

Sheep

Under a free pasture consumption system in the field, sheep consume less opuntia than goats, but when fed with burned-chopped *Opuntia*, their consumption reaches about 3-5 kg/day.

Other studies abroad report bovines being fed for 400 days exclusively on an opuntia diet without watering, without serious side effects (Rossouw, 1961). While in South Africa, reports indicate up to 525 days (Havard, 1969; Terblanche *et al*., 1971). Although there is not a real increase in weight, animals are saved from starvation.

The consumption of opuntia by sheep is associated with an improvement in the quality of the wool, attributed to an increase in the lanolin content, as reported by Ríos (1954) and Revuelta (1963). The effect was observed with a daily consumption of 7 kg/animal in Tamaulipas and Nuevo Leòn (Rios, 1954) and up to 9 to 10 kg in other regions (De Klerk, 1960).

Using a linear regression model, Flores (1977) predicted a 2- to 3-fold increase in body weight for sheep fed with opuntia supplemented with alfalfa hay, sugar beet and corn silage, for 32-kg sheep.

Table 5. Influence of *Opuntia* cladode dry matter content on body weight loss of "Merino" sheep

Cladode treatment	Dry matter intake (g/animal/day)	Weight loss (kg/animal/week)
Fresh	345.7	0.620
Intermediate	396.1	0.510
Dehydrated	507.1	0.230

Source: Terblanche *et al.*, 1971

Terblanche *et al.* (1971) studied the influence of a diet based exclusively on opuntia on the weight loss of Merino sheep using fresh (10% dry matter), dried (27% dry matter) and dehydrated cladodes (87.9% dry matter). The last treatment represented the best option (Table 5).

Other animals

In northern Mexico, goats browse freely and feed on *Opuntia* all year round, but rely more on the cactus from late autumn to late spring. Daily consumption ranges from 3 to 9 kg/day in the open field, and up to 11 kg when they are housed.

Open browsing, singeing *in situ*, and cladode collection are the methods of opuntia utilization, as for cattle.

The most commonly used species to feed goats in northern Mexico include *O. leucotricha, O. streptacantha, O. robusta, O. cantabrigiensis, O. rastrera, O. lindheimeri, O. imbricata, O. microdasys* and *O. leptocaulis*. All of these species used as forage sources have abundant spines, which are hard, large and have abundant glochids (*ahuates*), which can cause serious problems to eyes and mouth of domestic animals feeding on them.

Opuntia is extremely important for wildlife, probably even more than for domestic animals, supporting the rich fauna of the Chihuahua desert.

PROBLEMS AND PERSPECTIVES

The recent droughts in northern Mexico have resulted in the loss of more than 200 000 animals, and consequently the demand for opuntia is rapidly increasing. A few decades ago, opuntia was collected at distances up to 20 km away from urban areas, while now it is necessary to transport plants from distances exceeding 100 km (Marroquin *et al*., 1964).

Production systems practised today destroy vegetation and accelerate the desertification process, representing a serious danger to the native flora and fauna of northern Mexico. Therefore, it is very important to implement re-vegetation projects that include several important native species, such as *Opuntia, Agave, Prosopis, Acacia, Mimosa* and others.

OPUNTIA AS FODDER IN THE SEMI-ARID NORTHEAST OF BRAZIL

Djalma Cordeiro dos Santos and Severino Gonzaga de Albuquerque

INTRODUCTION

The history of the introduction of fodder opuntia into Brazil is a much debated topic, but probably it was introduced in the 18th Century, from the Canary Islands, to raise the cochineal insect (*Dactilopius cacti* L.) for dye production (Pessoa, 1967). After losing competitiveness, dye production died out, and both species of opuntia (*Opuntia ficus-indica* (L.) Miller and *Nopalea cochenillifera* Salm-Dyck) became ornamental plants. The use of opuntia as fodder in the semi-arid areas of northeast Brazil occurred only at the beginning of the twentieth century. The introduction of varieties bred in USA by the American geneticist Luther Burbank (Hardwood, 1930) is also controversial (Domingues, 1963). Opuntia was used as fodder after 1915 (Pessoa, 1967) and due to the great 1932 drought, the federal government established many propagation plots (Duque, 1973) that provided the stock for the dissemination of the species in the northeast.

Opuntia is cultivated in the semi-arid northeast, mainly by the dairy cattle ranchers, and the largest cropping areas are found in the States of Alagoas, Pernambuco and Paraíba. According to Corrêia (1986) and Timbau (1987), ca. 400 000 ha of opuntia were being grown in the northeast. To understand opuntia distribution, it is necessary to know the physiographic zones of the region, which in the State of Rio Grande do Norte and in the states cited above are defined in terms of rainfall, forming three large areas: the Mata, Agreste and Sertão zones (Figure 3). In the States of Rio Grande do Norte and Paraíba, there are zones with other names, such as Seridó and Cariri, that form part of Sertão. More detailed descriptions are available, e.g. Silva *et al.* (1992). However, to facilitate understanding, this zonation – which is also used in popular communication – will be maintained.

In the Mata zone there are two factors important to agriculture, namely high precipitation (over 1 400 mm annually), and fertile soils. This region has been, since colonization, dedicated to sugar cane. The Agreste zone is located towards the interior, in the Borborema Highlands, with annual precipitation around 700 mm, distributed irregularly but concentrated in the period March to August (which is the season of least evapotranspiration), with mild night temperatures. The Sertão zone has higher temperatures, and the rains occur during the hottest months. In the Agreste zone, as well as in the Sertão zone, the dry season is long, lasting six to seven months and seven to eight months, respectively, with severe droughts every 10 or 11 years. In the Agreste zone, the landholdings are smaller, ca. 40 ha in size, and more involved in dairy production. Felker (1995) reported that in the northeast, about every 10 km there was a 2- to 10-ha opuntia plantation, but in Agreste this occurs every 1-1.2 km, representing the largest cultivated area of opuntia in the world. In recent years, opuntia plantations have increased in most of the northeast states. The authors estimate that the actual total area covers about 500 000 ha.

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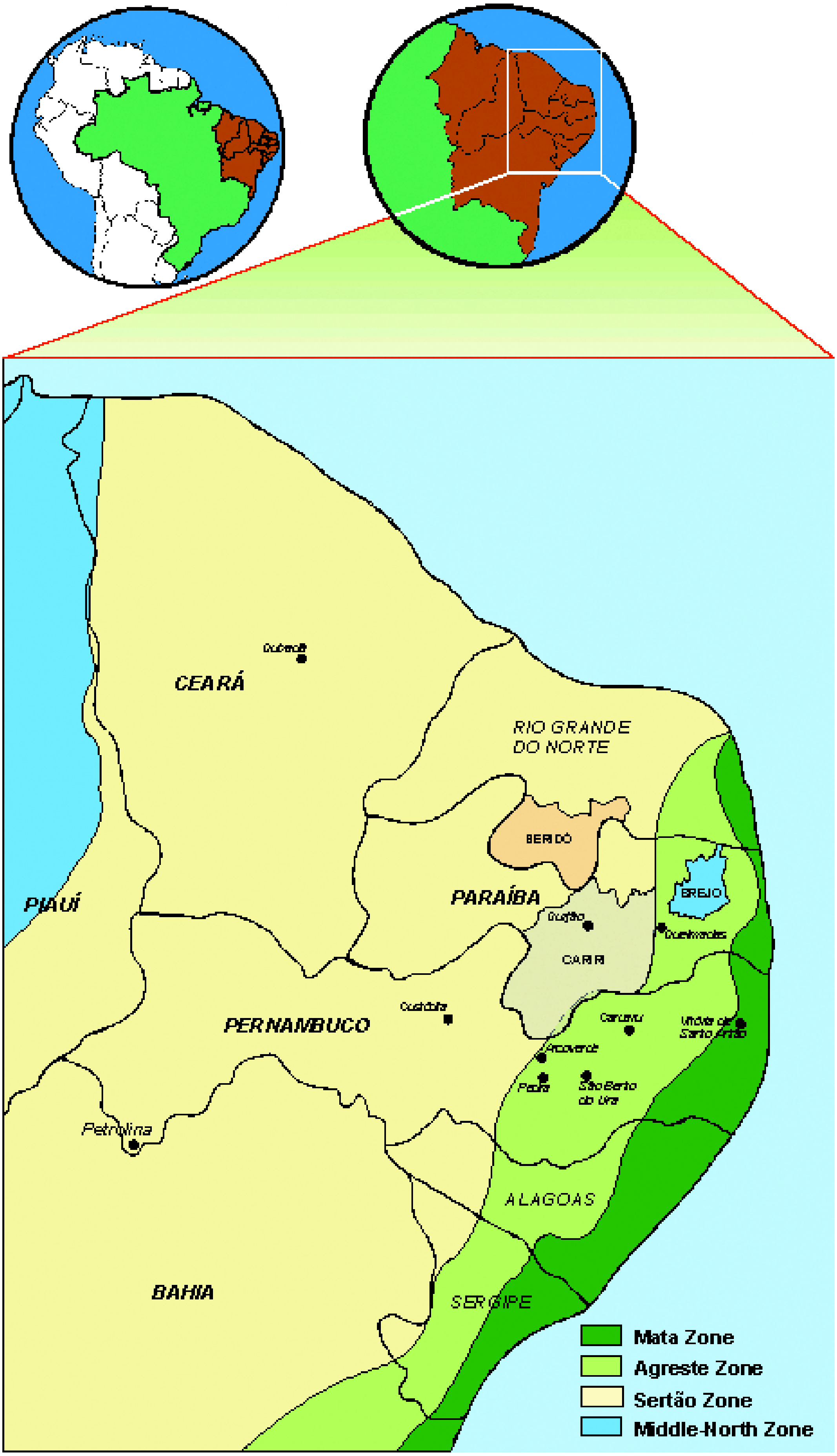

Figure 3. The agroclimatic zones of eastern Brazil

The regional variation in precipitation, ranging from 300 to 750 mm/yr, with irregular seasonal distribution, has not limited the establishment of this fodder plant, with its Crassulacean Acid Metabolism (CAM) photosynthesis, which allows highly efficient water use compared to other C_3 and C_4 fodder plants.

CHARACTERIZATION OF LIVESTOCK PRODUCTION SYSTEMS

In the period 1965 to 2000, some important factors have affected agriculture in the semi-arid northeast, including:

(1) Some cash crops lost economic competitiveness, and were retired from cultivation, like perennial cotton (*Gossypium hirsutum* L. var. *marie-galante*), annual cotton (*G. herbaceum* L.), sisal (*Agave sisalana* Perr.), and castor bean (*Ricinus communis* L.).

(2) Some social security regulations were extended to cover rural workers, and labour became very expensive.

(3) Probably as a result of the labour expense, there has been an intense exodus from rural zones to urban areas and other regions. Currently, only about 32% of the population of the semi-arid region lives in the countryside. At the same time, studies have shown that alternatives crops (represented by subsistence crops such as maize (*Zea mays* L.), beans (*Phaseolus vulgaris* L.) and cowpea (*Vigna unguiculata* (L.) Walp.)), were not attractive options because the probability of profitable yields was only 20%. Due to these facts, livestock rearing became the main activity in the semi-arid northeast, although its contribution to GNP is still very low.

Animal husbandry in the semi-arid regions is dual-purpose: milk and beef, although near to metropolitan centres, the proportion of Holstein in crossing increases. In some situations it becomes exclusively dairy oriented and the cow is milked without the calf. The most important opuntia production zones are Paraíba Agreste, Cariri, Pernambuco and Alagoas Agreste. Most of the pastures in Agreste are native, based on the annual grass *Brachiaria plantaginea* at the beginning of the rainy season and on the perennial grass *Chloris orthonoton* Doell. in the following months. These two grasses emerge after woodland clearing. Pangolagrass (*Digitaria decumbens* Stent.) had in the 1960s a certain adoption, but in years of below average precipitation it tended to disappear, and it was replaced by *D. pentzii*, buffelgrass (*Cenchrus ciliaris* L.) and *Urochloa mosambicensis* (Hack.) Dandy. In the Cariri zone, pastures are based on *caatinga*, a thorny deciduous dry woodland.

Opuntia is generally planted in January-February, before the onset of the rainy season, although in Alagoas some farmers plant it at the end of the rainy season, to have it established before the next growing season. Harvests are determined by need, but they are never performed annually. Transportation to yards is done variously using mules and oxen harnessed with “hooks” made of tree branches, while others use trucks and tractors. Some farmers chop it with knives, whereas others use the combined forage chopper machine. A fodder chopper was designed at the start of the 1960s: it has two inlets, one for grasses and similar material, and the other for opuntia. Chopped material is spread into the trough using baskets, ox-carts, or chopped directly into the troughs, which are generally roofed.

Aware of opuntia’s deficiencies when fed as sole fodder, farmers have adopted sorghum silage as an integral part of livestock production systems (Melo *et al*., 1992).

Planting density

The first publications on opuntia (e.g. Silva, 1931; Cesar, 1932) contained information on cultivation and nutritive value, although they were not based on experimental results. Research started at Pernambuco Agricultural Research Institute (IPA) (Souza, 1963).The goal was to obtain information on various factors, such as density, evaluation of cultivars present in the region, organic fertilization, etc., based on a 3^3 design to study cultivar × density × manure rates. Similar studies were established in the following years (Souza, 1963; Metral, 1965; Lima *et al*., 1974a, b). Intercropping with sorghum (*Sorghum bicolor* (L.) Moench.) in Agreste was another factor included (Farias *et al.*, 1989). Albuquerque and Rao (1997) studied planting density and intercropping with sorghum and cowpea in Sertão.

Until the 1990s, research results did not indicate great advantages with opuntia populations above 10 000 plants/ha (Table 6), except in Farias *et al.* (1986). In contrast, the use of wide spacing was more attractive to ranchers for intercropping and to facilitate weed control operations. Results of herbicide trials have not been satisfactory.

Table 6. Opuntia yield (fresh weight; t/ha) at various planting densities

Density ('000 plants/ha)					**Cultivar**	**Reference**
<10	**10**	**13 - 15**	**20**	**40**		
26.85	36.23		49.73		Three cvs.	Souza, 1963
52.55	75.61		78.50		Three cvs.	Souza, 1963
32.03	48.29	47.08	47.23		Redonda	Metral, 1965
21.98	32.82	39.60	50.50		Gigante	Metral, 1965
8.46	13.00	15.10	14.76		Miúda	Metral, 1965
14.88	20.38	22.36			Gigante + Miúda	Lima *et al.,* 1974a
14.66	18.51	19.22			Gigante + Miúda	Lima *et al.,* 1974a
21.51	22.56		25.00		Redonda + Miúda	Lima *et al.*, 1974b
19.00	19.13		21.98		Redonda + Miúda	Lima *et al.,* 1974b
28.37	52.13	66.87			Gigante	Farias *et al.,* 1986
41.84	53.32		70.21		Miúda	Santos *et al.,* 1996
3.78(1)	3.12(1)				Gigante	Albuquerque and Rao, 1997
4.00(1)	4.53(1)				Gigante	Farias *et al.* (undated).
			100.15	103.50	Miúda + IPA 20	Santos *et al.*, 1998a
			103.36	100.59	Miúda + IPA 20	Santos *et al.,* 1998a

Notes: (1) Data in dry weight (t/ha).

In this context, Santos *et al.* (1998a), working on opuntia with traditional spacing (5 000 plants/ha), found a Leaf Area Index (LAI) during harvest of 0.5, which was considered to be very low compared to 3 to 5 for forage plants (Peterson, cited by Zimer *et al.*, 1988). These results and the general trend of decreasing property size motivated the ranchers to adopt higher densities.

In 1995, there were numerous reports in Pernambuco (Corrêia, 1995; Castanha, 1995) of high-density opuntia plantings established in the Sertão zone (Custódia Municipality), supervised by C. Flores (Universidad Autónoma de Chapingo, Mexico). Densities ranged from 40 000 to 80 000 plants/ha, at a cost of ca. US$ 1 000/ha, including mineral fertilization. However, weeds became a serious problem, hand control was time consuming and expensive, and during the dry season there was great risk of fire.

Even though mineral fertilization had a significant effect on yield, other results were not consistent and it was concluded that a planting density of *ca.*10 000 plants/ha was adequate. IPA researchers established dense plantations of up to 40 000 plants/ha in Caruaru and Arcoverde municipalities, and initial yields of 135 t green matter (GM)/ha/year were reported in one bulletin (IPA, 1998) and at a field-day. Santos *et al.* (1998b) reported productivity of 15.7 and 12.9 t of dry matter (DM)/ha/year for IPA-Clone 20, and 10.7 and 15.0 t DM/ha/year for cv. Miúda, using 20 000 and 40 000 plants/ha, respectively. Based on results in Agreste zone, 40 000 plants/ha were recommended for biennial harvests. If plantings are expected to be harvested after three or more years, the authors recommend 20 000 plants/ha, but both densities can be combined: the higher density will be harvested biennially, whereas the lower density will be spared as a "live" (left growing in the field) strategic reserve for use during dry years.

For Sertão zone, Albuquerque and Rao (1997) recommended a density of 10 000 plants/ha, distributed in $3 \times 1 \times 0.5$ m spacing, i.e., pairs of rows (1 m apart), separated by 3 m alleys. With 20 t/ha systematic biennial manure fertilization, probably an adequate density lies between 15 000 and 20 000 plants/ha; four jointed lines result in a density of ca. 17 000 plants/ha. Opuntia production costs can be reduced by mechanizing weed control, manure spreading and opuntia transportation to the trough. Therefore, a 3 to 3.2 m alley spacing is very important.

Crop management

Fertilization is a intensively studied factor, using cattle manure as the main source of organic fertilizer. Data in Table 7 show that productivity is almost doubled by applying 20 t/ha of cattle manure every second year. It must be noted that this amount is not readily available in ranch yards, and unfortunately small-scale ranchers do not value the manure enough for its fertilizer value, giving it away or selling it at low prices to vegetable growers. Manure is used in other countries, such as North Africa (Monjauze and Le Houérou, 1965), USA (Gregory and Felker, 1992), in Chile for fruit production (Tironi-Compiano and Zuñiga-Oliver, 1983), and in Mexico (Mondragón and Pimienta, 1990). Carneiro and Viana (1992) found that highest efficiency occurs when it is spread in furrows before planting.

Studies on opuntia response to N and P started in 1957, and responses to N and P were reported by Souza (1963). Metral (1965), working in the northeast, also found significant responses to N and P, but not to potassium (K). Lima *et al.* (1974c) found N response up to 100 kg/ha, whereas P response was observed up to 50 kg P_2O_5/ha. Santos *et al*. (1996) recorded 30% increase in opuntia production in S.B. do Una, using 50-50-50 kg/ha/year of N-P_2O_5-K_2O. These results contrast with those of González (1989), working with *O. lindheimeri* Engelm in USA, who found a response to N-P_2O_5-K_2O at a rate of 224-112-0 kg/ha/ year.

Table 7. Effect of manure fertilization on the yield of forage opuntia

Yield (t FW/ha) at manure rates of			**Manure source**	**Cultivar**	**Reference**
0 t/ha	10 t/ha	20 t/ha			
14.75	33.10	41.05	Not specified	Three cvs.	Souza, 1963
35.49	43.24	57.65	Not specified	Three cvs.	Souza, 1963
27.35	31.67	41.10	Cattle	Gigante	Araújo *et al.,* 1974a
27.35	27.85	34.77	Goats	Gigante	Araújo *et al.,* 1974a
1.25$^{(1)}$		2.86$^{(1)}$	Cattle	Gigante	Carneiro and Viana, 1992
50.25	96.99		Cattle	Gigante	Santos *et al.,* 1996

Notes: (1) Data in dry weight (t DW/ha).

Soil preparation

In areas already cultivated in Agreste zone, soil preparation is done before the rains, starting with ploughing and furrowing, followed by manure spreading (20 t/ha) in the furrows. Rigorous selection of planting material is needed. Large and healthy cladodes ensure a high number of active buds. It is usually recommended to plant cladodes facing north-south, assuming a higher rooting rate. However, Becerra-Rodríguez *et al.* (1976) reported a higher productivity if cladodes were planted facing east-west. Light intensity in Mexico is lower than in northeast Brazil.

Intercropping is a way to increase land use efficiency. For annual crops, it has been studied worldwide, but few studies have been conducted with opuntia. In two places in Ceará State (SUDENE, 1972), various crops were intercropped with perennial cotton (*Gossypium hirsutum* L. var. *Marie-Galante*), and opuntia promoted an additional net income of ca. 31% compared to cotton as sole crop. Albuquerque and Rao (1997) found that cowpea decreased opuntia production by 40% in the first triennial harvest, but in the second harvest, there was an increase of 20%, giving a final decrease of 20% in the mean of two harvests. The legume grain helped to compensate for the weed control costs. Intercropping with grain sorghum reduced opuntia production by 40%, but crop residues compensated for the loss of fodder from opuntia.

The recommended practice of planting four opuntia lines, followed by a 3-3.2 m lane, besides the additional advantages of allowing a more efficient use of machinery, leaves space for intercropping with annual crops such as maize (*Zea mays* L.), sorghum or cowpea.

Cutting height

The cladode denomination proposed by Santos *et al.* (1990a) uses "base cladode" (the one that was planted); 1st order cladode; 2nd order cladode; and so on. Silva *et al.* (1974) found that leaving all 2nd order cladodes on each plant, nopalera recuperation was faster, and productivity more constant through the harvests. In contrast, much fodder is left on field when 2nd order cladodes are spared. So the authors recommend leaving all 1st order cladodes, and for each plant, to leave only one 2nd order cladode. By doing so, nopalera recuperation is reasonably fast, while less fodder is left on field. Leaving only 1st order cladodes is an option that must also be considered. Cuttings should be done on the joints, although Carneiro *et al.* (1989) found higher sprouting number when cuttings were done away from the joints. However, this results in plants with awkward architecture that will make future cutting more difficult, and a larger wounded surface which might facilitate pathogen entry.

Species comparison

Opuntia is represented in Northeastern Brazil by three varieties, which from now on will be referred to as cultivars, namely cv. Gigante, cv. Redonda (both *O. ficus-indica*), and cv. Miúda (*N. cochenillifera*), although in Gregory and Felker (1992), cv. Miúda is considered to be *O. cochenillifera*. Cvs Gigante and Redonda are cultivated in drier zones and on poor soils, whereas Miúda grows in more humid areas with better soils.

Excluding results obtained in V.S. Antão municipality, Gigante and Redonda had higher productivity than Miúda (Table 8). However, data for GM and DM content of Miúda indicate higher values than for the other two cultivars: 16.56% versus 10.39% (Santos *et al.,* 1990b). Another fact caught the attention of researchers, namely that cows lost less weight when fed with Miúda compared to the other cultivars, as reported by Santos *et al.* (1990b), representing a research priority for drier areas. Santos (1992) compared ten cultivars: there were no differences in DM production (P>0.05) among Gigante, Redonda and Miúda, although protein content was higher in Miúda. The author concluded that it is feasible to increase opuntia productivity and possibly protein content through genetic breeding. Santos *et al.* (1998a, b) conducted research in Arcoverde and S.B. do Una, finding similar results (Table 8) among the three cultivars as well as IPA-Clone 20. In the S.B. do Una work, yields of Miúda and Gigante were 8.64 and 7.82 t DM/ha/year, respectively.

Table 8. Productivity of opuntia cultivars

Cultivar and yield (t GM/ha)				**Reference**
Gigante	Redonda	Miúda	IPA Clone 20	
33.35	36.22	37.40		Souza, 1963
35.94	38.62	19.24		Souza, 1963
34.92	38.05	22.40		Araújo *et al.,* 1974b
21.84		16.58		Lima *et al.,* 1974a
20.20		14.74		Lima *et al.,* 1974a
	36.00 a(1)	27.86 b		Lima *et al.,* 1974b
	33.48 a	21.38 b		Lima *et al.,* 1974b
25.06	22.44	18.09		Alves, 1976.
7.82 a	10.07 a	8.64 a	11.95 a	Santos *et al.,* 1998a(2)
		12.62 a	14.12 a	Santos *et al.,* 1998b(2)

Notes: (1) Means with same letters in the same line do not differ (P<0.05). (2) Values expressed as DM.

In 1985 an opuntia breeding programme was initiated at IPA, using seeds from open pollinated cv. Gigante to generate 85 clones, which were integrated with another 17 clones from other places to establish a variety trial. In 1995, results indicated that IPA-Clone 20 was superior, producing 50% more than Gigante, the cultivar most cultivated in the northeast. The germplasm collection programme continued, with other genetic material brought from Algeria, Mexico, South Africa, USA, etc. New clones have been added, and the genebank at IPA now holds 1 400 clones. New material is now under trial in other northeastern states, such as Piauí, Ceará, Rio Grande do Norte, Paraíba, Alagoas, Sergipe and Bahia. Thus, with exception of Maranhão, in which there are no semi-arid lands, research is under way in all northeastern states.

Environmental constraints

The world's largest areas of cultivated opuntia are in the semi-arid northeast of Brazil, with *O. ficus-indica* predominating. It is a region with an annual average rainfall of 600 mm, not so limiting when compared to other semi-arid regions. However, rainfall is very variable (with a coefficient of variation (CV) of over 30%), and potential evaporation can reach *ca*. 2 600 mm, as in Bebedouro Experimental Field (Amorim Neto, 1989). According to Nobel (1995), the ideal day/night temperatures for opuntia are 25/15°C. There is no such night temperature in the northeast, but the zones with the largest concentration of opuntia areas are precisely Agreste-Cariri in Paraíba, Agreste in Pernambuco, and Agreste in Alagoas. In these regions, annual rainfall varies from 300 to 700 mm, irregularly distributed during the year, but this has not been a barrier to opuntia development. In these zones, the annual mean minimum temperature is *ca*. 18°C and the rains occur in the coolest months, when minimum temperature is around 14°C. Cooler temperatures and lower evaporation allows better use of soil moisture. In places having a minimum temperature of 18.1°C, such as S.B. do Una, Caruaru and Arcoverde, with rains occurring during the coolest months, opuntia is more productive and healthier than in Petrolina, where the minimum temperature is 20.4°C, and rains occur in the hottest months. These climatic conditions might explain the immense opuntia area in the semi-arid northeast. At the same time, in some zones, such as Seridó, opuntia is not grown because of the high day/night temperature.

A technical cooperation agreement was signed between IPA and Universidad Autónoma de Chapingo, and as a result a large number of clones were introduced, and C. Flores has indicated (pers. comm.) that among them there are clones adequate for Seridó, and some of them are already on test in that zone.

Shading by mesquite (*Prosopis juliflora*)

To help solve the opuntia high-temperature problem in the Sertão zone of the northeast, it was hypothesized that shading by mesquite could create a micro-environment inside the nopalera, and help increase production. Coelho and Godoi (1964) found that shaded opuntia became more turgid, but there was no production increase. Alves (1976) in Paraíba Cariri – a zone with high day temperature but cool (18°C) nights – found that shading gave a 56% increase in production from cv. Miúda. With cv. Gigante, the 18% increase promoted by shading was not significant. Mesquite trees planted at 15 × 15 m (44.4 plants/ha) do not provide the necessary shading effect, but the fence pole and vine yield that might result could justify such intercropping (Table 9).

Table 9. Opuntia productivity (two triennial harvests) under mesquite shade, number of mesquite trees/ha, and cover

Mesquite spacing	Productivity (Dec. 1982 to-Dec. 1988) (kg DM/ha/year)	Percentage cover	
		July 1988	June 1996
5 × 5 m	848.3	69.0	82.4
7 × 7 m	754.3	49.9	75.1
10 × 10 m	1 102.8	41.5	64.8
12 × 12 m	1 136.5	31.3	67.8
No mesquite	1 145.9	–	–

Source: Albuquerque, 1999.

Pests and diseases

The armoured scale insect (*Diaspis echinocacti* Bouché), also known as "mould" or "louse" (in Portuguese, *mofo* or *piolho*, respectively) is the most important insect attacking opuntia in the northeast. It covers the pads with its colonies; juvenile and adult individuals suck the pads. Juveniles cause chlorosis, followed by rotting and death of the plant. The attack is more severe in drier years in poorly managed plantations. This pest was first seen in Pernambuco in the 1960s, and since then IPA researchers have developed biological control in Caruaru, S.B. do Una, Arcoverde and Pedra. Integrated control is the most efficient way to combat the insect.

For integrated control, various natural enemies have been identified in the region, parasitoids as well as predators. The parasitoids are little wasps (Hymenoptera) that parasitize the armoured scale insect. The main parasitoid species are *Plagiomerus cyaneus* (Encyrtidae) and *Prospaltella aurantii* (Aphelinidae). Lady-beetles [ladybirds; lady bugs] (Colleoptera, Coccinellidae) are the main predators feeding on the armoured scale insect. The main predator species are little black lady-beetle (*Coccidophilus citricola*), yellow-and-black lady-beetle (*Chilocarus* sp.) and brown lady-beetle (*Pentilia* sp.). These predators can be reared in cages and distributed over infested opuntia fields.

Chemical control practices need to avoid killing the pest's natural enemies. Mineral oil at 1 to 1.5% in water is recommended (Longo and Rapisarda, 1995), as well as solid soap plus twisted dried tobacco (100g each, soaked in 20 litre of water for 12 hours). Observations of the co-author and information from technicians of Pernambuco Agricultural Extension Service (EMATER-PE) indicate that the combination of common salt (1 kg per 20 litre of water) plus mineral oil (1%) gives optimal results.

Opuntia diseases have been little studied, and they are described only in terms of occurrence, symptomatology and pathogenicity. The main diseases reported in Pernambuco and Alagoas are: cladode rot caused by various fungi (*Lasiodiplodia theobromae*, *Sclerotium rolfsii*, *Scytalidium lignicola*, *Fusarium solani*, *Rhizoctonia solani*, *Macrophomina* sp. and *Pollacia* sp.). *Pollacia* sp. was reported by Franco and Ponte (1980). Of bacterial diseases, only soft rot (*Erwinia* sp.) has been reported. These diseases currently do not cause severe damage to the crop, probably due to the traditional cropping system in the northeast. However, crop expansion and dense plantings might contribute to higher incidences and severity of diseases. There are no effective control measures, except planting in the dry season before the onset of the rainy season to avoid rot in the cuttings.

Weed control

Weed control is the main factor influencing opuntia production costs. In USA, Felker and Russell (1988) tested herbicides on 30 clones and found a ninefold increase in opuntia production with Hexazinone (8 kg/ha) compared to the control. In northeast Brazil, very little research has been conducted on herbicides. Farias *et al.* (1989), in Caruaru and S.B. do Una, found that post-emergence herbicides did not have satisfactory effects and induced burning of opuntia buds. Three pre-emergent herbicides (Terbuthiuron, Diuron and Ametryne) were effective and did not damage opuntia. Glyphosate, however, was phytotoxic.

Economic evaluation

Opuntia is vital to cattle raising in the semi-arid northeast, mainly during prolonged droughts. However, it is an expensive fodder, being produced at an estimated cost of US$ 0.05/kg DM. In S.B. do Una, with a strong tradition of dairy cattle production based on opuntia growing, 32% of landholdings are covered with opuntia (Chagas, 1992), and forage prices can rise up to US$ 2 200/ha. In dry years, for regular opuntia trading in the dairy basins of Pernambuco and Alagoas, the price is around US$ 600/ha. Price also varies according to season and volume available. In the same regions, the price of milk is about US$ 0.16/litre. The estimated costs of establishing, maintaining and harvesting during a six-year period are given in Tables 10 to 14.

Table 10. Cost of establishment of 1 ha of opuntia at four spacings

Parameter	**Cost** (US$/ha)(1)			
	2 × 1 m	1 × 0.50 m	1 × 0.25 m	3 × 1 × 0.50 m
Soil preparation	26.32	26.32	31.58	31.58
Opuntia cuttings + transportation	36.84	131.58	263.16	63.16
Organic fertilization	131.58	131.58	131.58	131.58
Phosphorus fertilization	52.63	52.63	52.63	52.63
Weed control (herbicides)	84.21	84.21	84.21	84.21
Planting	47.37	89.47	136.84	52.63
Total	**378.95**	**515.79**	**700.00**	**415.79**

Note: (1) US$ 1 = reais 1.90 on 30 August 1999.

Table 11. Cost of establishing and maintenance of 1 ha of opuntia in the first two years at four spacings

Parameter	**Cost** (US$/ha)			
	2 × 1 m	1 × 05 m	1 × 0.25 m	3 × 1 × 0.5 m
Soil preparation(1)	26.32	26.32	26.32	26.32
Opuntia cuttings	41.45	165.79	331.58	82.89
Organic fertilization	108.95	108.95	108.95	108.95
Phosphorus fertilization	52.63	52.63	52.63	52.63
Planting	47.37	89.47	136.84	52.63
Weed control	337.37	373.16	568.95	262.11
Total	**614.08**	**816.32**	**1225.26**	**585.53**

Note: (1) Ploughing + furrowing

Table 12. Production cost of 1 ha of opuntia during the first two years, at four spacings

Parameter	**Estimated cost** (US$/ha)			
	2 × 1 m	1 × 0.5 m	1 × 0.25 m	3 × 1 × 0.5 m
50% of establishment cost	189.47	257.89	350.00	207.89
Interest	45.26	76.32	104.21	50.00
Subtotal	**234.74**	**334.21**	**454.21**	**257.89**
Harvest	263.16	394.74	526.32	236.84
Total cost	**497.90**	**728.95**	**980.53**	**494.73**

Table 13. Estimated cost of maintenance of 1 ha of opuntia in the 3rd and 4th years, at four spacings

Parameter	**Estimated Cost** (US$/ha)			
	2 × 1 m	1 × 0.5 m	1 × 0.25 m	3 × 1 × 0.5 m
Planting (including interest)	117.37	160.00	216.84	128.95
Fertilizer – acquisition	78.95	78.95	78.95	78.95
Fertilizer – spreading	6.32	9.47	12.63	6.32
Weed control	94.74	102.63	126.32	94.74
Harvest	263.16	394.74	526.32	236.84
Total	**560.53**	**745.79**	**961.05**	**545.79**

Table 14. Estimated dry matter (DM) production cost during the first two years, at four spacings

Parameter	**Estimated cost** (US$/ha)			
	2 × 1 m	1 × 0.5 m	1 × 0.25 m	3 ×1 × 0.5 m
Total cost (US$/ha)	497.89	728.95	980.53	494.74
Production (t DM/ha)	10.0	15.0	20.0	9.0
Production cost (US$/kg DM)	**0.050**	**0.048**	**0.049**	**0.055**

NUTRITIVE VALUE STUDIES

Even though opuntia adoption was very intense in recent decades, until the late 1970s there was still some prejudice because of its high water content, and increasing use of pangolagrass (*Digitaria decumbens* Stent.) encouraged ranchers to abandon growing opuntia. However, the great 1979-83 drought proved that opuntia's high water content was vital to livestock raising. In Paraíba Cariri and in Pernambuco Agreste, in long-term droughts, the authors observed ranchers feeding opuntia in the trough all year round.

COMPARISON WITH OTHER FORAGES

This vital role of opuntia as a source of emergency water and forage for livestock raising compelled researchers to give higher priority to its nutritive value. IPA and Pernambuco Federal Rural University (UFRPE) have been the institutions most involved. In Arcoverde, Viana *et al.* (1966) compared opuntia to maize silage for steer fattening, mixing both forages with cassava roots, commercial concentrate, bone meal and mineral salts. They found differences (P<0.05) for liveweight (LW) gain only after 287 days of the trial, favouring silage, but no differences were detected (P>0.05) at 84 and 126 days. Daily intakes were 17, 19 and 19 kg for silage and 29.4, 27.3 and 35.1 kg for opuntia after 84, 126 and 287 days, respectively. Considering that the DM contents of silage and opuntia are *ca*.35.0% and 10.0% respectively, and that the steers were above 400 kg LW, the steers fed on opuntia consumed less DM than steers fed on silage in the last period, and consequently gained less weight.

Research with dairy cattle was initially reported by Santana *et al.* (1972), feeding lactating Holstein cows with maize silage versus opuntia cv. Gigante. No difference was found (P>0.05) in milk production and fat content. However, the cows had LW gains of 437, -465 and -230 g/day when fed on silage, opuntia and opuntia + 10 kg of silage, respectively. Lima *et al.* (1985) evaluated three levels of associations, i.e., 25, 50 and 75% of opuntia cv. Gigante versus sorghum silage, and concluded there was no difference among treatments for LW gain and milk production.

COMPARISON AMONG CULTIVARS

The next step was the comparison among the three major opuntia cultivars used in the northeast, where cattle raisers considered cv. Miúda as better for dairy production. A trial was undertaken involving Holstein cows in S.B. do Una (Santos *et al.*, 1990b), looking at DM, crude protein, crude fibre and mineral contents of three cultivars, sorghum silage and commercial concentrate (Table 15). Cv. Miúda was superior (P<0.05) to Redonda or Gigante in DM content, but inferior (P<0.05) in protein, fibre and minerals. The higher DM content of Miúda could reduce the problems associated with diets high in water content, as reported by Lima *et al.* (1981) and Farias *et al.* (1984). At the same time, data on protein and fibre suggest opuntia must be given in combination with other fodder to ensure higher protein and fibre intake.

Table 15. Dry matter (DM), crude protein (CP), crude fibre (CF) and mineral extract (MEx) contents (%) of three opuntia cultivars, sorghum silage, and commercial concentrate.

Feed	DM	CP	CF	MEx
Opuntia cv. Gigante	9.85 b	4.83 a	9.53 a	10.85 b
Opuntia cv. Redonda	10.93 b	4.21 a	8.62 a	12.02 a
Opuntia cv. Miúda	16.56 a	2.55 b	5.14 b	7.72 c
Sorghum silage	37.60	5.49	25.78	5.10
Commercial concentrate	80.66	24.57	3.63	8.2

Note: Means with same letters in the same column do not differ (Tukey; P<0.05)
Source: Santos *et al.,* 1990b.

Results for *in vitro* DM digestibility (IVDMD), dairy production, fat content and LW gain for opuntia, sorghum silage and concentrate intake and cultivars are presented in Table 16. GM intake was lower (P<0.05) in cv. Miúda, followed by sorghum silage and concentrate, due to its higher DM and soluble carbohydrate content. Regarding opuntia IVDMD, the mean of 75.5% for all cultivars indicates its value as a fodder plant. Cows in all treatments lost weight, which implies deficits in protein and energy ingestion (Gomide *et al.*, 1987). A lower LW loss in cows fed on cv. Miúda indicates that energy deficit was inferior, which might be explained by its twofold soluble carbohydrates content. Regarding dairy production and rate of DM consumed/milk produced, there was no difference (P>0.05) among cultivars.

It has been shown that Holstein cows lost weight when fed on opuntia cv. Gigante as the only fodder (Santana *et al.*, 1972) or when it comprises more than 73% of the fodder (Santos *et al*., 1990b). Rearing cross-bred cows (Holstein × Zebu), which are less demanding in their nutritional requirements, could be an alternative.

It was hypothesized that crossbred cows would lose less weight, even if opuntia makes up 73% of all fodder, with less concentrate intake. A trial was conducted in Arcoverde, in which Girolando cows (a cross-bred 3/8 Gir × 5/8 Holstein, resulting from crossing a Gir Zebu breed with Holstein) were fed on three opuntia cultivars, but there was no overall difference (P>0.05) among cultivars for dairy production (Table 17), although cows fed on cv. Miúda increased dairy production by 9% compared to cv. Redonda: 7.2 vs. 7.0 kg/cow/day. Zebu crossbreed cows were also involved, milking with calves left with the cow, allotting ca. 3 kg of milk/day to the calf. Considering the milk reserved for the calf, the authors estimate a daily production of ca. 10 kg/cow/day.

Table 16. Forage intake, milk production, dry matter (DM) consumed/milk produced, and liveweight gain of Holstein cows fed on three opuntia cultivars, and *in vitro* DM digestibility (IVDMD)

Parameter	**Cultivar**			**Mean**	**CV** (%)
	Redonda	Gigante	Miúda		
Opuntia intake (kg FW/cow/day)	62.30 a	66.30 a	46.72 b	**58.44**	13.55
Sorghum silage intake (kg FW/cow/day)	6.24 a	6.15 a	4.51 b	**5.63**	1622
Concentrate intake (kg/cow/day)	4.18 a	4.18 a	3.85 b	**4.07**	5.27
Total DM intake (kg/cow/day)	12.14 a	12.14 a	12.35 a	**12.18**	5.70
Opuntia IVDMD (%)	74.11 c	75.12 b	77.37 a	**75.53**	1.20
Milk yield (kg/cow/day)	12.44 a	12.36 a	12.27 a	**12.35**	6.20
Milk fat content (%)	3.15 a	3.11 a	3.17 a	**3.14**	6.60
4%-fat-corrected milk yield (kg/cow/day)	10.79 a	10.63 a	10.80 a	**10.74**	7.66
DM intake/milk yield proportion (kg/kg)	1.02 a	1.03 a	0.99 a	**1.01**	9.22
Liveweight gain (g/cow/day)	-565 a	-640 a	-77 a	**-**	141.08

Note: Means in same line with same letters do not differ (Tukey; P<0.05).
Source: Santos *et al*., 1990b.

Table 17. Milk production, fat content, density, dry extract, and rate of DM consumed/milk produced from Girolando cows fed on three opuntia cultivars.

Parameters	**Redonda**	**Gigante**	**Miúda**	**Mean**
Milk yield (kg/cow/day)	7.0 a	7.1 a	7.2 a	**7.1**
Milk fat content (%)	3.9 b	4.1 ab	4.2 a	**4.1**
4 %-fat-corrected milk yield (kg/cow/day)	6.8 a	7.2 a	7.4 a	**7.1**
Milk density	1.028 a	1.028 a	1.057 a	**1.037**
Milk total solids (%)	12.23 a	11.88 a	12.54 a	**12.21**
DM intake/milk yield proportion (kg/kg)	1.39 a	1.36 a	1.38 a	**1.37**

Note: Means with same letters in the same line do not differ (P<0.05; Tukey Test)
Source: D.C. dos Santos (unpublished data)

Table 18. Feed intake and liveweight gain of Girolando cows fed on three opuntia cultivars

Intake	Cultivar			Mean
	Redonda	Gigante	Miúda	
Opuntia (kg GM/cow/day)	53.64 a	53.13 a	55.87 a	**54.21**
Silage (kg GM/cow/day)	8.16 a	7.97 a	7.60 a	**7.91**
Concentrate (kg/cow/day)	1.00	1.00	1.00	**1.00**
Opuntia (kg DM/cow/day)	5.90 b	5.65 b	6.75 b	**6.10**
Silage (kg DM/cow/day)	2.09 a	2.07 a	1.95 a	**2.03**
Concentrate (kg DM/cow/day)	0.85 a	0.85 a	0.85 a	**0.85**
Total DM (kg/cow/day)	8.84	8.57	9.55	**8.98**
Liveweight gain (g/cow/day)	-323	-111	164	–

Note: Means with same letters in the same line do not differ ($P<0.05$; TukeyTest)
Source: D.C. dos Santos (unpublished data)

Table 19. Cow breed and opuntia cultivar influences on forage intake, milk yield and liveweight gain by lactating cows

Parameter	Breed	Opuntia cultivar		
		Redonda	Gigante	Miúda
Opuntia intake (kg DM/cow/day)	Holstein(1)	6.80	6.53	7.74
	Girolando(2)	5.90	5.65	6.75
Silage intake (kg DM/cow/day)	Holstein	2.35	2.45	1.69
	Girolando	2.09	2.07	1.95
Concentrate intake (kg DM/cow/day)	Holstein	3.37	3.37	3.11
	Girolando	0.85	0.85	0.85
4%-fat-corrected milk yield (kg/cow/day)	Holstein	10.8	10.6	10.8
	Girolando	6.8	7.2	7.4
Liveweight gain (g/cow/day)	Holstein	-565	-640	-77
	Girolando	-323	-111	164

Notes: (1) Data for Holstein cows from Santos *et al.*, 1990b.
(2) Data for Girolando cows from D.C. dos Santos (unpublished data)

Regarding feed intake, cv. Miúda was superior ($P<0.05$) to Redonda or Gigante (Table 18). Variations in liveweight gain indicate that, after a certain time, cv. Miúda would be superior to the other cultivars in dairy production. A comparative analysis between data of Santos *et al.* (1990b) with Holstein cows, and the author´s (not published) with Girolando cows show that they consume less concentrate, lose less weight, and apparently perform better in dairy production (Table 19). Therefore, Girolando cows could be fed mainly with opuntia cv. Miúda.

STORAGE EFFECT

The low DM content is not a barrier for opuntia to be considered an optimal fodder, but its water content makes handling expensive. Harvesting a large amount of opuntia, storing it near the trough and furnishing it in small batches could solve the problem. Table 20 shows the effect of post-harvest storage on chemical composition and DM content for three cultivars when piled up in 500-kg mounds and stored for 0, 4, 8, 12 and 16 days (Santos *et al.*, 1990c).

The results showed no storage effect for cv. Redonda ($P>0.05$) and only slight differences in fibre and carbohydrate contents in cv. Gigante, and in fibre and DM contents in cv. Miúda. DM contents were 15.9, 15.1 and 23.4% for Redonda, Gigante and Miúda respectively, considered high when compared to other results. However, it should be noted that opuntia DM content in the dry season varies according to the year.

A trial was conducted with Holstein cows to study the effect on animal performance of opuntia stored for 0, 8 and 16 days. Results showed that there was no storage effect (Tables 20 and 21) and thus little variation in opuntia chemical composition during storage. This is very important, as it implies that large amounts can be harvested at once, decreasing harvest and transport costs.

In this trial, opuntia as well as maize silage were fed *ad libitum*, and there was no difference in opuntia intake among storage periods. It is important to note that cows consumed up to 104 kg GM/day. The high palatability and DM digestibility and low DM content compels animals to consume a large amount. These factors, combined with its low fibre content and high calcium and phosphorus levels, induce nutritional disequilibrium: a probable cause of the diarrhoea common in animals fed with large quantities of opuntia, as occurred in this research. Santos *et al.* (1990b) state that to overcome this problem, opuntia should not exceed 40% of total feed DM.

Mean DM consumption equivalent to 2.68% of LW for cows fed on opuntia stored for three different periods might be considered low, since recommended feeding levels lie between 3 and 4% for lactating cows. Protein consumption might also be considered low, according to NRC standards (NRC, 1968). LW gain during the experimental period was -0.13, 131.03 and -87.21 g/day for cows fed on opuntia stored for 0, 8 and 16 days, respectively. These data indicate large variation among treatments, and should be disregarded due to the short trial period (21 days) and the fact that the cows were not fasted before weighing. However, the weight losses are in agreement with Santana *et al.* (1972) and Santos *et al.* (1990b). Dairy production and fat content of cows fed with opuntia for different storage periods were similar ($P<0.05$). Santana *et al.* (1972) and Santos *et al.* (1990b) obtained similar results.

To demonstrate that opuntia must be mixed with other fodder, a trial was conducted in Arcoverde by Estolano (unpub. data) to verify which fodder would combine the best with opuntia cv. Gigante fed to lactating Girolando cows. He found sorghum silage, sucrose, *in natura* sugar cane bagasse, and hydrolyzed sugar cane bagasse affect neither DM intake nor milk fat content. Cows fed with sorghum silage had higher dairy yield than those consuming hydrolyzed bagasse. Cows fed with opuntia plus *in natura* bagasse produced 13.6 kg milk/day, showing its suitability for dairy enterprises. Sugar cane bagasse is a by-product of sugar factories in Pernambuco and Alagoas Mata Zone, and it is sold by the factories at the low price of US$ 4/tonne.

According to overall results from IPA/UFRPE, opuntia must be complemented with other forages having high DM and fibre contents. A study of carbohydrates and minerals present in opuntia should help us to better understand the causes of diarrhoea.

Opuntia is mostly grown in the northeast for dairy cattle, but is also utilized for other ruminants, such as goats and sheep, during the dry season. Cunha (1996), in a nutritional study with sheep, found that when opuntia was associated with napier grass (*Pennisetum purpureum* Schumach.), the addition of fibre affected neither apparent digestibility nor nutrient digestion, and there was no difference in rumen pH ($P>0.05$).

FINAL CONSIDERATIONS

* Opuntia is the only forage that can be stored "live" as it keeps growing in the field without losing nutritive value, even though it has low DM and protein contents. Droughts have proved that it is a vital fodder to the region.
* It is an expensive forage because establishment, weed control and transportation to yards requires high labour inputs, but herbicides and mechanization might decrease production costs.
* Opuntia is deficient in protein, but at the same time is rich in soluble carbohydrates, and its DM digestibility is above 70%. Diarrhoea is a problem that might be related to high levels of some minerals, but further research is needed in this area.
* Appropriate cultivars for the various ecological zones, including those in which opuntia is not currently, grown could be obtained through genetic improvement. Cultivars resistant to armoured scale insect are also needed.

* The use of opuntia with sugar cane bagasse has been shown to be viable in Alagoas and Pernambuco Agreste Zone.

Table 20. Dry matter (DM), crude protein (CP), crude fibre (CF) and soluble carbohydrate (SCH) contents (%) of opuntia after various storage periods

Storage (days)	DM	CP	CF	SCH
Redonda				
0 (no storage)	15.35 a	3.51 a	14.53 a	27.95 a
4	15.18 a	3.65 a	12.88 a	30.86 a
8	17.63 a	3.86 a	13.45 a	29.58 a
12	15.18 a	3.58 a	13.15 a	28.25 a
16	16.12 a	3.71 a	14.18 a	29.10 a
Mean	**15.89**	**3.66**	**13.64**	**29.15**
CV (%)	11.95	13.79	10.70	12.38
Gigante				
0 (no storage)	13.79 a	3.91 a	16.58 a	26.16 b
4	14.61 a	4.08 a	12.90 b	32.96 a
8	17.02 a	5.14 a	13.29 b	29.53 ab
12	14.74 a	4.01 a	13.19 b	29.37 ab
16	15.32 a	4.12 a	13.42 b	29.68 ab
Mean	**15.10**	**4.05**	**13.88**	**29.54**
CV (%)	11.26	10.29	9.75	10.22
Mìuda				
0 (no storage)	22.49 b	2.25 a	12.34 a	56.63 a
4	22.80 b	2.23 a	9.87 ab	57.38 a
8	23.71 ab	2.23 a	11.90 ab	58.85 a
12	24.19 a	2.20 a	9.65 b	57.66 a
16	23.76 ab	2.14 a	10.87 ab	59.20 a
Mean	**23.39**	**2.21**	**10.93**	**57.94**
CV(%)	3.05	12.52	11.98	5.01

Note: Values with same letters in the same column do not differ significantly ($P<0.05$; Tukey Test).
Source: Santos *et al.*, 1990b.

Table 21. Dry matter (DM), crude protein (CP), mineral extract (MEx), fat extract (FE) and digestible non-nitrogen extract (DNNE) content (%) of opuntia cv. Gigante after three storage periods, and of maize silage and of concentrate.

Forage	DM	CP	MEx	FE	DNNE
Opuntia (no storage)	10.33	5.27	11.10	2.32	70.12
Opuntia (8 days of storage)	8.17	5.12	12.48	2.34	68.26
Opuntia (16 days of storage)	9.76	5.22	12.19	2.22	68.39
Maize silage	34.41	6.99	7.22	0.97	58.53
Commercial concentrate	82.97	26.37	10.99	2.19	52.68

Source: D.C. dos Santos (Unpublished data)

UTILIZATION OF *OPUNTIA* FOR FORAGE IN THE UNITED STATES OF AMERICA

Peter FELKER

INTRODUCTION

The literature on uses of opuntia in the USA is most colourful. During the Civil War (*ca* 1850), freighters loaded with cotton were pulled by oxen to the only safe port of export at the southern tip of Texas (Brownsville). The route passed through extensive stands of spiny opuntias. The teamsters scorched the cactus by burning with brush, and chopped or slashed it with an axe, spade or machete to feed their oxen (Griffiths, 1905). Because of the high water content of the cactus, the oxen needed to drink water only once weekly in winter, and two to three times weekly in summer.

In the early twentieth century, pressurized, backpack "white gasoline" pear burners were used in Texas to singe the spines from opuntia so that the cattle could eat it (Pluenneke, 1990). Kerosene became available in the 1930s and replaced white gasoline. In the 1950s, butane gas became available in Texas and was then used in single-backpack pear burners and in rigs with multiple hoses, supplied by large tanks in pick-up trucks.

As early as 1905, Griffiths (1905) reported that opuntia had been succesfully fed to dairy and beef cattle, oxen, sheep and pigs (extreme care being taken to remove all the spines), but not to horses. However, Argentine farmers state that when opuntia is fed to pregnant sows, they abort. Lukefarh and Ruiz (1998) recently conducted an opuntia feeding trial with rabbits and found that the Brazilian forage variety Palma Redonda had good palatability and also supported moderate weight gains.

Public opinion concerning the value of cactus for livestock varies considerably between the regions south and northwest of San Antonio, Texas. In southern Texas, opuntia is highly regarded as an emergency feed for livestock and as a mainstay for the wildlife population. North of San Antonio, where the rainfall is lower and where *Opuntia lindheimeri* is less abundant, cactus is less appreciated. In this region, sheep and goats begin eating first the fruits, then the cladodes without the spines being burned off. As a result, spines and glochids become lodged in their gastrointestinal tracts and bacterial infections of the lesions may follow (Merrill *et al.*, 1980; Migaki *et al*., 1969).

Spineless opuntia plantations in Texas must be very well protected against herbivores such as rabbits, rats, deer and peccaries, using a 2.4-m tall netwire fence with a 5-cm mesh band at the bottom. The adoption of portable electrical fences within these exclosures could permit stock to graze only one row of a spineless opuntia plantation at one time.

While spineless opuntia plantations require fencing, the spiny types do not. However, the spines must be singed off with a flame thrower (known as a "pear burner" in Texas) before the cladodes are fed to the livestock. Thus the flame thrower is a management tool that allows the rancher to decide when and how much of this resource to use at one time.

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A study in Texas measured all the water inputs to cactus and the corresponding dry matter production (Han and Felker, 1997). Of the 662 mm of rainfall input, 143 mm was lost to runoff, 214 mm was lost to soil evaporation, and 17 mm stored in the plant. The resulting 285 mm left for growth of *Opuntia ellisiana* resulted in 17 670 kg of dry weight/ha for a water use efficiency of 162 kg of water/kg of dry matter. This water use efficiency is greater than that measured in the field for any C_3 or C_4 plant and thus emphasizes the basic physiological advantage of CAM plants in arid regions. It is also significant that the fourth-year fresh weight growth of 194 200 kg/ha contained 170 000 kg/ha of water, that would greatly reduce the water needs for livestock in drought periods. At the rate of 45 kg fresh cactus per day (discussed later), this 194 200 kg/ha would be sufficient for 4 315 days (11.8 years) of feed per cow.

NUTRITIONAL PROPERTIES AND SUPPLEMENTATION REQUIREMENTS

The nutritional quality of forage cacti can be expected to exhibit considerable variation due to the age of the plant (Gregory and Felker, 1992), the season of the year (Retamal *et al*., 1987b) and the fertility of the soil (Gonzalez, 1989; Gathaara *et al*., 1989). Despite the considerable importance of opuntia to domestic stock and wildlife, there are only a few reports of the nutritional quality of opuntia in animal diets (Griffiths and Hare, 1906; Shoop *et al*., 1977; De Kock, 1980; Meyer and Brown, 1985; Retamal *et al*., 1987a). Typical values for nutritional components in these studies were found to be: moisture content, 85-90%; crude protein, 5-12%; phosphorus, 0.08-0.18%; calcium, 4.2%; potassium, 2.3%; magnesium, 1.4%; energy, 2.6 Mcal/kg; carotenoids 29 µg/100 g; and ascorbic acid, 13 mg/100 g. The *in vitro* digestibility values were 72% for protein, 62% for dry matter, 43% for crude fibre and 67% for organic matter.

Another significant advantage of cactus for animal feed is that it is often the only source of green forage in the dry season capable of providing vitamin A precursors. Rodríguez-Felix and Cantwell (1988) reported 29 µg of carotenoids and 13 mg of ascorbic acid per 100 g of immature cladodes to be used as vegetables for humans.

The only metabolizable energy and digestibility data for cactus are for wild opuntias in Texas and Colorado. Everitt and González (1981) found that, of all species examined, although *O. lindheimeri* had one of the lowest protein contents (6%), it had the highest dry matter digestibility (76%). Meyer and Brown (1985) also found that *O. lindheimeri* had higher digestibility throughout the year than the other plants in their south Texas study area.

Data on digestible energy and protein content of the small, low growing *O. polyacantha* on the ranges of Colorado may serve as a useful guide to other opuntia forage species (Shoop *et al*., 1977). While this opuntia was lower in crude protein (5.3%) than grassland hay (5.7%) or alfalfa hay (16.8%), its digestible energy of 2.61 Mcal/kg, compared favourably to grassland hay (2.08 Mcal/kg) or alfalfa (2.64 Mcal/kg). *O. polyacantha* had 85% as much neutral detergent fibre and 70% as much as acid detergent fibre as alfalfa, but it contain 55% more hemicellulose and 40% more soluble carbohydrates (Shoop *et al*., 1977). As might be expected due to the faster growth and less lignification, *O. ficus-indica* was found to have greater digestible energy values, ranging from 3.32 to 3.54 Mcal/kg (Retamal *et al*., 1987b).

While the amino acid profile of the opuntia stems is only useful for non-ruminant nutrition, Teles *et al.* (1984) found the amino acid profile of immature opuntia stems to have a biological value of 72, compared to hen egg protein of 100.

Texas rancher Bill Maltsberger has spent many years developing protein and mineral supplements for his herd of 800 Santa Gertrudis cattle on 4 000 ha of rangeland south of San Antonio. Although Maltsberger routinely supplemented cactus with cottonseed meal as a protein supplement and allowed the cattle free range, there was subtle evidence of nutritional disorders. After considerable post-mortem testing of organs for trace elements, it was found that the cattle were low in copper, molybdenum and zinc. On the basis of these analyses, Maltsberger began using the supplements shown in Tables 22 and 23. Regular vitamin E injections have been also helpful after many months on this cactus diet. When cattle were fed cactus that had had its spines burned off (as discussed later) and were supplemented with protein cubes and mineral supplements, excellent weight gain, body conformation and 90% conception rates were achieved. This supplementation also seemed to reduce the percentage of abnormalities in newborn calves.

Maltsberger (1993, pers. comm.) stressed that the mineral deficiencies in his animals were not directly caused by the cactus, but were a result of the fact that during droughts cattle often have no other source of minerals and vitamins than cactus. Thus in drought periods, when no other significant quantities of forage are available for many months, it is critical to address the issue of lack of proteins and minerals.

The protein ration in Table 22 is formulated in the form of 2-cm cubes, and only fed during drought periods when no other forage is available. The mineral supplement in Table 23 contains phosphorus and calcium in the form of meat and bone meal that is not contained in the protein supplement. This mineral supplement is made available all year round regardless of drought status.

While the feed rations have been optimized for cattle, it is reasonable to expect that these rations could be easily adapted to other ruminants such as goats, sheep and deer. There are very old reports of cactus being fed to pigs. However, well-replicated trials feeding cactus to non-ruminants like pigs have not been conducted. Lukefahr and Ciro-Ruiz (pers. comm.) have succesfully fed an opuntia strain (#1270) from Brazil (Palma Redonda) to rabbits. It is interesting that rabbits did not like the nopalito variety *O. cochellinifera* #1308, but they liked Brazilian forage variety #1270.

Table 22. Protein supplement for cattle during droughts.

Ingredient	Amount (kg)
Cottonseed meal	475
Soybean meal	450
Manganese sulphate	2.75
Zinc oxide	1.5
Copper sulphate	1.25
Vitamin E-20	3.125
Cobalt sulphate	0.080
Ethylenediamine dihydroxide (EDDI)	0.025
Selenium oxide mixture (0.02%)	0.0625
Vitamin A-30	0.45
Masonex (clay binder)	12.5
Molasses	53.25
Total	**1000**

Source: Data courtesy Bill Maltsberger, Rancher, Cotulla, Texas.

Table 23. Mineral supplement* for cattle for cactus supplementation

Ingredient	Amount (kg)
Bone meal	450
Meat and bone meal	150
Sodium chloride	300
Manganese sulphate	22
Zinc oxide	11.5
Copper sulfate	10
Vitamin E-20	25
Cobalt sulphate	0.625
Ethylenediamine dihydroxide (EDDI)	0.20
Selenium oxide mixture (0.02%)	0.50
Vitamin A-30	3.65
Molasses	26.5
Total	**1000**

Note: *The mineral supplement is fed all year long.

Source: Data courtesy of Bill Maltsberger, Rancher, Cotulla, Texas.

METHODS TO INCREASE THE PROTEIN CONTENT OF CACTUS FORAGE

Fortunately, there are several techniques to increase protein content of cactus forage to minimize the cost of protein supplementation. The first method is with N and P fertilizers, since González (1989) found that crude protein in *O. lindheimeri* increased from 4.5% for the zero fertility treatment to 10.5% for the treatment containing 224 kg N and 112 kg P/ha. This is especially important, since this fertilization treatment raised the protein content above the requirements for dry and lactating cattle, namely 6.0 and 9.25% respectively.

Since most commercial cactus fruit orchards receive N fertilization, it is reasonable to believe that the N content of the pads from these orchards would approach the 9% protein content level. Potgieter (1997 pers. comm.) in South Africa obtained 40 ton of pads from annual pruning of cactus fruit orchards, which could be a significant source of high protein forage for livestock.

Based on the 40 kg/ha consumption of pads per animal recommended by Maltsberger (Table 24), these annual prunings would provide approximately 3 animal-years of forage per hectare.

Table 24. Daily ration for adult cow with calf

Ingredient	**Amount** (kg)
Fresh cactus	40
Protein supplement	1.4
Mineral supplement	0.1

Source: Data courtesy of Bill Maltsberger, Rancher, Cotulla, Texas.

The second route to increased protein content of cactus forage is through the use of genetic selections containing higher protein. In a comparison of eight opuntia forage clones, Gregory and Felker (1992) found one Brazilian clone (#1270, i.e. cv. Palma Redonda) from CPATSA Petrolina, Brazil, that had over 11% protein content in all four age classes. In contrast, the Texas native opuntia had high protein in the youngest age class (11%), but only 5% protein in the three older age classes. Additionally, the Brazilian clone had four times the P content (i.e. 0.41%) of the native Texas clone.

Lastly, it is also possible that inoculation of cactus roots with the free living, nitrogen-fixing bacteria *Azospirillum* sp. could increase the protein content of the cladodes, since Rao and Venkateswarlu (1982), Caballero-Mellado (1990) and Mascarua-Esparza *et al.* (1988) found this bacterium could associate with opuntia roots. While these authors did not demonstrate N fixation from the *Azospirillum* in association with cactus roots, Mascarua-Esparza *et al.* (1988) did report a 34% increase in cactus root dry weight and a 63% increase in root N content with *Azospirillum* inoculation. *Azospirillum* inoculation may also help control the rotting of cladodes caused by *Erwinia* sp. that is often associated with new plantings, since laboratory culture studies have shown that *Azospirillum* inhibited the growth of both *Xanthomonas* and *Erwinia*.

PLANTING, CULTIVATION, FERTILIZATION AND CARE

The most common problem with new cactus plantings is rot of the plant material at the surface where it was cut or broken off. Cactus cladodes should either be dried in the shade for several days to allow the cut surface to "heal over," or the new cladodes treated with lime/copper sulphate solution to control bacterial rots. The soil should be ploughed and cultivated as for any other crop. Cladodes should be planted with about 1/3 of their height below the soil surface, with the flat cladode surface facing east-west.

During the initial growth stages, the growth of cactus can be severely retarded by grass and other herbaceous vegetation. Thus it is very important to provide good weed control until the cactus is well established. Pre-emergent herbicides, such as karmex, simazine and treflan all provide good weed control at rates of 2-4 kg/ha, without harming cactus. If no pre-emergence herbicide is available, it is essential to plant the cactus in an arrangement that permits easy and frequent mechanical weed control, such as disking. If a 2.5-m wide disk unit is available for weed control, it is recommended to plant the cactus on a 1 m × 4 m row spacing to allow easy access of the disk and tractor down the rows.

In Argentina, horses are admitted to the spineless cactus plantations as they will eat most forage but not the cactus. As discussed later, after the cacti reach a height of more than 1 m, livestock can be admitted at rates of 1 cow per hectare. At this time the cattle will consume both the grass (weeding the cactus) and the cactus, thus eliminating the need for weed control in the cactus.

Even unselected stock of the common *O. lindheimeri* can have high productivity with fertilization. For example, González (1989) examined eight fertilization treatments on the native *O. lindheimeri* over a four-year period in a zone with 430 mm/yr rainfall. The dry biomass productivity in this trial increased from 7 t/ha/year to 62 t/ha/year for the maximum N and P rate, i.e. 224 kg N and 112 kg P/ha. This productivity compares very favourably with other forage species. In addition to the increased yield, the crude protein in the cladodes increased from 4.5% to 10.5%. González (1989) recommended fertilizing cactus with 224 kg/ha N every 2 years to maintain crude protein levels at about 10%, with productivity in the 50 ton/ha/year range.

THORNLESS VERSUS THORNY CACTUS FORAGE VARIETIES

There are significant advantages to both thorny and thornless cactus varieties. Thornless varieties must be fenced to prevent cattle and wildlife from totally consuming plantings less than 2 years old. In Texas, deer, *javelina* (wild pigs) and rabbits will completely consume new plantings. In areas where deer are abundant, it is necessary to establish 2.2-m tall fences around the thornless cactus plantings. In contrast, thorny varieties do not have to be fenced, but the spines have to be burned off with propane torches before utilization. In Texas, by purchasing propane in large truck loads (40 000 litre/truck), it has been possible to purchase propane for US$ 0.11/litre. In a good stand of native *O. lindheimeri,* one man, using an 8-litre propane tank and a propane torch, can burn enough cactus to feed 100-200 head of cattle per day, using 1.0 to 1.3 litre of propane/animal (Maltsberger, 1989). To avoid overcooking the cactus, only enough flame should be used to burn the spines from both sides of the plant. Maltsberger also recommended burning more cactus than is actually needed to last until the next feeding and to not overutilize the resource, by leaving at least one joint above the ground uncooked.

To reduce the cost of burning cactus bushes at random in the wild, Pluenneke (1990) described systems in which cactus were planted in rows. In some special applications, such as the need to take cactus to the penned mother cows and calves, cactus has been harvested and transported short distances to animals. Specialized hand tools have been developed to first cut the cactus at the base and then to pitch it 1 m above head height onto a wagon or truck. In Texas, this cactus was then windrowed, the spines burned off and fed into a tractor-powered ensilage chopper. In Mexico, the spines were not burned off, but merely passed through the chopper before being fed to dairy cattle (Felker, unpub. obs.).

It would seem highly advantageous to take the principles of hand harvesting and feeding hand-cut cactus to a tractor-powered ensilage chopper and adapt them to larger-scale, mechanized operations. For example, it would be useful if a self-propelled tractor or tractor-powered ensilage harvester could be modified to harvest cactus planted in rows, chop and blow it into a wagon in the field. This chopped cactus could be most useful in either dairy or beef cattle feedlot operations in arid regions. Alternatively, it might be possible to use a heavy-duty rotary disk mower conditioned to sever and windrow cactus. After drying the cactus for several weeks, it would be useful if a modified forage harvester could move down the rows, pick up the dried cactus, chop it and blow it into a wagon.

While it takes labour to burn spines from cactus, there are some useful management options that result from burning spines from cactus. Since the cattle do not eat cactus that is not burned, burning allows control over the amount of cactus that is used per day. Additionally, cattle quickly become acquainted with the sound of the propane burner and can be drawn for up to 700 m in the brush to the sound of a propane burner. This conditioning to the sound of the propane burner allows cattle to be drawn into corrals and pens.

Thornless cactus varieties offer the advantage of not having to burn off the spines, but intensive management of domestic stock and wildlife is necessary to keep the cactus resource from being overutilized. As the thornless opuntia varieties are not as cold hardy as spiny forms, such as *O. lindheimeri*, care must be taken in selecting suitable planting stock of spineless cactus forage varieties.

If freezing water is not a concern (minimum temperatures no lower than -5°C for a few hours), the Brazilian forage variety #1270 is specially promising as it was found to have rapid growth and nearly 10% crude protein versus 6 to 9% protein for other varieties (Gregory and Felker, 1992). A spineless variety (accession #1233), that is possibly a hybrid between the Texas native *O. lindheimeri* and some *O. ficus-indica* type, suffers only minor damage from temperatures as low as -12°C, whereas -12°C causes complete mortality to accession #1270. This accession #1233 is almost as fast growing as Brazilian clone #1270. In areas where extended temperatures of -18°C routinely occur, the only spineless type available that is cold hardy is the slow growing *O. ellisiana*. On a 1.2 × 1.2 m spacing, with good care, this selection will only produce 1 600 kg DM/ha the first year and 4 400 kg DM/ha the second year. However, after it reaches a leaf area index of about 1, some 11 000 kg DM/ha was produced in the third year, and 17 670 kg DM/ha in the fourth year.

Given yearly fresh weight production rates in excess of 100 000 kg/ha after a leaf area index of 2 have been achieved, and cattle consumption rates of 40 kg/day, it would appear that at a stocking rate of 1 cow/ha, livestock could never consume cactus faster than it grows. Thus it would seem possible to plant, cultivate and care for cactus until it is about 1 m in height.

COMPARISON OF CACTUS WITH HAY

Spiny or spineless cactus has been compared by farmers to "hay in the barn," with up to 200 ton/ha of fresh weight. Several hectares of cactus can provide a considerable reserve of animal feed during drought periods. Unlike hay stored in the barn, the cactus in the fields does not deteriorate in quality with storage and there are no problems with rats eating the hay in storage. Even during drought periods in the summer or winter, cactus is green, with vitamin A and only needs to have the spines burned off or cattle admitted to the fenced area. In drought periods, cattle have to walk long distances to get water. If they are supplemented at one location by the rancher they must walk to this location every day. By consuming 40 kg of cactus per day – containing about 85% water – cattle are also consuming 35 litres of water per day, which can be beneficial in drought periods.

CONCLUSIONS

Either spiny or spineless opuntia clones, when planted in rows, fertilized and weeded, can achieve annual dry matter and fresh weight yields of 17 000 kg/ha and 170 000 kg/ha respectively, with crude protein concentrations of about 10%. When properly supplemented with protein, trace elements and critical vitamins, excellent growth and conception rates are possible. Opuntia has great potential for increasing production in average rainfall years, and to provide a critical reserve of forage for animals in severe drought years. In droughts, cactus can also provide a source of green forage and a much appreciated source of water for livestock.

OPUNTIA AS FEED FOR RUMINANTS IN CHILE

Patricio Azócar

INTRODUCTION

In arid and semi-arid zones, rangelands utilized by sheep and goats are characterized by large seasonal changes in forage production, and marked seasonal and annual fluctuations in forage quality. In Coquimbo, northeast Chile, annual records show dry matter yields of 3 t/ha in a rainy year and less than 0.2 t/ha in a dry year. Shrub species ranged from 36% to 95% of the total dry matter for a dry and wet year respectively (Azócar and Lailhacar, 1990).

In Chile, goat raising is based exclusively on rangeland, allowing only their maintenance or survival. Consequently, to reach income levels of production it is necessary to supplement animal feeding with low-cost feedstuffs that supply energy and protein in the critical periods, to extend the suckling period and maintain milk and meat production (Azócar and Rojo, 1991; Azócar *et al*. 1996). In regard to the management of stock feeding, it was found that the use of opuntia cladodes to feed growing sheep increased by 30% the efficiency of utilization of drinking water. It is therefore proposed that supplementing sheep, goats and cattle feed in dry periods could be done using low-cost supplements.

Productivity varies considerably among species according to environmental conditions (García de Cortázar and Nobel, 1991). Crassulacean Acid Metabolism (CAM) plants, such as opuntia (*Opuntia ficus-indica* (L.) Miller), are often considered to have lower productivity than C_3 or C_4 plants. However, opuntias are highly efficient in the use of water and withstand dry periods and high temperatures. These traits make them highly promising for poor soils with limited water supply (Silva and Acevedo, 1985). The productivity of cultivated opuntia is generally below 10 t/ha/year worldwide, although it can reach 20 t/ha/year. It is an important feeding resource in rangelands of zones with Mediterranean arid climate, and is used in dairy and meat production (Azócar and Rojo, 1991; Azócar, 1992; Azócar *et al*., 1996; Ben Salem *et al*., 1996; Santana, 1992).

Utilization of opuntia for livestock feeding is an old practice in Brazil, Chile, Mexico, Sicily (Italy); South Africa, Tunisia, the southern USA, and other countries (Santana, 1992). Most Mexican forage species are thorny, which is the main constraint to their use in livestock feeding. The problem is overcome by means of simple techniques, such as propane burners (Felker, 1995). Some *O. ficus-indica* varieties do not have thorns, and cladode pieces are easily consumed by livestock. Another limitation of the Mexican species is their low digestibility, which could be overcome by cutting the material into small portions to facilitate its ingestion, by including other ingredients in the ration (like straw), and by utilizing two- to three-year-old plants, since younger plants are more laxative, as are older (>4 year) plants (INIF, 1983).

Advantages of opuntia include high biomass yield, high palatability and good nutritive value, evergreen habit, drought resistance and soil adaptability (Monjauze and Le Houérou, 1965; Le Houérou, 1992; Nefzaoui *et al*., 1993; Ben Salem *et al*., 1996). Opuntia has high contents of ash (260 g/kg DM) and water

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(926 g/kg fresh weight), and low contents of crude protein (58 g/kg DM) and neutral detergent fibre (185 g NDF per kg DM) (Ben Salem *et al*., 1996). The same authors reported that drinking water consumption by sheep is substantially reduced as the level of opuntia consumption increases.

CULTIVATION OF FORAGE OPUNTIA

Climate

Opuntia does not adapt to zones with extreme temperatures. In their place of origin – the highlands of Mexico – temperatures seldom reach +40°C or -10°C (Felker, 1995). The best temperatures for opuntia production range between 18 and 26°C, although some species can tolerate temperatures as high as 40°C and as low as -8°C. It grows in zones with annual precipitation of 200 to 250 mm, but the limits to commercial production are around 450 mm/yr (Pimienta, 1995).

Water requirement

Opuntia uses water more efficiently than conventional fodder crops, as illustrated in Table 25 (Le Houérou, 1994, cited by De Koch, 1998; Silva and Acevedo, 1985).

Table 25. Opuntia water use efficiency (WUE) under rainfed and irrigated conditions

Crop	Water use efficiency (WUE)	
	kg H_2O/kg DM	mg DM/g H_2O
Opuntia[1]	15-43	23-65
Agave	93	10.7
Opuntia	267	3.7
Atriplex nummularia	304	3.3
Pear millet	400	2.5
Barley	500	2.0
Sorghum	666	1.6
Wheat	750	1.3
Alfalfa	1000	1.0
Rangeland	2000	0.5

Sources: (1) De Koch, 1998. Other data Le Houérou, 1994.

Planting

Opuntia cultivation relies mainly on vegetative propagation, which is preferred by growers for its simplicity (Mondragón and Pimienta, 1995). Planting is done in furrows (De Koch, 1998). Rows are usually laid out 2 to 6 m apart and cladodes are planted 1 to 2 m apart. Depending on the purpose, planting density may vary from 850 to 5 000 plants/ha. Results of modelling research predict that opuntia could achieve higher biomass productivity at closer plant spacings (García de Cortázar and Nobel, 1990).

Productivity

In Brazil, Santana (1992) reported a range of fresh weight yields from 106.9 to 205.0 t/ha/yr (approximately 16 to 31 t DM/ha/yr), with yield varying according to geographical zone, type of soil, fertilizer rate used, planting density and association with other crops.

In Chile, yields of cladodes have ranged from 13 t DM/ha/year in crops that only covered 30% of the land, to 40 t DM/ha/year in simulated conditions of high planting density, optimum watering and good fertilization. Average yields of 8 t/ha in non-irrigated lands of the central zone of Chile have been reported by García de Cortázar and Nobel (1990) and Riveros *et al.* (1990).

García de Cortázar and Nobel (1991) studied biomass productivity of opuntia at La Rinconada Agricultural Experiment Station of the University of Chile (about 20 km southwest of Santiago, Chile, [33°19' S, 70°55' W] 500 m elevation). Mature cladodes were planted in January 1988 (summer) at 24 plants/m^2 (0.25 m × 0.17 m) facing east-west. Productivity per unit row length of the inner five rows was assumed to resemble the productivity of a uniform field. Annual predicted dry matter productivity was 40 t/ha. Further analysis indicated that dry matter productivity of opuntia could reach 50 t/ha/year.

NUTRITIONAL QUALITY OF FORAGE OPUNTIA

Nutritional quality of forage opuntia depends on plant species, variety, cladode age, growing season and crop management. In general, opuntia is high in moisture content (about 85 to 90% water), it has high *in vitro* digestibility (about 75%), high content of soluble carbohydrates, vitamin A and ash (20% of dry matter), and low content of crude protein, crude fibre and phosphorus (Tables 26 and 27).

Table 26. Chemical composition of opuntia cladodes and alfalfa hay used to supplement goats in the suckling period (Las Cardas Experimental Station, University of Chile)

	Alfalfa hay	Cactus pear cladodes
Dry matter (%)	93.06	15.04
Organic matter (%)	88.75	90.00
Crude protein (%)	18.86	3.51
Metabolizable energy (Mcal/kg)	2.52	2.25
Ca (%)	1.68	2.01
P (%)	0.29	0.11

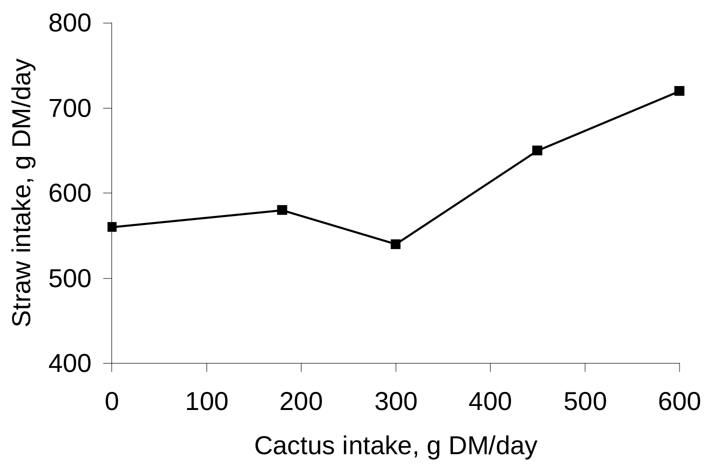
Source: Azócar and Rojo, 1991

Table 27. Chemical composition and organic matter digestibility of *Acacia cyanophylla, Atriplex halimus, O. ficus-indica* and barley hay (Ousseltia Central Experimental Station, INRAT, Tunisia.)

Composition	*Acacia cyanophylla*	*Atriplex halimus*	*Opuntia ficus-indica*	Barley hay
Dry matter (DM) (g/kg)	555	464	100	808
Organic matter (OM) (g/kg DM)	900	799	779	916
Crude protein (CP) (g/kg DM)	129	161	38	64
Crude fibre (CF) (g/kg DM)	254	164	154	350
Neutral detergent fibre (NDF) (g/kg DM)	469	328	197	605
Organic matter digestibility (%)	51.2	79.3	82.3	-

Source: Ben Salem, Nefzaoui and Abdouli (1994)

Figure 4. Cactus versus straw intake (Source: Ben Salem *et al.*, 1996, cited by Nefzaoui and Ben Salem, 1998).



Crude protein content decreases (5 to 3% dry matter) and crude fibre increases (9 to 20% dry matter) with cladode age (1 to 5 years). Crude protein content decreases significantly ($R^2 = 0.6$) when cladode dry matter increases with age. This trend is similar to other fodder sources, where valuable nutrients decrease with plant age because of the relative increase in fibre content (Nefzaoui and Ben Salem, 1998).

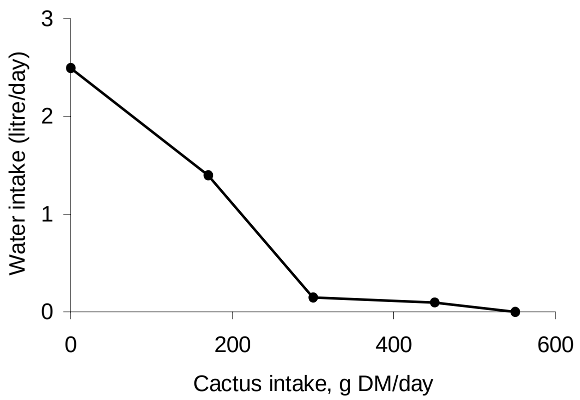
Opuntia cladodes are highly digestible. Average values of *in vivo* digestibility coefficients obtained with sheep varied from 60 to 65 %, 60 to 70 %, 35 to 70% and 40 to 50 for DM, OM, CP and CF, respectively. These coefficients are quite similar to those observed with common forage crops (Nefzaoui and Ben Salem, 1996, cited by Nefzaoui and Ben Salem, 1998). Nefzaoui and Ben Salem, (1998) showed in Tunisia that combining straw with opuntia led to increased straw intake and consequently better animal performance (Figure 4).

EFFICIENCY OF WATER UTILIZATION IN DRYLAND ZONES

Watering animals during summer and drought periods is a serious problem in arid zones. Animals use a lot of energy to reach water holes, and rangeland degradation in the area surrounding watering points is common. Feeding with cactus cladodes reduce watering needs in dry areas.

In Tunisia, Nefzaoui and Ben Salem (1998) showed that water intake is nil when daily cactus consumption by sheep is about 300 g of dry matter. The volume of water consumed by animals decreased from 2.4 litre for the control diet, to 0.1 litre when the level of spineless cactus was above 300 g DM. Animals even stopped drinking water at the highest level of cactus intake (Figure 5).

Figure 5. Opuntia intake (g DM/day) versus water intake (litre/day) (Source: Ben Salem *et al*., 1996, cited by Nefzaoui and Ben Salem, 1998)



Riveros *et al.* (1990), in the semi-arid zone of Santiago (Chile), studied the effect of replacing alfalfa hay by opuntia cladodes on the liveweight and water intake of sheep. During two summer months, 20 lambs, 6 to 7 month old, were randomly allotted to two treatments. One group was fed on alfalfa hay at a maintenance level. The other group was fed on alfalfa hay plus opuntia cladodes that replaced about 25% of the dry matter maintenance requirements. The groups were penned, collective feed and water intake was recorded daily. A third drinking dish was located outside the dry lots to record daily evaporation. Results showed that liveweight showed only slight variation among weeks ($P < 0.05$). Dry matter intake was very similar between treatments ($P < 0.05$), the group fed on alfalfa hay fluctuated from 0.87 to 1.35 kg/animal/day, and the one fed on alfalfa plus opuntia from 0.65 to 1.32 kg/animal/day. The latter consumed between 28.1 and 31.8% of the dry matter as opuntia, starting from the second week.

Water intake differed significantly between treatments ($P < 0.01$): the group fed on alfalfa hay fluctuated from 2.48 to 3.26 litre/animal/day, and between 0.71 and 1.51 litre/animal/day for the animals fed on alfalfa plus opuntia. Considering both direct and indirect water intake, derived from the alfalfa and opuntia requirements to produce 1 kg dry matter, the animals that consumed alfalfa hay plus opuntia cladodes were about 30% more efficient with respect to water utilization than the group that consumed only alfalfa hay.

The authors concluded that utilization of a crop like opuntia could be an interesting possibility to increase forage and animal productivity and particularly as an alternative to improve the efficiency of water utilization in dryland zones (Figure 6).

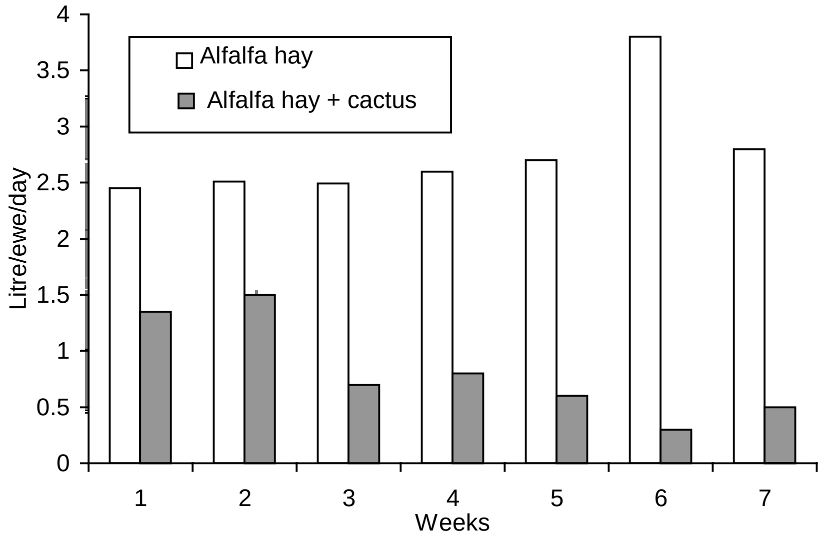
In the arid zone of Coquimbo, Azócar and Rojo (1991) demonstrated that supplementing goats with alfalfa hay and opuntia cladodes in the suckling period significantly increased (55.4%) milk production. When only hay was provided, hay replacement with 16, 21 and 34% cladodes favoured even larger yields: 93.8, 103.6 and 125% respectively. Under local conditions, up to 34% hay could be replaced by opuntia cladodes to supplement goats fed on rangeland and stimulate milk production. This effect can be attributed to the high water content of cactus tissues. Utilization of opuntia cladodes as a summer supplement is relevant to increase milk production of local herds in zones with a Mediterranean arid climate (Table 28 and Figure 7).

Table 28. Goat milk production at Las Cardas Agricultural Experiment Station, Coquimbo, Chile. Means of the last two months of goat's lactation

Treatment	Milk yield (g/goat/day)*
Control on rangeland without supplementation	193 c
Rangeland + alfalfa hay *ad libitum*	300 b
Rangeland + 84% alfalfa hay + 16% cactus pear	374 b
Rangeland + 79% alfalfa hay + 21% cactus pear	393 ab
Rangeland + 66% alfalfa hay + 34% cactus pear	436 a

Note: * Means followed by same letter are not significantly different (Duncan`s multiple range test)
Source: Azócar and Rojo, 1991

Figure 6. Weekly water intake of suffolk ewes at La Rinconada de Maipú Experimental Station, University of Chile, Santiago (Source: Riveros *et al.,* 1990)



INTEGRATION OF CACTUS WITH OTHER NATURAL FEED RESOURCES OF ARID ZONES

Opuntia cannot be fed alone due to its poor nitrogen content, which needs to be supplemented with an appropriate and cheap source of nitrogen, such as saltbush (*Atriplex* sp.) or non-protein nitrogen from treated straw. Nefzaoui *et al.* (1995, cited by Nefzaoui and Ben Salem, 1998) showed that opuntia diets could be supplemented efficiently with *Atriplex nummularia*. Intake of *Acacia cyanophylla* was low because of its high content of condensed tannins (7% of dry matter). Tannins are also responsible for the low digestibility of acacia crude proteins (Nefzaoui and Ben Salem, 1998).

Azócar *et al.* (1996) evaluated the consumption, liveweight and milk production of goats feeding on green forage of either *Atriplex nummularia* or *O. ficus-indica*, as a 30% inclusion in an alfalfa-based diet. Treatments were: (1) 100% alfalfa hay; (2) 70% alfalfa hay and 30% of *A. nummularia*; and (3) 70% alfalfa hay and 30% opuntia. Goats were permanently confined. Replacement of alfalfa hay by the experimental forage was dry-matter based. Hay was fed unchopped, opuntia cladodes chopped, and *A. nummularia* as twigs. Intake was measured daily, and the amount offered was adjusted weekly. Liveweight and milk production were measured at the start of the pre-experimental and the experimental periods and from then on every twenty days.

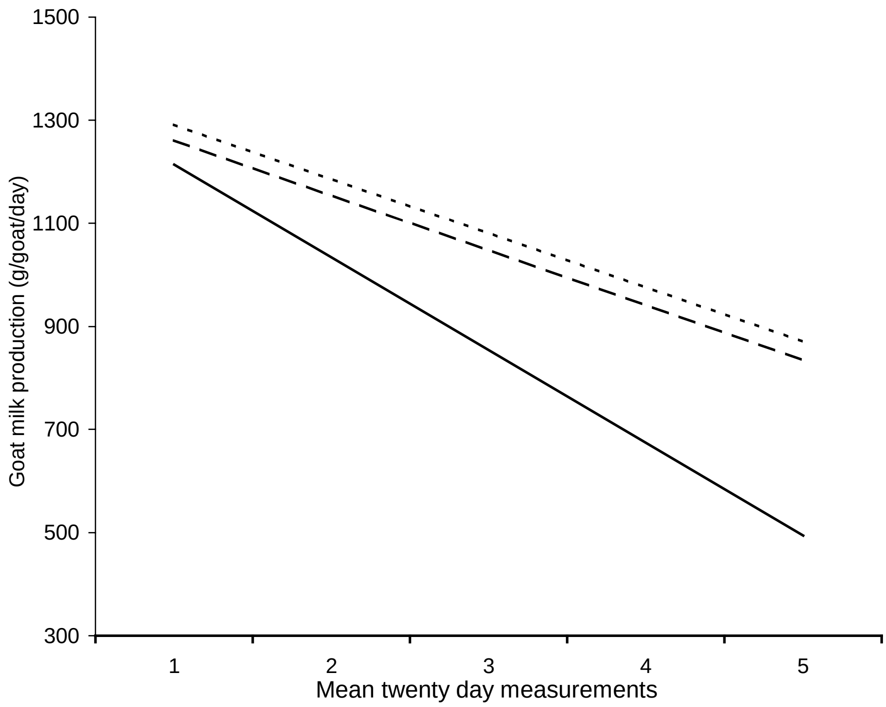
Results showed no significant differences for dry matter intake between treatments 1 and 2 ($P < 0.05$), and significantly higher mean intakes for treatment 3 (Figure 7). Total liveweight gains and daily gains were significantly higher in treatment 3 compared to the others ($P < 0.05$). Daily and total milk production were significantly reduced by the inclusion of *A. nummularia*. Opuntia produced a positive effect on milk production. According to the results (Azócar *et al.*, 1996):

(i) it is feasible to replace up to 30% of the alfalfa hay ration by opuntia without significantly affecting consumption, liveweight and milk production;

(ii) the presence of opuntia cladodes in the ration of goats in the suckling period induces a higher intake and an increase in milk production, which is probably due to the "lactose effect," as yet not explained; and

(iii) replacement of alfalfa hay by *A nummularia* at a level of 30% did not significantly affect the dry matter intake, but had a negative effect on liveweight and significantly reduced milk production.

Figure 7. Goat milk production at the start of the experiment and at 20-day intervals thereafter (Source: Azócar *et al.*, 1996)



Key: ------- = 100% alfalfa hay
– – – = 70% alfalfa hay + 30% *Atriplex nummularia*
—— = 70% alfalfa hay + 30% cactus pear.

OPUNTIA SPP. FOR FODDER AND FORAGE PRODUCTION IN ARGENTINA: EXPERIENCES AND PROSPECTS

Juan C. Guevara and Oscar R. Estevez

INTRODUCTION

Cactus is extensively used as an emergency livestock feed during times of extreme droughts, i.e. a kind of "drought insurance" (Le Houérou, 1994), in arid and semi-arid areas of the world (northeast Brazil, Mexico, southern Africa, USA, and the Mediterranean Basin).

Cactus plantations in Argentina have increased from around 90 ha in 1993 to 840 ha in 1997. Most of the plantations are located in the Provinces of Tucumán (39%), Catamarca (22%), Santiago del Estero (14%), La Rioja (12%) and Salta (10%) (Ochoa de Cornelli, 1997). Among the main traditional, current and potential uses of cactus (Barbera, 1995), the consumption of fruits, fresh or processed in syrup, is the most important in Argentina (Ochoa de Cornelli, 1997). Most of the cactus producers use cactus as an activity complementary to their agricultural systems. Cactus production is very popular in smallholder operations, where the cladodes are used as forage for cattle and goats (Ricarte *et al.*, 1998), although mainly in winter, when the water supply for livestock is limited (Ochoa de Cornelli *et al.*, 1992).

A few studies and experiences have been reported on cactus as fodder and forage in Argentina. The ecological productivity and the nutrient content of the cladodes (Braun *et al.*, 1979), the current status of plantations (Ricarte *et al.*, 1998) and their productivity under different management practices (Reynoso *et al.*, 1998) have been studied for *Opuntia ficus-indica* L. f. *inermis* (Web.) Le Houérou in Los Llanos of La Rioja Province.

Our studies with *Opuntia* spp. began in the Mendoza plain at the end of 1995 in response to the suggestions of Le Houérou (1995a). The experiments comprised effect of fertilizers, irrigation and planting distances on the above-ground biomass production (experimental work still in progress at time of writing); evaluation of plant survival and production in marginal lands (Guevara *et al.*, 1997); micropropagation of *O. ellisiana*, material with low availability of planting stock (Juárez and Passera, 1998); and cold hardiness of *Opuntia* species and clones (in progress). At the same time, the economic feasibilities of cactus plantations for cattle (Guevara *et al.*, in press) and goat production (Guevara *et al.*, 1999) have been assessed.

This chapter summarizes the studies and experiences in Argentina on opuntia for forage production and its prospects.

BIOCLIMATIC CLASSIFICATION OF THE ARID AND SEMI-ARID ZONES

Data from around 40 weather stations were classified (Le Houérou, 1999) based on two main indices: the rainfall (R) to potential evapotranspiration (PET) ratio (R/PET), representing the water stress; and the mean daily minimum temperature of the coldest month (m), representing the winter thermal stress. These two criteria allowed the construction of the orthogonal matrix shown in Figure 8. The discriminating threshold

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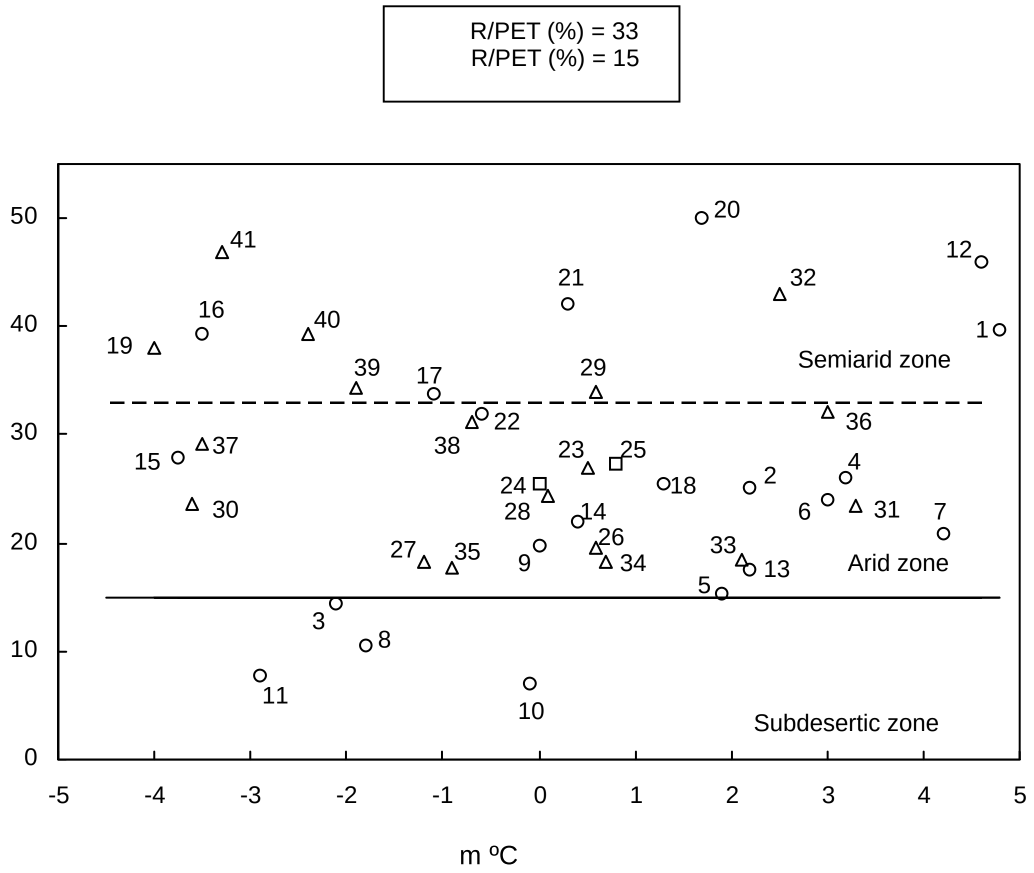
values in the classification were:

Water stress		
Sub-desertic zone:	0.06 < R/PET < 0.15	100 < R < 200 mm
Arid zone:	0.15 < R/PET < 0.33	200 < R < 400 mm
Semi-arid zone:	0.33 < R/PET < 0.50	400 < R < 600 mm
Winter thermal stress		
R/PRT (%)		
-5 < *m* <-3	Extremely cold winter	
-3 < *m* <-1	Very cold winter	
-1 < *m* < 1	Cold winter	
1 < *m* < 3	Cool winter	
3 < *m* < 5	Temperate winter	

The weather stations were also classified according to the rainfall regimes: tropical (over 70% of annual precipitation falling during the summer season); Mediterranean (over 70% of annual precipitation as winter rains); and well balanced (between 40 and 60% of annual rainfall in winter).

The absolute minimum temperatures for most of the weather stations ranged from -5°C (La Rioja) to -13.9°C (Chos Malal, Neuquén). The lowest temperatures recorded were -18°C (El Divisadero, Mendoza) and -23.6°C (Malargüe, Mendoza).



KEY TO SITES

1 Santiago del Estero
2 Andalgalá
3 Tinogasta
4 Catamarca
5 Chilecito
6 La Rioja
7 Chepes
8 S.J.de Jachal
9 Punta del Agua
10 San Juan
11 Barreal
12 Villa Dolores
13 Mendoza
14 La Paz
15 El Divisadero
16 San Carlos
17 San Rafael
18 General Alvear
19 Malargüe
20 San Luis
21 Unión
22 Santa Isabel
23 Puelches
24 Chos Malal
25 Las Lajas
26 Cutral-Có
27 Cipoletti
28 Choele Choel
29 Río Colorado
30 Maquinchao
31 San Antonio Oeste
32 Carmen de Patagones
33 Puerto Madryn
34 Trelew
35 Sarmiento
36 Comodoro Rivadavia
37 Gobernador Gregores
38 Puerto San Julián
39 Puerto Santa Cruz
40 Lago Argentino
41 Río Gallegos

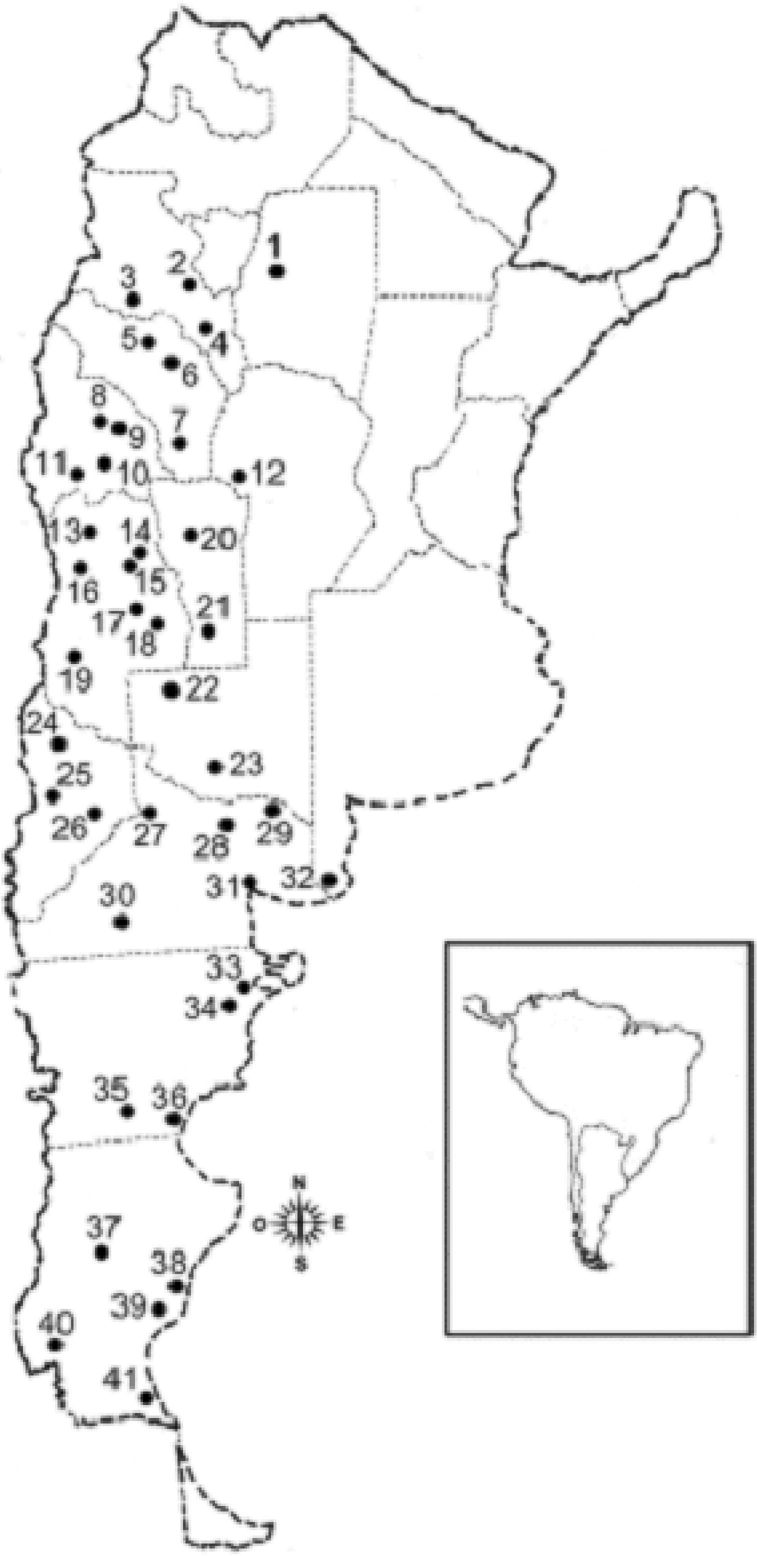


Figure 9. Location of weather stations in arid and semi-arid zones of Argentina

MAIN CONSTRAINTS FOR CACTUS PLANTATIONS

Temperature

Under different climatic conditions, the thermal limit for frost-sensitive species such as *Opuntia ficus-indica* is indicated by an *m* of 1.5 to 2.0°C in the arid steppes of North Africa (Le Houérou, 1995b).

The authors' observations from several species and clones established in the Mendoza plains suggest that winter cold temperatures are the major limitation to cultivation of cactus in this area. When night temperatures in El Divisadero dropped to -17°C in August 1999, the young cladodes from 9-month-old plants of *O. ficus-indica* were almost destroyed, while the 3-year-old plants of *O. ficus-indica*, *O. spinulifera* Salm-Dyck f. *nacuniana* Le Houérou, f. nov. and *O. robusta* Wend. had mean frost damage of 25, 5 and 2%, respectively.

Experiments to evaluate forage production of the cold-hardy forage species *O. ellisiana* Griff. and the cold-hardy clone #1233 (hybrid between *O. lindheimeri* Engelm. and some unknown parent) have recently begun in the Mendoza plains. This material is being tested because *O. ellisiana* was not damaged when temperatures at Kingsville, Texas, dropped to -12°C in 1989 (Gregory *et al.*, 1993). Furthermore, *O. ellisiana* experienced no damage and clone #1233 had only slight damage from this freeze when temperatures of -20°C were recorded on a site located about 500 km north of Kingsville (Wang *et al*., 1997).

According to Han and Felker (1997), the average water use efficiency (WUE) of *O. ellisiana* was 162 kg H_2O per kg DM. This is among the highest WUE of any plant species measured under long-term field conditions.

However, *O ellisiana* is a slower growing species compared to *O. ficus-indica.* In fact, the productivity *O. ellisiana*/*O. ficus-indica* ratio ranged from around 0.35 (Han and Felker, 1997) to 0.5 (H.N. Le Houérou, pers. com.). Considering that the WUE measured for *O. ficus-indica* was 250-300 kg H_2O per kg DM (Le Houérou, 1996a), the WUE of *O. ficus-indica* is about 55 to 85% lower than *O. ellisiana*. Thus, we can assume that the lower productivity of *O. ellisiana* could be explained by its higher transpiration ratio. Clone #1233, introduced by P. Felker at Santiago del Estero, has exhibited high above-ground biomass productivity there (P. Felker, pers. com.).

Rainfall

Cactus and other drought-tolerant and water-efficient fodder shrubs (DTFS) can survive under rainfall as low as 50 mm in a particular year, but with neither growth nor production (Le Houérou, 1994). Mean annual rainfall of 100-150 mm corresponds to the minimum required to successfully establish rainfed plantations of DTFS (Le Houérou, 1994), provided soils are sandy and deep (Le Houérou, 1996a). These limits can be applied in the Mediterranean Basin, and North and South America (Le Houérou, 1994). Thus, cactus plantations are eliminated from the arid (R/PET < 0.03; R < 50 mm) and hyper-arid (0.03< R/PET < 0.06; 50 < R < 100 mm) regions of Argentina.

Land tenure

Land tenure often constitutes a paramount constraint. The establishment of shrub plantations requires long-term planning, relatively heavy investments and therefore land tenure security that provides possible returns for such heavy investments. Land tenure and the control of livestock movements are therefore prerequisites for shrub development (Le Houérou, 1996b).

ABOVE-GROUND BIOMASS PRODUCTIVITY

Soil texture and rainfall are the main factors related to productivity of *O. ficus-indica* (Table 29). On sandy soils, productivity ranges from 2.1 to 2.4 t DM/ha/year in areas with 300 mm of rainfall. This translates into mean rainfall-use efficiency (RUE) of 7.4 kg DM/ha/year/mm. These yield and RUE values are lower than those in arid lands under mean annual rainfall of 200 to 400 mm on deep, sandy soils (3 to 9 t DM/ha/year and 15 to 22.5 kg DM/ha/year/mm, respectively) when competition from native vegetation and weeds was kept under control (Le Houérou, 1996a). The low yield from El Divisadero cactus plantation is probably due to its unweeded condition, as they produced 300% less biomass production than weeded plots (Felker and Russell, 1988). On silty sand soils, productivity reached only 0.75 t DM/ha/year at a site with rainfall slightly higher than 200 mm, i.e. a RUE factor of only 3.5.

Table 29. Above-ground biomass production from *Opuntia ficus-indica* in Argentina

Site	**Mean annual rainfall** (mm)	**Soil texture**	**Spacing** (m)	**Plantation age** (years)	**Aboveground biomass production** (t DM/ha/year)
Los Llanos (La Rioja) [(1)] (30º 22'S, 66º 15'W)	317	Sandy	3 ∆ 3	5-7	2.4
Los Llanos (La Rioja) [(2)] (30º 30'S, 66º 15'W)	317	n.a.	4 ∆ 4	10	1.7
El Divisadero (Santa Rosa, Mendoza) [(3)] (33º 45'S, 67º 41'W)	294	Sandy	3 ∆ 1	3	2.1
Mendoza [(3)] (32º 53'S, 68º 50'W)	215	Silty sand	5 ∆ 1	3	0.75

Sources: (1) Braun *et al.*, 1979. (2) Reynoso *et al.*, 1998. (3) Present authors' data. (4) n.a. = not available.

MICROPROPAGATION OF *OPUNTIA ELLISIANA*

O. ellisiana was multiplied from explants containing areolas using *in vitro* culture techniques (Juárez and Passera, 1998). The sterilization procedure that showed the best results (only 12% areolas infected) consisted of the immersion of the entire cladodes in sodium hypochlorite plus Tween 80, and then in benzalkonium chloride solution.

Explants were cultivated in Murashige and Skoog culture medium, supplemented with sucrose and different Indole-3-butyric acid (IBA) and 6-benzylaminopurine (BAP) concentrations, at 27±2°C, 100% relative humidity and a 16-hour photoperiod. Explants in the medium containing 2.25 mg/litre BAP and 2.0 mg/litre IBA showed 100% shoot development in 35 days of culture. The mean shoot length was 10.2 mm after 49 days.

A 100% root induction in shoots was obtained in a medium with 5 mg/litre IBA after 12 days in culture. The highest numbers of roots were obtained when the entire shoots were cultivated in a medium supplemented with 5 mg/litre and 10 mg/litre IBA after 48 days of culture.

The acclimatization of *in vitro* regenerated plants was accomplished in a greenhouse and the plants showed good performance when transferred to soil.

ECONOMIC FEASIBILITY OF FORAGE OPUNTIA PLANTATIONS

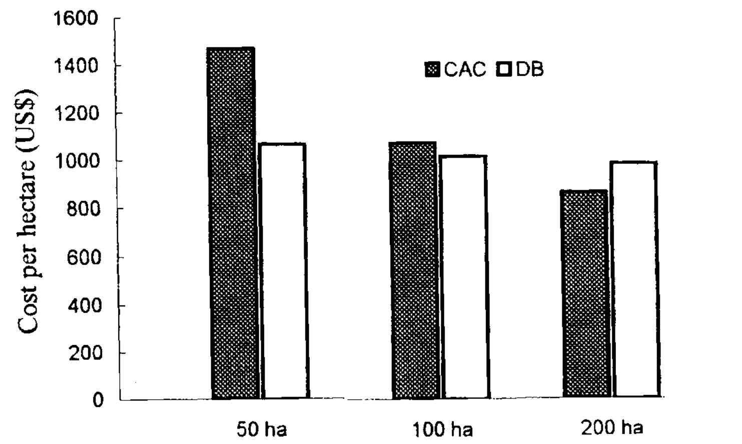
Cattle production

The economic feasibility of 50, 100 and 200 ha cactus plantations in the Mendoza plains was examined by simulation models (Guevara *et al.*, in press). Models were run with 200, 300 and 400 mm annual rainfall and two management systems: cut-and-carry (CAC) for pen feeding, and direct browsing (DB). The study was based on several assumptions related to spacing and density strategies, planting material availability, yield and utilization schedule, nutrient content of the pads, composition of cattle daily ration, and opportunity cost of prohibited grazing.

Two approaches were used to assign monetary values to the cactus feed and the range forage forgone by livestock. In the first approach, the shadow prices were calculated using the regional prices of metabolizable energy (ME) and crude protein (CP) in concentrates (EP shadow price). In the second approach, the authors assumed the shadow price to be the price of steer meat on the hoof at the producer level (SM shadow price). This latter approach also assumed a conversion rate of 115.4 MJ of ME per kilogram of liveweight gain (Le Houérou, 1989). Thus, the monetary values (US$ per tonne DM) were 95.4 (EP) and 66.3 (SM) for cactus and 102.2 (EP) and 59.4 (SM) for range forage production.

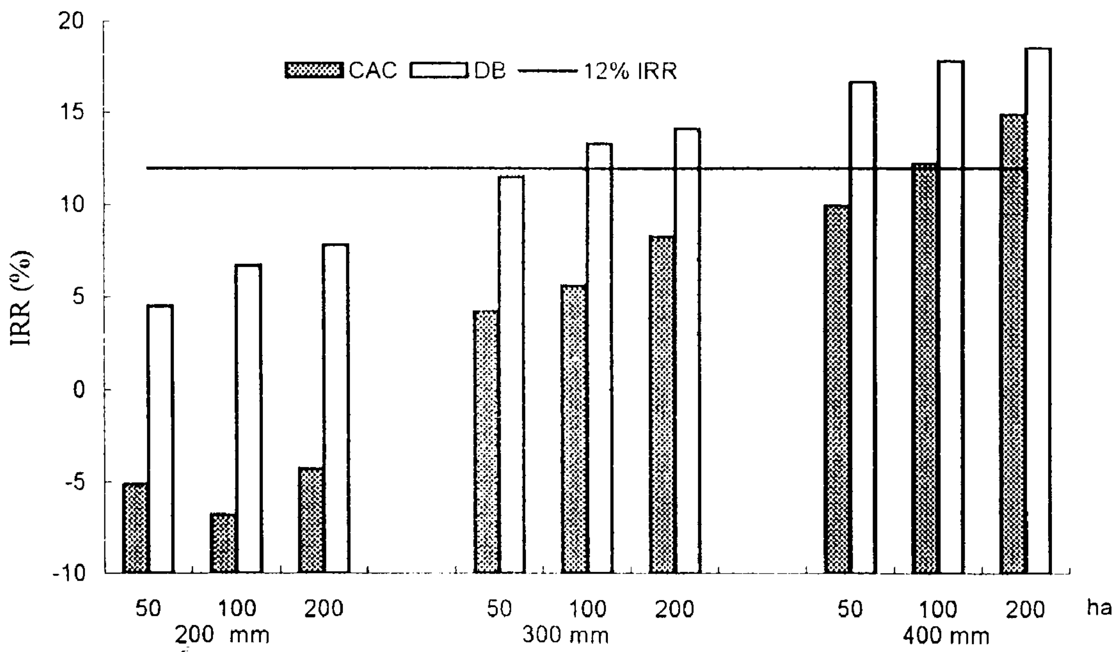
Information obtained through the establishment and monitoring of experimental cactus plantations in the Mendoza plains was used to estimate the establishment cost (Figure 10). The values correspond to the mean of the two shadow prices. This cost ranged from around US$ 1 490 (50-ha plantation; EP shadow price) to US$ 850 (200-ha plantation; SM shadow price) in the CAC system, and from US$ 1 080 (50-ha plantation; EP shadow price) to US$ 970 (200-ha plantation; SM shadow price) in the DB system.

Figure 10. Average establishment cost of cactus plantations in the Mendoza plains according to plantation size and management system (Source: Guevara *et al.* in press)



Using 12% as the capital opportunity cost and the shadow price of meat, cactus production was found to be feasible in DB systems with 300 mm rainfall on a 100 ha plantation and with 400 mm rainfall on a 50 ha plantation; and in the CAC systems with 100-200 ha plantations and 400 mm rainfall (Figure 11).

Figure 11. Internal rates of return (IRRs) from cactus plantations in the Mendoza plains according to plantation size, rainfall and management system (Source: Guevara *et al.*, in press)



The economic analysis did not take into account the secondary benefits mentioned by Le Houérou (1994, 1996a), such as runoff and erosion control, climate buffering, increased land fertility, landscaping and amenities, stabilization of animal production and reduction in the cattle water requirement. This resulted in a very large underestimation of the economic impact of cactus plantations.

Without the incorporation of cactus plantations, the cow-calf operation size necessary to yield positive returns in the Mendoza plains was estimated to be 37 500 ha (Guevara *et al*., 1996). If a 3-year cactus production accumulation and a daily consumption of 36 kg of fresh cactus material per animal unit (AU) were assumed, the cactus plantation required to feed all the cattle (1580 and 2270 AU in areas with 300 and 400 mm rainfall, respectively), for the entire year in this cow-calf model would be about 0.3% of the ranch size. This cactus plantation would increase the current ranch investment by 7 to 10% (Guevara *et al.*, 1996).

Goats for meat production

The study addressed small-scale stockmen (50-200 does), located in areas with mean annual rainfall below 200 mm (Guevara *et al*., 1999). Their goat production systems have the following characteristics: (i) goats are basically fed on rangelands, (ii) most of the goats kid in the dry season (autumn-winter), when the forage on offer is insufficient to meet the nutrient requirements for goat lactation; and (iii) there is high kid and doe mortality as a consequence of the feed deficit in this period.

A simulation model examined costs and benefits derived from the introduction of cactus plantations into these goat production systems. Several scenaRíos were generated by varying the goat herd size (50, 100, 150 or 200 does) and the annual rainfall probability (f) from 0.1 to 0.9.

The assumptions were, in general, the same as those described earlier. However, some particular aspects were included in the study. Cactus plantations could be established in bare areas near settlements of the herders where no grazing currently occurred due to overgrazing and wood extraction. Herbaceous vegetation, which could grow in the inter-row alleys, was scarce and therefore the opportunity cost of prohibiting grazing in the cactus plantation was not considered. Only 10% of the wages were included as goat herder opportunity cost. The method of management proposed was cut-and-carry.

This type of management is recommended for areas in which there is insufficient grazing discipline and therefore a high risk of cactus plantation destruction (Le Houérou, 1989).

A decrease in doe annual mortality from 10 to 2% and an additional annual amount of kids per goat were considered as the direct benefits derived from the reduction of forage deficit in the autumn-winter period. An external benefit was the reduction of water consumption by goats in terms of the monetary value of the labour not used for obtaining water.

Figure 12 shows the establishment cost of cactus plantations for three selected rainfall probabilities. Costs ranged from US$ 525/ha (50-head goat herd; f 0.1) to US$ 242/ha (200 head goat herd; f 0.9). The cost of establishment could be considered high and not all the stockmen could afford such investment. The cost of installing the fence, the main item of the establishment cost in most of the scenaRíos analysed, could be reduced if thorn hedges were considered. Thorn bush fences could be established for only 40% of the cost of metal fence (Le Houérou, 1989). A fence made of a double row of spiny cactus at a distance of 1 m and a space of 1 m between plants should be established at least two years before cactus planting (Le Houérou, 1989).

The annual additional amount of kids required to reach an internal rate of return (IRR) equal to the opportunity cost of capital (12%) is shown in Figure 13. This amount increased as annual rainfall probability increased, i.e. as cactus production decreased. An annual additional amount of 0.2 kid per goat seems possible in practice because of supplementing goats with spineless cactus. In a 50-head goat herd, the threshold of 0.2 kids is reached at f 0.5. The same number of kids is attained at f 0.7 to f 0.8 in 150- and 200-head goat herds.

If dependable rain (f 0.8) is considered, the additional kids per goat required to reach 12% IRR would range from 0.21 to 0.29 for 200- and 50-goat herd size, respectively. Further research is needed to establish, under field conditions, the actual additional amount of kids that might be obtained as a consequence of supplementing goats with spineless cactus in the dry season.

Figure 12. Total costs of cactus plantation establishment and fence installation cost in the Mendoza plains, for three annual rainfall probabilities (f) and four goat herd sizes (Source: Guevara *et al.*, 1999)

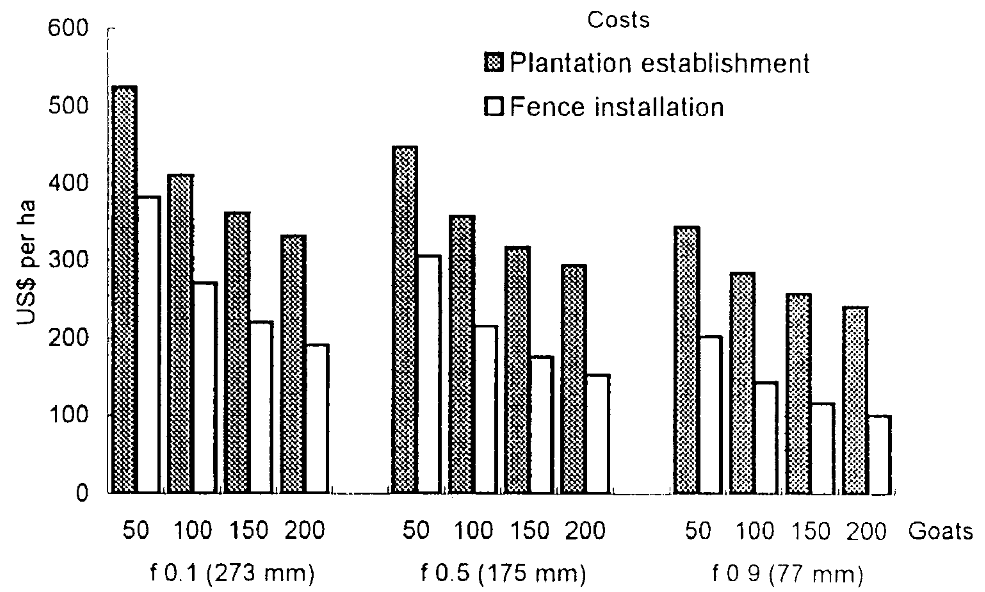
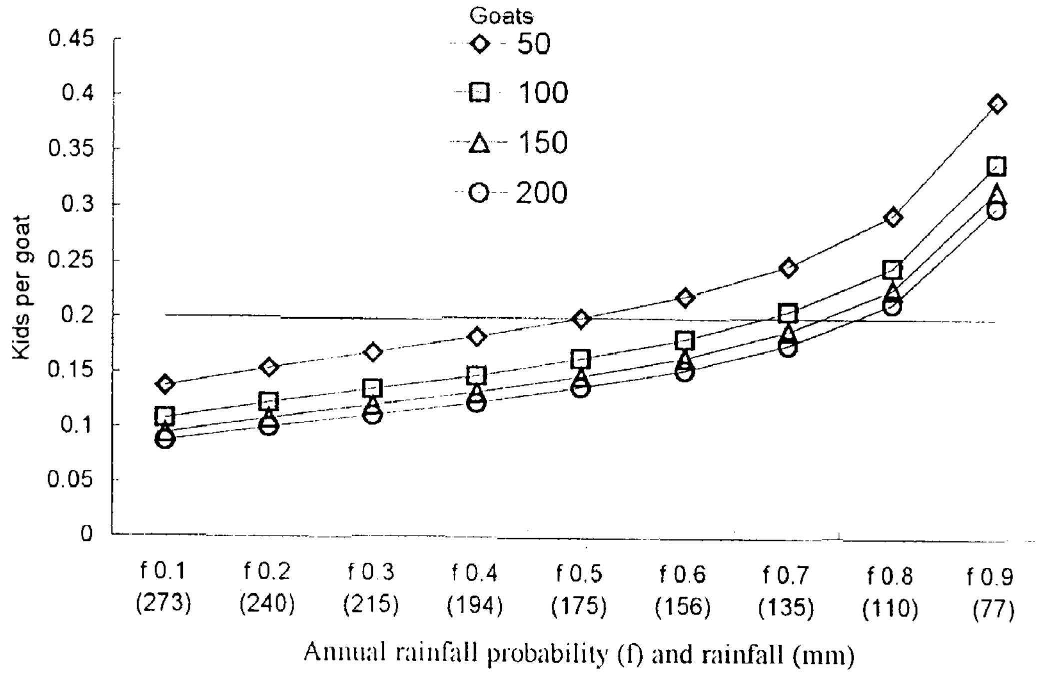


Figure 13. Annual additional amount of kids per goat required to reach 12% IRR in the Mendoza plains according to annual rainfall probability and goat herd size (Source: Guevara *et al.*, 1999)



PROSPECTS AND RECOMMENDATIONS

Cactus plantations could be successfully developed in most of the arid and semi-arid zones of Argentina, provided frost-tolerant species or clones were used. The trials that have been carried out indicate that *O. spinulifera* Salm-Dyck and *O. robusta* are the most frost-tolerant species and hence the most promising for cactus forage production programmes.

The establishment cost of cactus plantations appears to be high and out of reach of most ranchers and graziers. Intensive research and extension efforts are needed to make cactus plantations more attractive to them in terms of feed value, their role as "drought insurance" and economic benefits, and in particular reducing the cost of establishment. At the same time, government should consider appropriate incentives and legal tools favouring security of land tenure.

The system applied in Tunisia for *Acacia saligna* and in Syria for *Atriplex halimus* (Le Houérou, 1996b) could be adopted in Argentina. It is based on the planting of state-controlled land. Such plantations, usually fenced and excluded from stock, are opened to graziers on a temporary basis, subject to payment of a grazing fee, under the control of the Forest Service, who decides on the time of plantation use, on the number of animals admitted and on the fee per animal/day to be paid.

Furthermore, in Tunisia, there are legal incentives for fodder production development. These incentives include state assistance through loans, when economically justified, for establishing fodder shrub plantations, in particular using spineless cacti, saltbushes and acacias (Le Houérou, 1996b).

OPUNTIA - A STRATEGIC FODDER AND EFFICIENT TOOL TO COMBAT DESERTIFICATION IN THE WANA REGION

Ali Nefzaoui and Hichem Ben Salem

INTRODUCTION

The West Asia/North Africa (WANA) region contains large areas with rainy winters and hot, dry summers. WANA is characterized by its high population growth, low and erratic rainfall, limited areas of arable land, harsh deserts and limited water resources for irrigation development (Nordblom and Shomo, 1995).

As much as 50% of the arid rangeland may have lost its vegetation since the Second World War, as the human population has increased fourfold (Le Houérou, 1991a). The sheep population has increased by 75% and the stocking rate jumped from 0.25 sheep/ha to 1.0 sheep/ha between 1950 and 1989. The rangeland degradation is simply the outcome of these changes, besides increased cropping activities and increased use of feed grains.

Thus, contribution of rangelands to the annual feed requirements of livestock is diminishing continuously; from 80% three to four decades ago, to less than 25% currently. Overgrazing and the associated range deterioration are the major factors that have forced pastoralists to change their migration and feeding patterns. In some countries, animals are heavily supplemented with barley grain and other concentrate feeds. Table 30 summarizes a typical feed calendar common for agropastoral systems of the arid and semi-arid zones of the WANA region.

Table 30. Typical feeding calendar for small ruminants in the WANA region

Period	Physiological stage	Area	Type of feed	Supplement
May to July	Mating to early pregnancy	Agricultural land	Cereal stubble	Bran, barley, cactus
August to September	Pregnancy	Agricultural land	Cereal stubble, straw	Bran, barley, cactus, shrubs (*Atriplex*)
October to January	Late pregnancy to early lactation	Rangeland, agricultural land	Fallow, hay, natural grazing	Barley, wheat bran, olive tree by-products
February to April	Weaning, fattening	Rangeland, agricultural land	Natural grazing, fallow, standing barley, straw	Olive tree leaves and twigs, barley, bran

Therefore, most of the WANA countries are seeking appropriate tools to prevent rangeland degradation and restore productivity. Some of the improved rangeland techniques include (i) reduction of stocking rates; (ii) controlled and deferred grazing; (iii) periodic resting; (iv) extended water supplies; (v) reseeding; and (vi) shrub planting.

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Moreover, productivity can be improved by increasing feed supplies from alternative sources, including (i) legumes or other forage crops grown in place of fallow; (ii) fodder banks of naturally grown legumes fertilized with phosphate; (iii) treatment and suitable supplementation of straw; and (iv) other crop residues and agro-industrial by-products. In addition, a planned government strategy for drought relief should reduce the risk to small ruminant producers and increase production.

The search for appropriate plant species to grow in arid areas is a permanent concern of most people living in harsh environments. Cactus species fit most of the requirements of a drought-resistant fodder crop. According to De Kock (1980), they must:

* be relatively drought resistant, survive long droughts, and produce large quantities of fodder during the rainy season, which can be utilized during dry season;
* have a high carrying capacity;
* supply succulent fodder to animals during droughts;
* not have an adverse effect on the health of the animals utilizing it;
* tolerate severe utilization and have high recovery ability after severe utilization;
* have a low initial cost (establishment and maintenance); and
* tolerate a wide range of soil and climatic conditions, so that they can be planted where the production of ordinary fodder crops is uncertain.

The future of the arid and semi-arid zones of the world depends on the development of sustainable agricultural systems and on the cultivation of appropriate crops. Suitable crops for these areas must withstand drought, high temperature and poor soil fertility. The opuntias fit most of these requirements and they are important to the economy of arid zones, for both subsistence and market-oriented activities (Barbera, 1995).

IMPORTANCE OF CACTI IN ARID ZONES

The increased importance of cacti in arid zones is because of their ability to:

- ➢ be more efficient than grasses or legumes in converting water to dry matter, based on their specialized photosynthetic mechanism (CAM) (Russell and Felker, 1987a; Nobel, 1989a)
- ➢ remain succulent during drought;
- ➢ produce forage, fruit, and other useful products; and
- ➢ prevent long-term degradation of ecologically weak environments.

It is suggested that cacti, and *Opuntia* spp. in particular, were introduced into the WANA region by Spanish Moors. Nevertheless, large plantations were not established until the 1900s. These plantations were implemented to create living fodder banks to feed animals during drought and to combat desertification.

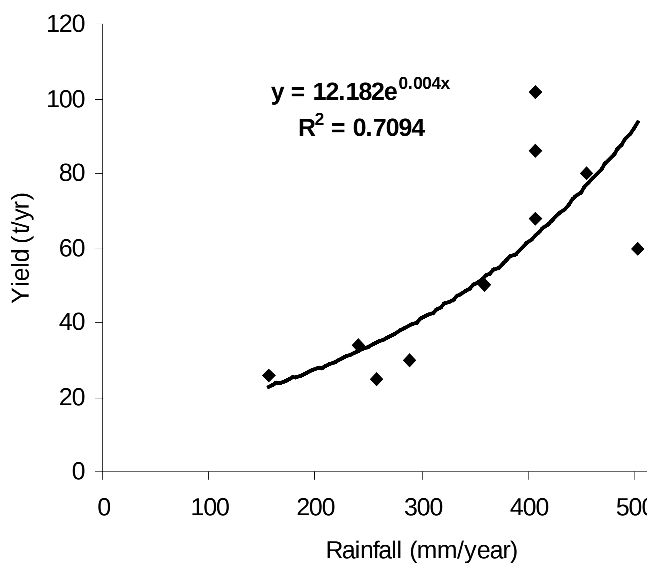
CACTI AS A FODDER BANK

Opuntias used for animal feeding are abundant, easy and cheap to grow, palatable and drought tolerant (Shoop *et al.*, 1977). Such characteristics make them a potentially important feed supplement for livestock, particularly during periods of drought and low feed availability. A large portion of opuntia plant biomass is vegetative material rather than fruits, and it can be fed to livestock as fresh forage or stored as silage for later feeding (Castro *et al.*, 1977). The idea of using cactus to feed livestock is not recent. Griffiths (1905) was certain that feeding cactus to livestock started in the USA before the Civil War, and before and after the war, there was extensive freight transportation of cactus pads between Brownsville, Indianola, San Antonio and Eagle Pass in Texas. The plant has become important fodder in many parts of the world, based on natural and cultivated populations. It is cultivated in Africa, Argentina, Bolivia, Brazil, Chile, Colombia, Israel, Italy, Mexico, Spain, USA and Peru (Barbera *et al.*, 1992; Le Houérou, 1979; Brutsch, 1984; Clovis de Andrade, 1990; Curtis, 1979; Pimienta, 1990; Russell and Felker, 1987a; Saenz, 1985).

Large areas are found in Algeria, northeast Brazil, Mexico and South Africa. The opuntia is used all year round, or as emergency feedstock during drought. In many arid areas (Mexico, south Texas, South Africa, Tunisia, etc.), farmers use cactus extensively as emergency forage that is harvested from both wild and cultivated populations to prevent the disastrous consequences of frequent and severe droughts (Le Houérou, 1992).

From the early 1900s in North Africa, several strategies were introduced to reduce water and wind erosion and rangeland degradation, using shrubs (*Acacia cyanophylla, Atriplex nummularia* and A. *halimus*) and cacti (*Opuntia ficus-indica* f. *inermis*). Large areas have been planted in Algeria, Morocco and Tunisia since the 1950s. It is estimated that in low rainfall areas, some 0.7 to 1 million ha of plantings are helping to combat erosion and desertification and to provide feed for livestock during drought.

Figure 14. Yield of *Opuntia ficus-indica* f. inermis in relation to rainfall in Tunisia (adapted from Monjauze and Le Houérou, 1965)



The importance of opuntia became evident when research showed that CAM plants could have high productivity in dry regions. Due to their high water use efficiency (Nobel, 1989a), their aboveground productivity is much higher than any other arid plant species. In Tunisia, under rainfed conditions and with no fertilizer application, spineless cactus yield from 20 t/yr of fresh cladodes in areas with 150 mm/yr rainfall, to 100 t/yr in areas with an average rainfall of 400 mm/yr (Figure 14).

USE OF CACTI AGAINST DESERTIFICATION IN NORTH AFRICA

Marginal lands are fragile ecosystems, and when they are subjected to cultivation and indiscriminate vegetation removal, large-scale degradation and destruction of vegetative cover occurs. The disappearance and scarcity of several plant species indicate the magnitude of genetic and edaphic losses.

To reverse desertification and restore the vegetative cover in those areas, appropriate integrated packages are used for rangeland monitoring, livestock and natural resources conservation. Spineless opuntia *(Opuntia ficus-indica*) is used in Algeria and Tunisia to slow and direct sand movement, enhance restoration of the vegetative cover and avoid erosion of the terraces built to reduce runoff.

In central and south Tunisia, opuntia plantations provide a large amount of fodder for livestock and play a key role in soil conservation. Terraces are easily damaged by runoff, but opuntia roots help to hold them in place, ensuring stability of the terraces. Two rows of cactus pads are planted on the inner side of the terraces. The moisture stored at the base of the terrace enhances plant growth. In addition, pads are harvested and used as an animal feed during drought spells. Cactus can be used in combination with cement barriers or cut palm leaves to reduce wind erosion and sand movement, maintaining the soil and improving vegetative cover.

USE OF CACTI AS FODDER

Opuntia is not a balanced feed and should rather be considered as a cheap source of energy. Cladodes have low crude protein content and consequently should be supplemented with protein sources. They are also low in phosphorus and sodium.

Chemical composition

Hoffman and Walker (Table 31) analysed *Opuntia* nutrient content in 1912. These early investigations indicate that spiny and spineless cactus have practically the same chemical composition and are of equal value for feeding purposes (Woodward, 1915). Cladodes have high water content (90%), ash (20% DM), Ca (1.4% DM), soluble carbohydrate and vitamin A. They have low contents of crude protein (CP) (ca. 4% DM), crude fibre (CF ca. 10% DM), and phosphorus (P ca. 0.2% DM) (Nefzaoui *et al.*, 1995).

Table 31. Average chemical composition (as % of DM) of *Opuntia engelmannii* and *O. lindheimeri*

Fraction	Content	Fraction	Content
Water	85	Phosphoric acid	0.33
Crude protein	1.4-4.4	Potassium	3.04
Nitrogen-free extract	7.85	Magnesium	1.6
Fat	1.55	Calcium	2.84-13.85
Crude fibre	8.65		

Source: Hoffman and Walker, 1912

Table 32. Average chemical composition of *Opuntia ficus-indica* cladodes produced in Tunisia

	DM (%)	Chemical content (as % of DM)							
		Ash	CP	CF	NFE	P	Ca	K	Na
Average	13.48	27.41	3.84	8.55	58.16	0.04	8.66	1.09	0.05
Minimum	8.95	23.11	1.90	7.39	52.60	0.02	7.56	0.43	0.001
Maximum	21.48	33.70	7.51	10.60	63.79	0.07	10.62	1.92	0.17
Standard deviation	4.50	3.77	1.48	1.03	4.02	0.02	1.09	0.45	0.05

Key: DM = dry matter. CP = crude protein. CF = crude fibre. NFE = nitrogen-free extract. P = phosphorus. Ca = calcium. K = potassium. Na = sodium.

Table 32 summarizes nutrient content of cactus pads determined in Tunisia. Water content is high (80-95%) and ash content can reach 33% of DM. The crude protein content is low, often below 5% of DM. Fibre content is also relatively low: its average value is about 9% of DM. These data are similar to those reported in other countries (Table 33).

Table 33. Average chemical composition of cactus cladodes

	DM (%)	Chemical content (as % of DM)			
		Ash	CP	CF	NFE
Average	11.01	17.19	4.76	10.91	65.30
Minimum	4.74	8.18	2.50	7.82	56.70
Maximum	17.00	23.53	7.87	14.50	72.67
Standard deviation	3.87	4.61	1.90	2.24	5.25

Key: as for Table 32.
Sources: De Kock, 1965; Lozano, 1958; Morrison, 1956; Teles, 1978; and Theriez, 1965.

Contents of major macro-elements show again very low levels of P and Na and high levels of Ca. Recent investigations (Ben Salem and Nefzaoui, unpublished data) show that cactus cladodes have high oxalate content. Total oxalate is about 13% of the DM, of which 40% is in a soluble form. These oxalates are probably bound to Ca, making this anion less available to animals. This high amount of oxalates may also explain the laxative effect of cactus cladodes when fed to animals.

Crude fibre percentage is a poor indicator of feed fibre status, and improved methods, such as the Van Soest fractionating procedure, are more appropriate. It appears that, compared to alfalfa, cacti have a relatively low fibre content, especially the lignocellulose fraction (Table 34). It is well known that high levels of lignocellulose or lignin are responsible for low digestibility of foodstuffs. According to these data, the digestibility cactus pads could be expected to be high.

Table 34. Average neutral detergent fibre, acid detergent fibre, hemicellulose, cellulose and lignin contents (as % of DM) of some *Opuntia* species compared to alfalfa

Species	NDF	ADF	Hemicellulose	Cellulose	Lignin
Alfalfa (reference species)	45.15	29.91	15.24	21.49	7.93
O. engelmannii	31.18	11.29	19.88	7.95	2.89
O. filipendula	33.30	15.31	17.99	10.49	3.97
O. versicolor	39.85	18.98	20.87	13.73	3.86
O. polyacantha	31.16	18.42	12.74	12.69	4.79
O. fragilis	35.08	15.47	19.61	10.97	3.91

Key: NDF = neutral detergent fibre. ADF = acid detergent fibre.
Source: Ben Thlija, 1987

Ash content of cactus pads is high, ranging from 10 to 25%, mainly because of the high calcium content. Most of the opuntia species have phosphorus levels below animal requirement (Tables 31 and 32).

Water deficiency and high levels of Ca compounds in arid and semi-arid soils lead to cactus accumulating high quantities of Ca solutes in its pads. This process allows the plant to extract, through osmosis, as much water as possible from the soil. In any case, the Ca content of cactus pads well exceeds animal requirements. An excess of calcium is not problematic in itself, but an unbalanced Ca/P ratio requires correction. Most authors report a Ca/P ratio of about 35.

Shoop *et al.* (1977) working with *O. polyacantha*, indicated that phosphorus content was below livestock dietary requirements. Calcium levels seemed to be adequate, but the Ca/P ratio, at about 36/1, is too high for optimal livestock performance. According to the same source, the other minerals (manganese, copper, zinc, magnesium and iron) had concentrations within the acceptable range for ruminant diets, except for sodium, which was relatively low (0.02%).

Protein content of cactus cladodes is low, but tends to increase after fertilizer application. Species or varieties also have influence on this parameter. Thus, Gregory and Felker (1992) found that some clones from Brazil had over 11% crude protein.

González (1989) found that N and P fertilizers increased crude protein contents of opuntia cladodes from 4.5% to 10.5% of dry matter. This is rather spectacular. However, in the WANA region, large plantations of opuntia are located in dry areas where poor soil, low rainfall and limited financial resources do not allow fertilizer application. Therefore other methods of increasing nitrogen content of cladodes – through selection, hybridization and inoculation – are very attractive. Protein deficiency can also be solved through appropriate supplementation and/or feed source combination.

Little attention has been paid to the quality of cladode proteins. Investigations conducted in the authors' laboratory showed that the amino acid composition of cladodes is satisfactory and comparable to that of barley grain (Table 35).

The nutritive quality of opuntia depends on plant type (species and variety), cladode age, season, and agronomic conditions (soil type, climate, growing conditions, etc.). Nutrient content variation is similar for cladodes in their first and second years. The general trend is that dry matter content is high during summer months, while crude protein content is at its lowest level. The trend for ash content is less clear, but seems to be high for spring months. Crude fibre is less variable and seems to be higher during winter (Figure 15).

Table 35. Amino acid composition of *Opuntia ficus-indica* var. *inermis* cladodes (g N/16 g N).

Amino acid	**Opuntia CP** (4.24% of DM)	**Opuntia CP** (7.51% of DM) (Site: Ousseltia)	**Opuntia CP** (4.24% of DM) (Site: Bourebia)	**Barley grain CP** (11% of DM)
Aspartic acid	9.29	11.66	10.98	5.70
Threonine	3.83	4.96	4.22	3.40
Serine	4.19	4.25	4.37	4.20
Glutamic acid	12.88	12.72	13.25	24.80
Proline	6.38	5.73	7.25	12.80
Glycine	4.66	4.69	4.86	3.80
Alanine	8.19	6.33	8.38	3.80
Cysteine	0.94	0.31	0.94	2.40
Valine	7.14	6.52	7.14	4.80
Methionine	1.82	2.33	1.99	1.40
Isoleucine	4.94	5.20	5.25	3.50
Leucine	7.99	8.58	8.43	6.90
Tyrosine	4.01	4.14	4.01	3.13
Phenylalanine	4.76	5.66	4.81	5.40
Lysine	4.86	6.32	6.56	3.60
Histidine	1.89	2.42	2.40	1.10
Arginine	5.60	5.31	5.60	4.90

Key: CP = crude protein

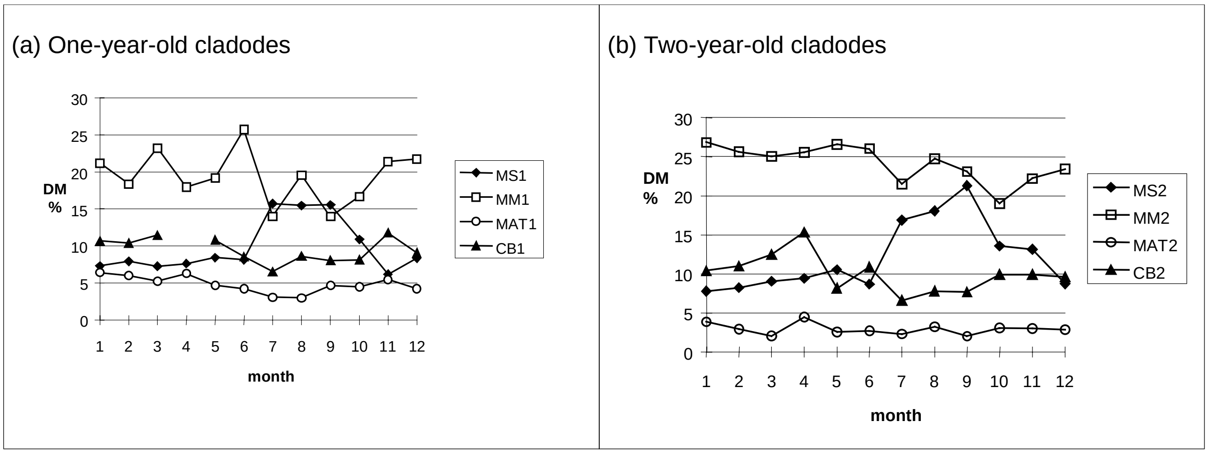
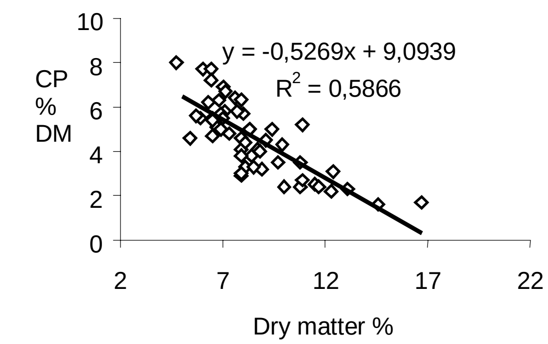


Figure 15. Variation of chemical composition of opuntia cladodes *(Opuntia ficus-indica* var. inermis*)* in the first (a) and second (b) years. **Key:** MS = dry matter. MM = ash. MAT = crude protein. CB = crude fibre.

The effect of cladode age on nutrient content is quite interesting. It is obvious that dry matter increases as cladodes get older. Analysing data related to this aspect, the authors found that crude protein contents decreased (5 to 3% DM) and crude fibre increased (9 to 20% DM) as cladodes aged from 1 to 5 years. Crude protein content decreased significantly ($R^2 = 0.6$) when cladode dry matter/age increased (Figure 16).

Figure 16. Changes in crude protein content associated with DM (Nefzaoui, unpubl. data)



This trend is similar to other fodder sources, where valuable nutrients decrease with plant age, a result of the relative increase in fibre content. Thus, opuntia behaves like any other conventional fodder where crude protein content decreases and crude fibre increases with age (Figure 17).

Digestibility

Opuntia cladodes are highly digestible. *In vivo* average values obtained with sheep varied from 60 to 65%, 60 to 70%, 35 to 70% and 40 to 50%, for DM, OM, CP and CF, respectively. An example of digestibility data obtained with sheep is given in Table 36. These coefficients are similar to those observed with common forage crops. Since opuntia should not be used alone to feed animals, digestibility is calculated by difference, assuming no interaction between diet components.

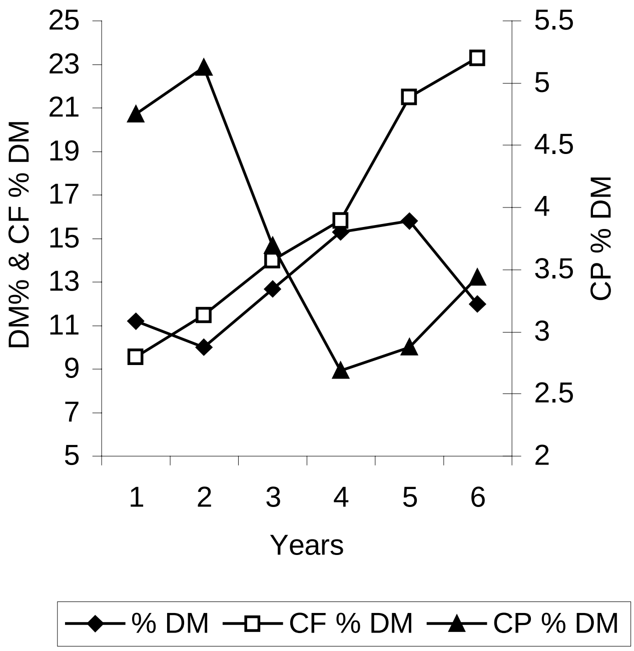
The main difference between cactus and other forage crops is nutrient degradability in the rumen. While forage crops potential degradability in the rumen is often reached after 48 hours, cactus nutrients are rapidly degraded (in between 6 and 12 hours), so it can be assumed that no significant nutrient extraction is operating after 24 hours (Ben Thlija, 1987).

According to Shoop *et al.* (1977), 80% of the total digestion of Great Plains opuntia (*O. polyacantha*) occurred during the first 16 hours of a 48-hour incubation period, whereas only 73% and 71% of total digestion for hay pellets and alfalfa hay, respectively, occurred during the initial 16 hours. Comparative dry matter digestibility of these forages is shown in Table 37.

A rapid rate of digestion means a faster passage of the material through the digestive tract. This also means that cactus dry matter remains in the gastrointestinal tract only for a short time, leaving more volume available for further intake. In other words, the gut fill of cactus is low, explaining why an increase of cactus volume in the diet does not reduce the intake of other components of the ration. These findings are similar to those obtained by Ben Salem *et al.* (1996) in Tunisia.

These results are very important for arid zones where livestock is fed mainly with straw or cereal stubble: both coarse feeds are of poor quality and have low intakes, which lead to poor animal performance.

Figure 17. Dry matter (DM), crude fibre (CF) and crude protein (CP) content associated with cladode age (Nefzaoui, unpublished data).



A USDA report indicated that feeding trials using heifers showed that cactus cladodes are readily and more completely digestible than grass-hay (*Agropyron cristatum* and *Bromus* spp.). A study conducted by Rossouw (1961) comparing yield and digestible portion of opuntia and other fodders is summarized in Table 38.

Table 36. Effect of spineless cactus (*Opuntia ficus-indica* var. *inermis*) supply on intake, total diet digestibility and water consumption by sheep fed straw-based diets

	Rate of spineless cactus (g DM/day) **in ration**				
	0	150	300	450	600
DM intake (g/day)					
Straw	550^{c}	574^{bc}	523^{c}	643^{ab}	716^{a}
Cactus + straw	550^{e}	724^{d}	823^{c}	1093^{b}	1278^{a}
DM intake (g/kg $M^{0.75}$day)					
Straw	43.6^{b}	42.2^{bc}	37.7^{c}	44.8^{b}	54.7^{a}
Cactus + straw	43.6^{e}	53.3^{d}	59.6^{c}	76.3^{b}	97.6^{a}
Total diet digestibility					
Organic matter (OM)	0.453^{b}	0.504^{ab}	0.543^{a}	0.577^{a}	0.587^{a}
Crude protein (CP)	0.495^{c}	0.550^{bc}	0.537^{bc}	0.585^{ab}	0.643^{a}
Crude fibre (CF)	0.525	0.508	0.534	0.523	0.468
Neutral detergent fibre (NDF)	0.504	0.495	0.483	0.523	0.506
Acid detergent fibre (ADF)	0.524	0.473	0.473	0.522	0.484
Digestible OM and CP intakes (% maintenance requirements)					
DOMi	93	123	158	193	212
DCPi	52	52	64	93	111
Daily drinking water consumption (litre)	2.42^{a}	1.49^{b}	1.49^{b}	0.11^{c}	0^{c}

Note: Means in the same row followed by different letters differ significantly at the 5% level.
Source: Ben Salem *et al.*, 1996

Table 37. Dry matter digestibility (%) *in vivo* (NBDMD) and *in vitro* (IVDMD) of singed opuntia, grass-hay pellets and alfalfa

Feed	**NBDMD**		**IVDMD**
	16-hour Incubation	48-hour Incubation	96-hour Incubation
Opuntia	52.9 a	66.4 a	63.8 a
Grass-hay pellets	39.3 c	54.1 c	53.0 b
Alfalfa hay	44.5 b	62.9 b	63.7 a

Note: Means in the same column followed by different letters differ significantly at the 5% level.
Source: Shoop *et al.*, 1977

Table 38. Total yield and amount (as fed) of digestible nutrients of some fodders

Crop	**Yield** (t/ha)	**Digestible nutrients** (t/ha)	**Digestible nutrients** (%)
Opuntia	80	5.0	6.25
Maize (silage)	25	4.2	16.80
Mangelwurzel	25	3.7	14.80
Lucerne hay	5	2.5	50.00

Source: Rossouw, 1961

EFFECT OF FEEDING CACTUS ON RUMEN FERMENTATION PATTERN

The effect of spineless cactus supply on digestion of wheat straw was studied in rumen-cannulated sheep. Animals received wheat straw *ad libitum*, with graded levels of cactus (0, 150, 300, 450 or 600 g DM/day). When the level of cactus in sheep diet increased, fibrous feed intake, rumen volatile fatty acids concentration, rumen protozoa number and rumen ammonia concentration increased, while water intake, rumen cellulolytic activity and rumen acetic acid/propionic acid ratio decreased (Ben Salem *et al.*, 1996).

Rumen pH

Rumen pH remained in the range of 6.80 to 7.13, even when animals received the highest level of spineless cactus (Table 39), so pH of rumen fluid was not affected by the presence of spineless cactus in the diet. Even though spineless cactus is rich in highly fermentable carbohydrates, no differences were observed. Consumption of large volumes of spineless cactus probably enhanced salivation as a result of the high level of mineral salts and the abundance of mucilage in cactus, which might explain the discrepancy. Efforts to quantify effects of mucilage on saliva production and rumen buffer would be worthwhile.

Table 39. Effect of spineless cactus supply on ruminal pH ammonia nitrogen (NH_3-N), volatile fatty acids (VFA) concentration and protozoa count in sheep fed on straw-based diets

	Rate of spineless cactus supply (g DM/day) **in ration**				
	0	150	300	450	600
pH	7.16^{ab}	7.03^{bc}	7.19^{a}	7.13^{ab}	6.96^{c}
NH_3-N (mg/100 ml)	4.7^{b}	7.1^{b}	11.3^{a}	12.0^{a}	10.8^{a}
Total VFA (mmol/l)	43.4^{c}	60.4^{b}	77.6^{a}	60.2^{b}	55.1^{b}
Acetate	63.7^{a}	57.8^{b}	61.2^{ab}	59.2^{ab}	61.4^{ab}
Propionate	21.0^{b}	25.4^{a}	24.2^{a}	25.7^{a}	23.6^{ab}
Butyrate	6.7^{b}	6.8^{b}	8.3^{a}	7.9^{a}	7.9^{a}
Acetate/Propionate	3.29^{a}	2.34^{b}	2.72^{b}	2.55^{b}	2.57^{b}
Protozoa ($\times 10^4$/ml)	3.5^{d}	9.3^{c}	13.0^{b}	17.7^{a}	13.1^{b}

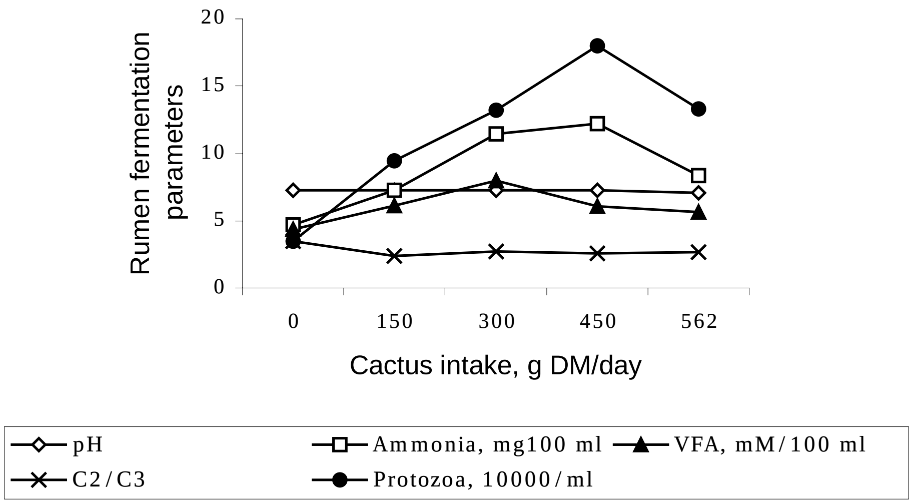
Note: Means in the same row with different superscripts differ (P<0.05).
Source: Ben Salem *et al.*, 1996

Ammonia concentration

Animals supplied with spineless cactus showed an increase in ammonia nitrogen (NH_3-N) concentration in the rumen. Rumen NH_3-N increased (P<0.001) from 4.7 mg/100 ml in the control diet to 11.3, 12 and 10.8 mg/100 ml for diets including 300, 450 and 600 g DM of cactus, respectively (Table 39 and Figure 18).

Ruminal ammonia concentrations were relatively high in animals supplemented with spineless cactus. Even when sheep were fed with straw alone, NH_3-N concentrations in the rumen fluid were quite similar to those reported by Satter and Slyter (1974) as the optimal level for microbial growth and fibre digestion in the rumen.

Figure 18. Cactus intake effect on ammonia, volatile fatty acid (VFA) and protozoa contents in the rumen (Source: Ben Salem *et al.*, 1996)



Volatile fatty acids

Spineless cactus supply significantly increased ($P<0.001$) total volatile fatty acid (VFA) concentrations. Highest total VFA concentrations were obtained with 300 g DM of cactus in the diet. Propionate and butyrate proportions increased significantly in animals receiving spineless cactus. Cactus supply resulted in a slight decrease in the acetate proportion in rumen fluid and an increase in propionate and butyrate concentrations. Spineless cactus seems to have the same effect on ruminant digestion as soluble carbohydrates (Table 39 and Figure 18).

Protozoa counts

The positive effect of spineless cactus supply on NH_3-N concentration was coupled with a significant increase in the total protozoa number in the rumen fluid ($P<0.001$). The average number of protozoa shifted from 3.5×10^4/ml to 13, 17.7 and 13.1×10^4/ml with diets supplemented with 0, 300, 450 and 600 g DM of spineless cactus, respectively (Table 39 and Figure 18).

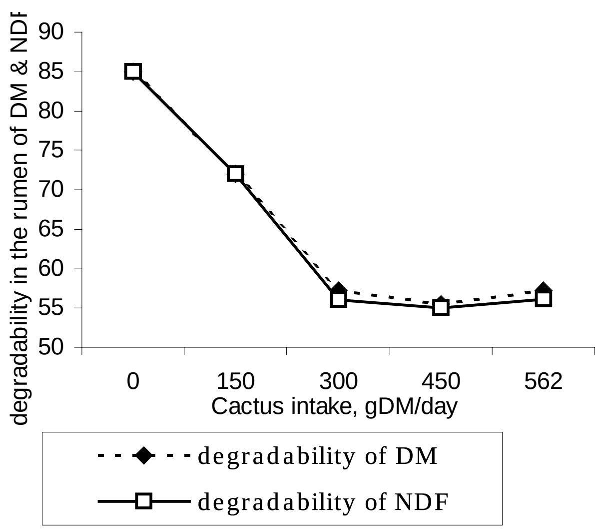
The higher protozoa count observed in animals supplemented with spineless cactus was associated with high levels of ruminal NH_3-N concentration. It is claimed that protozoa contribute to dietary protein digestion and thus ammonia production (Ushida and Jouany, 1985).

Cellulolytic activity

Increasing the cactus level in the diet increased DM intake of fibrous feeds but decreased fibre digestibility, probably because of the depressing effect on rumen cellulolytic bacteria of large amounts of soluble carbohydrates in cactus pads.

Effective degradability of DM and NDF were significantly decreased by spineless cactus supply ($P<0.001$), indicating an impairment of cellulolytic activity in the rumen. However, the rate of degradation (c) was not affected by spineless cactus supply ($P>0.05$) (Figure 19).

Figure 19. Effect of spineless cactus intake on rumen cellulolytic activity. (Source: Ben Salem *et al*., 1996)



Cellulolytic activity measured by the *in sacco* technique clearly shows some depression in fibre degradation (Figure 19). Such a trend is consistent with results reported by Chappel and Fontenot (1968). It is now well documented that ciliate protozoa have a negative effect on the number of bacteria in the rumen and thus on ruminal cellulolytic activity (Demeyer and Van Nevel, 1979). Moreover, the high level of minerals in spineless cactus can be a limiting factor for microbial growth in the rumen, as suggested by Komisarczuk-Bony and Durand (1991).

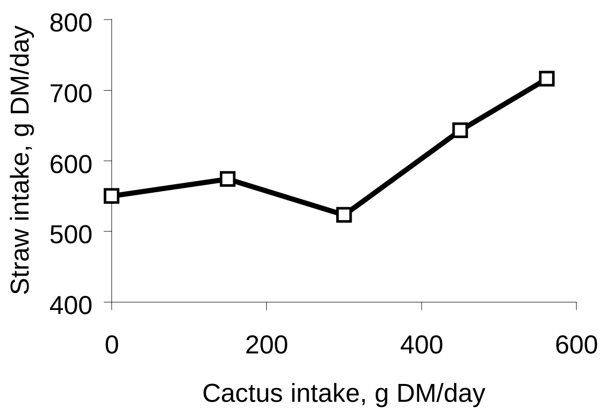
It may be concluded that a combination of spineless cactus (*Opuntia ficus-indica* var. *inermis*) with cereal straw is a nutritionally satisfactory solution for maintaining small ruminants in arid zones. Spineless cactus provides a fodder rich in energy and a water source in drought conditions. Animals receiving cactus reduce water intake substantially and may even stop drinking water. Moreover, this trial indicates that spineless cactus may improve the nutritive value and intake of poor quality roughages. It may be offered to sheep without any risk of digestive disturbances, provided that it is mixed with a fibrous feed. Finally, it is expected that supply of a protein nitrogen source in conjunction with spineless cactus could result in a further improvement of the nutritive value of straw-based diets. Additional work is required to test this hypothesis.

Intake

Generally, cacti are highly palatable. Jersey cows fed on opuntia and supplemented with 1 kg of concentrate feed/day, ate 50.6 kg/day of fresh cactus. Metral (1965) obtained similar results, with cows consuming a voluntary intake of 60 kg when cactus was fed alone. Viana (1965) obtained higher values, with an average voluntary intake of 77.3 kg and 117 kg/day maximum.

Valdes and Flores (1967) observed higher intakes with sheep fed with *Opuntia ficus-indica* (11 kg/day) than with *Opuntia robusta* (6.5 kg/day). Monjauze and Le Houérou (1965) reported intake values ranging from 2.5 to 9 kg/day. It is also reported that higher intakes are observed when water content of pads is higher. Similar results were observed in the authors' work (Nefzaoui and Ben Salem, unpublished data). The gut fill value is low, and, unusually, feeding cactus enhances intake of fibrous feeds like straw (Figure 20 and Table 36). This result is very interesting because straw is the main feed source in the arid environments of the WANA region. It is well established that besides its low feed value, straw intake is low. Combining straw with cactus increases straw intake and consequently animal performance (Figure 20).

Figure 20. Relationship between cactus and fibre intake (Source: Ben Salem *et al.*, 1996).



Sheep fed with straw were able to consume up to 560 g DM of spineless cactus. This level represents nearly half of the total diet. This beneficial effect of spineless cactus could be explained by the improvement in rumen fermentation conditions. Spineless cactus increased by almost 2.5 times the supply of easily fermentable organic matter (Table 36). Animals receiving diets containing up to 500 g of spineless cactus did not show any digestive disturbance, supporting earlier findings (Cordier, 1947). The response pattern to spineless cactus supply with respect to straw intake is in agreement with those generally observed with soluble-carbohydrate-rich diets. Earlier reports (Preston and Leng, 1987; Rangnekar, 1988) indicated that supplementation of poor quality roughages with molasses increased their palatability. Thus, spineless cactus may have a similar effect. Absence of a negative effect of spineless cactus supply on straw intake presumably lies in the high digestibility of spineless cactus in the rumen and in the rapid outflow rate of this feed from the rumen, as it is rich in water.

CACTUS FEEDING HELPS TO SOLVE THE PROBLEM OF WATERING ANIMALS IN ARID ENVIRONMENTS

Water is scarce in arid zones of the WANA region, and animal watering is a real problem during summer and drought periods. Animals expend a lot of energy to reach watering points, and rangeland degradation is a serious risk in the area surrounding watering points. Therefore, the high water content of cactus pads could help mitigate the problem of watering animals in dry areas. Research clearly shows that water intake is nil when cactus intake by sheep is about 300 g of dry matter (Figure 20). The volume of water consumed by animals decreased from 2.4 litre for the control diet to 0.1 litre when the level of spineless cactus consumption exceeded 300 g DM. Terblanche *et al.* (1971) reported similar findings.

Feeding cactus helps to solve the problem of animal watering. Sheep fed for a long period (400 to 500 successive days) with large amounts of cactus stopped drinking (Rossouw, 1961; Harvard-Duclos, 1969). Woodward *et al.* (1915) with Jersey cows reported similar results. However, Cottier (1934) suggested that it is not possible to suppress water in cattle fed on cactus.

Energy content

Gross energy content of most cacti species ranges from 3500 to 4000 Kcal/kg DM. Digestible energy is about 2000 Kcal, which is comparable to a medium quality grass (Ben Thlija, 1987). Thus energy levels of cacti make them a valuable component to include in livestock diets. This energy comes mainly from the high carbohydrate concentration of cladodes.

According to De Kock (1985), the feeding value of spineless cactus is equivalent to 65% TDN, while the authors' measurements (Nefzaoui, unpublished data) are about 0.7 Milk Forage Unit (MFU).

SOME PRACTICAL CONSIDERATIONS

The method of utilization of spineless cactus will differ from farm to farm according to circumstances, such as available labour, facilities, volume of spineless cactus, etc. It is often recommended to use opuntia for feeding livestock by:

- Grazing of cladodes *in situ*. Although this is the simplest method, it is not the most efficient, and care should be taken so that the animals do not overgraze and destroy the plants.
- Cutting harvested cladodes into small pieces or strips and feeding them in a confined area to limit unnecessary wastage.
- Making silage. The cladodes are cut into small pieces and mixed with hay or low quality alfalfa. If no fruits are included it is necessary to add molasses. The silage container must be airtight.
- Supplementation in case of emergency. Cactus, fed in any form, will keep the animals alive for long periods. De Kock (1980) emphasized the desirability of supplementing opuntia with a protein-rich supplement of alfalfa or hay (200 g in winter and 100 g in summer) with cactus fed *ad libitum*. A lick of equal parts by mass of bone meal, salt and fodder lime is recommended by De Kock (1980) to supplement the phosphate and sodium.

STORAGE

Since cacti are evergreen, it is better to store the product *in situ* to avoid expensive processes like silage or drying, even if they are technically feasible. Chaffed spineless cactus pads can be dried on any suitable surface and then ground in a hammermill through a 6-mm sieve. In the form of meal, the spineless cactus material is not only ingested better, but is also easier to store. A supply of spineless cactus meal can thus be stored for use during droughts.

Good quality silage can be made from spineless cactus by chaffing the pads together with oat straw, low grade lucerne hay or any other roughage on the basis of 84 parts by mass of spineless cactus and 16 parts by mass of roughage, with the addition of 2% molasses meal.

GRAZING VERSUS CUT-AND-CARRY

The easiest way to utilize spineless cactus is by grazing, as it requires very little labour and is therefore also the cheapest method. However, overgrazing must be avoided, particularly on young plants that can be destroyed by sheep. Even older plants can be badly damaged by overgrazing, and subsequent production will be considerably lower. The best method of grazing is to divide the plantation into small paddocks and graze each of them intensively for a short period. Large losses occur during grazing due to wastage.

Direct browsing needs very tight grazing control, otherwise wastage may reach 50% of the fodder produced (cladodes partially eaten and abandoned) and the plantation itself may be destroyed by overbrowsing within a few months of overstocking (Monjauze and Le Houérou, 1965; De Kock, 1980). The advantage of this type of management is its very low cost and the fact that the grass layer between the shrubs is available to the stock. These two advantages result in an economically more efficient system. It is best to utilize spineless cactus in rotation so that a plantation is utilized every three to five years. In this way a plantation can be chopped or grazed each time to the height of one pad higher than the original planting. When spineless cactus are utilized in this manner, the plants recover well, the material available for use is of good quality and the plants are kept within a suitable height range.

Zero grazing or the cut-and-carry technique is more efficient. Loss of feed is virtually nil and risk of over-utilization is considerably reduced. Over-exploitation may occur, however, especially in case of early harvest in young plantations; which is detrimental to future production. But the zero grazing technique is costly, although the method is amenable to the stock. In most cases in North Africa, zero grazing management would be recommended because of insufficient grazing discipline and therefore a high risk of destruction.

SPINES

Cactus pads are valuable feed provided the spines are singed off first, usually through the use of a propane weed burner (Shoop *et al.*, 1977). Other practices were discussed by Griffiths (1905). Steaming to moisten the spines and chopping of the large pads were, and are, very efficient practices to facilitate the use and maximize the amount of cactus eaten by livestock. According to the same author, tools and machines have been built for these purposes.

While in some countries (Mexico and USA) the whole standing plant is burned before grazing, in North Africa individual pads are burned and chopped into small pieces with hand tools or appropriate cutting machines.

LAXATIVE EFFECTS – EASY TO SOLVE

A problem experienced when spineless cactus pads are fed to sheep in any form is the severe laxative action they have. This laxative effect is not a disease symptom, it just happens that the food passes past through the animal’s digestive system faster, and as a result digestion is poorer. It appears that hay as a supplement retards this rapid transit to a certain extent.

A laxative effect appears when the volume of cactus in the diet is high (more than 50 to 60% of the DM intake). This problem is easy to solve, and feeding small amounts of straw or hay prior to cactus distribution is sufficient to have normal transit.

INTEGRATION OF CACTI WITH OTHER ARID ZONES FEED RESOURCES

As stated in the introduction, rangeland areas and productivity in WANA countries are decreasing dramatically and currently provide only a small portion of livestock needs.

Moreover, the seasonality of range production due to climatic conditions results in two feed gaps: one in winter (2-4 months) and a longer one in the summer period (5-6 months). These gaps are very difficult to manage by livestock owners, and require large volumes of imported concentrate feeds to supplement animal requirements. Since it is almost impossible for social reasons to reduce animal numbers, most national strategies aim to increase rangeland productivity, using several techniques, including re-seeding, fertilizer application, resting, and establishing shrub plantation. The last option, even if it is not the cheapest one, is the most attractive. Most of these plantations are based on the introduction of highly productive species such as *Acacia cyanophylla*, *Atriplex nummularia* (or A. *halimus*) and spineless opuntia. According to the land tenure system in operation, several techniques are used for planting shrubs and cacti.

* On communal rangeland, introduced species are planted in rows without removal of natural herbaceous or woody species.
* On private land, the alley cropping technique is preferred, where farmers can crop the area between rows when the rainfall conditions are favourable.
* On both categories of land, water and soil conservation techniques are applied. In this case, shrubs and cactus are planted according to the contour lines in order to consolidate the so-called *tabias*.
* Another approach is related to cactus, and the oldest one is the *bosquet* type, which is a dense plantation surrounding the house, used for fruit cropping as well as fodder to supplement animals indoors.

Because of these actions, shrubs (i.e. *Acacia* and *Atriplex*) and opuntia became an integral part of the livestock production system in North Africa. It is also evident that a better integration of these feed resources with conventional ones is necessary. In the following section, selected examples of resource integration are discussed.

Example 1. Poor quality roughages supplemented with opuntia

Poor quality roughage can be supplemented with cactus. Indeed, the intake of straw increases significantly with the increase of the amount of cactus in the diet (Nefzaoui *et al.*, 1993; Ben Salem *et al.*, 1996). Cactus is also a good supplement to ammonia- or urea-treated straw, since it provides the necessary soluble carbohydrates for the efficient use of the non-protein nitrogen in the rumen (Nefzaoui *et al.*, 1993).

To study the effect of using large amounts of cactus (*Opuntia ficus-indica* var. *inermis*) in order to quantify non-protein nitrogen from ammonia- or urea-treated straw, six groups of six Barbarine sheep were submitted to diets that included cactus *ad libitum* and two levels (300 and 600 g) of untreated, urea- or ammonia-treated straws (Table 40). Results showed that cactus voluntary intake can be high (450 g DM) and remain important when straw daily ingestion increased from 300 to 600 g. Diets containing 64% of cactus caused no digestive disturbance. Data indicated that it is possible to cover sheep maintenance requirements for energy by using diets based on cactus given *ad libitum* together with 300 g of straw per day. With high levels of straw (600 g/day) it is possible to cover 170 to 190% of maintenance energy requirement. To cover nitrogen maintenance requirements, straw should be treated. Therefore, cacti may be used as a major component of diets containing cereal straws; it is only necessary to add appropriate supplements in order to overcome the nitrogen deficiency and to supply the fibre needed for normal rumen function.

Table 40. Straw supplementation with spineless cactus

Straw ration	300 g/day			600 g/day		
Straw treatment	US	ATS	UTS	US	ATS	UTS
DM Intake (g)						
Opuntia	445	447	425	432	462	439
Straw	254	242	249	494	466	486
Diet *in vivo* digestibility (%)						
OM	67.9	64.0	63.3	66.5	69.8	72.6
CP	41.1	48.0	43.3	45.9	61.0	77.1
CF	37.5	30.5	29.2	46.5	49.2	52.7
N retained	-0.2	-0.2	-0.6	0.8	2.8	3.9

Key: US = untreated straw. ATS = ammonia-treated straw. UTS = urea-treated straw.
DM = dry matter. OM = organic matter. CP = crude protein. CF = crude fibre. N = nitrogen.
Source: Nefzaoui *et al*., 1993

Example 2. *Atriplex* as a nitrogen supplement to cactus

In a first experiment (Nefzaoui and Ben Salem, 1996), Barbarine sheep were randomly allotted into three equal groups, and fed diets (80% of the diet) based on opuntia (*Opuntia ficus-indica* var. *inermis*) and atriplex (*Atriplex nummularia).* Limited amounts of wheat straw (180 g/day) and commercial mineral and vitamin supplement (30 g/day) were distributed. Diet dry matter (DM) intakes were similar for all groups. Digestibility coefficients of organic matter (OMD) and crude protein (CPD) of the three diets were relatively high, averaging 68, 74, and 75%, respectively (Table 41). In contrast, fibre digestibility was low, as the soluble carbohydrates of cactus might have depressed rumen cellulolytic activity. The diets provided about 1.7 times sheep energy and digestible crude protein (DCP) requirements. Diet 1 covered 1.65 and 2.3 times energy and DCP requirements of sheep, respectively. Thus, it provided excess nitrogen and should be supplemented with an energy source such as barley grain. Diet 2 was relatively well balanced in both energy and nitrogen, while diet 3 had excess energy and needed to be supplemented with a nitrogen source (non-protein nitrogen, like urea).

Table 41. Nutritive value of three diets

	Diet 1	Diet 2	Diet 3
Total intake (g DM/day)	941 (70)(1)	930 (72) (1)	983 (73) (1)
Cactus intake	197	353	550
Atriplex intake	554	391	236
Straw intake	160	159	167
Diet OMD (%)(2)	67.7	69.3	74.4
Diet CPD (%)(3)	74.5	76.6	75.5
Retained N (g/day)	4.1	3.9	4.1
Feeding value(4)			
Energy	167	174	184
Nitrogen	230	190	184

Notes: (1) The values (in parentheses) correspond to intakes stated in g DM/kg of $LW^{0.75}$.
(2) OMD = organic matter digestibility.
(3) CPD = crude protein digestibility.
(4) Feeding value is expressed in % of sheep maintenance requirements in terms of energy (as digestible organic matter intake (DOMi)) and nitrogen (as digestible crude

Sheep energy and N requirements may be matched using diets based on these two feeds. The level of cactus in the diet can reach 55% on a DM basis without any digestive side effect. It is advisable that small amounts of fibrous feed (straw, hay) be fed to animals before cactus. Better dietetic efficiency can be obtained if the mineral balance is improved.

In another experiment, the effect of nitrogen supplement (urea, soybean meal, *Atriplex halimus*, *Atriplex nummularia*) on cactus-pear-based diets, voluntary intake and growth of Barbarine yearlings, was investigated (Nefzaoui *et al.*, 1996). Four iso-nitrogenous and iso-energetic diets (D1 to D4) were offered to four groups with six Barbarine yearlings in each, during 60 days in summer (Table 42). For all diets, freshly cut cactus was fed *ad libitum* in addition to a limited amount of hay (170 g/day). Diets were supplemented respectively with 8 g/day urea (D1), 770 g/day *Atriplex halimus* (D2), 740 g/day *A. nummularia* (D3), and 65 g/day soybean meal (D4). Results showed that cactus based-diets could be supplemented efficiently by *Atriplex nummularia*. Use of urea and *A. halimus* led to low growth rates in comparison with diets supplemented with soybean meal or *A. nummularia*.

The voluntary intakes were 694, 844, 858 and 674 g DM/day, for diets D1, D2, D3 and D4, respectively. The average daily liveweight gains were 55, 58, 74 and 70 g for D1, D2, D3 and D4 respectively. Such diets, using low quantities of cereals (28%) and forage (17%) in the ration, are recommended to cope with feed deficiency in the arid and semi-arid areas prevailing in West Asia/North Africa.

Table 42. Feed intake and liveweight gains

	D1	D2	D3	D4
Intake (g DM/day)				
Cactus	241	252	241	228
Atriplex halimus	0	224.2	0	0
Atriplex nummularia	0	0	225.8	0
Soybean meal	0	0	0	57.6
Barley	308.8	243.6	243.6	243.6
Hay	149.0	142.9	147.5	150.6
Urea	8	0	0	0
Total intake	706.8	862.7	857.9	679.8
Average daily gains (g/day)	55	58	74	70

Source: Nefzaoui *et al*., 1996

Example 3. Can acacia supplement cactus?

Acacia cyanophylla – a widespread, introduced shrub – was used to supplement cactus-based diets. Acacia is rich in crude protein (about 13% of DM). To assess the effect, four Barbarine sheep groups were fed with various diets (R00, R21, R22 and R23) (Table 43). Because of cost, hay was given in limited amounts. The intake of acacia was low (250 g DM/day) because of its high content of condensed tannins (7% DM). These tannins also caused low digestibility of the acacia crude proteins. Such diets need to be supplemented with an appropriate source of nitrogen.

Table 43. Nutritional value of opuntia-based diets supplemented with *Acacia cyanophylla*

	R 00	R 21	R 22	R 23
Feed intake (g DM/day)				
cactus	0	167	246	267
acacia	241	373	211	177
Diet digestibility (%)				
OM	67.7	76.5	73.9	74.6
CP	45.8	49.4	34.8	16.9
CF	62.8	80.5	77.4	79.9
Retained N (g/day)	2.77	2.73	0.46	-1.07
Feeding value[(1)]				
energy	147	151	131	116
nitrogen	75	67	35	10

Note: DM = dry matter. OM = organic matter. CP = crude protein. CF = crude fibre.
(1) Feeding value is expressed as % of sheep maintenance requirements in energy (DOMi = digestible organic matter intake) and nitrogen (DCPi = Digestible crude protein intake).

Source: Nefzaoui *et al*., 1996

CONCLUSIONS

Opuntia cladodes behave like common forage crops:

(i) As cladode age increases, so dry matter and fibre contents increase and crude protein content decreases.

(ii) They have high contents of water (≈90%), ash (≈20%) and calcium (≈1.4%), soluble carbohydrates and vitamin A.

(iii) They are poor in crude protein (≈4% DM), fibre (≈10 % DM) and P (≈0.2% DM).

(iv) Their digestibility can be compared to a good forage crop, with average digestibility coefficients ranging from 60 to 70% for organic matter, 35 to 70% for crude protein and 40 to 50% for crude fibre.

When fed to animals they show some differences with forage crops and behave more like a sugar-rich foodstuff (similar to cereal grain or molasses). Indeed, when the level of cactus cladodes in the diet increases:

(v) there is an increase in the intake of fibre feeds, and the rumen volatile fatty acids, the rumen protozoa count and the rumen ammonia concentration all increase.

(vi) There is a decrease in water intake, rumen cellulolytic activity and the acetic acid/propionic acid ratio.

Cactus cladodes are highly palatable, with average daily consumptions of 6 to 9 kg for sheep and 50 to 80 kg for cattle observed. They have a very low gut fill value, because their intake does not reduce fibrous feed intake and the improved rumen conditions enhance the fibrous feed intake.

The high moisture content of cladodes should be considered a positive factor, because it helps mitigate the problem of animal watering in dry areas. Feed values of spiny or spineless cactus are similar. Spines are not a limiting factor because they can be removed.

When feeding cactus, two simple rules should be observed:

(vii) Cactus is an unbalanced diet and should be fed in association with fibrous foodstuffs (straw, hay, shrubs, etc.). It also needs to be supplemented with an appropriate and cheap nitrogen source.

(viii) Cactus is rich in soluble carbohydrates and Ca, but poor in P. Therefore it is recommended to (a) add molasses to the ration to avoid decreasing rumen cellulolytic activity; (b) limit the amount of grain in the diet for the same reason; (c) feed animals with fibrous feeds (straw, hay, etc.) before giving the cactus. Moreover, a special mineral supplement is required to provide sufficient sulphur (S) to maintain an equilibrium Ca/P ratio.

NUTRITIONAL VALUE OF *OPUNTIA FICUS-INDICA* AS A RUMINANT FEED IN ETHIOPIA

Firew TEGEGNE

INTRODUCTION

Most tropical livestock production systems have low productivity due to low feed availability and quality, especially in drought-prone areas where the livestock sector regularly suffers large losses.

The problem is not limited to arid and semi-arid regions of Ethiopia. Declining crop yields accompanied by increasing requirements for food are forcing farmers of the central and northern highland regions to cultivate more land at the expense of grazing pasture and browses. These problems are exacerbated by poor management and financial limitations.

Research efforts to match seasonal fluctuations in feed supplies to needs include: treating crop residues; modifying agronomic practices; varietal selection; pasture improvement; supplementing with non-protein nitrogen (NPN); planting multi-purpose forages; conservation; and rumen manipulation.

However, there are financial limitations and inadequately qualified staff to carry out analytical work. If treated feeds were to be used, animal products would be at unaffordable prices (Nkhonjera, 1989). Availability of crop residues is limited to areas suitable for crop production. In some arid and semi-arid areas, improvement of pasture is restricted to sowing improved grasses on more fertile soils (Evans, 1982). The nitrogen (N) from NPN or legumes degrades very rapidly and there is a mismatch between the degradation of organic matter and N. Manipulation of the rumen ecosystem does not seem economically effective in extensive forms of farming (Leng, 1982). Silage making from low-nutritive-value tropical forages involves the risk of bad fermentation and needs more facilities (Jarrige *et al*., 1982). Consequently, there is a need to get N-source feeds that can immediately supply rumen degradable organic matter to serve as a link between NPN, forage legumes and crop residues.

Most experts recommend planting of trees and shrubs to provide standing feed resources so that herds and flocks can survive critical periods of shortage and prolonged drought. In screening plants for animal nutrition for drought-prone regions, the two most important criteria are drought tolerance and palatability for animals. However, adaptability of forage to marginal land, ease of propagation, persistency, dry matter (DM) yield, high digestibility (D), and N contents are also important. Opuntia meets all of these requirements. Most important, opuntia is suitable as a human food and has other miscellaneous uses. However, more information is needed concerning its nutritive value, its utilization for animal feed, management, establishment and its integration into pastoral and agropastoral systems.

The study of the potential and nutritive value of opuntia could contribute to the development of the livestock sector in dry regions of Ethiopia. This chapter reviews the feasibility and nutritional value of *O. ficus-indica* as a feed resource for farm animals in such areas.

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ECOLOGICAL DISTRIBUTION AND UTILIZATION OF OPUNTIA IN ETHIOPIA

Opuntia ficus-indica (L.) Miller was taken to North Africa from Mexico in the sixteenth century (Pimienta, 1993) and introduced into Ethiopia at the end of the 19th century (CFDP, 1994). It is widely distributed in the northern arid and semi-arid regions of Ethiopia. A survey indicated that about 30 520 ha (1.88% of the total area of the Tigray region) were covered with *O. ficus-indica*, 48.62% growing wild and 51.34% cultivated. It was also found in the hills of the Welo region, where the vegetation is severely degraded.

Since the 1960s, the fruit has been consumed by almost all domestic animals, and livestock totally depends on opuntia during the dry season. Planting of *O. ficus-indica* is common and extensive. Two Ethiopian organizations that play an important role in the expansion of cactus acreage are the Relief Society of Tigray (REST) and the Regional Natural Resource Conservation and Development Bureau. The Cactus Fruit Development Project (CFDP) has promoted the selection, production and distribution of cactus varieties, identification of diseases and design of erosion control measures as part of its strategies (CFDP, 1994).

NUTRITIONAL VALUE OF *OPUNTIA FICUS-INDICA*

The fruits of *O. ficus-indica* contain water (92%), carbohydrates (4-6%), protein (1-2%), minerals (1%) and a moderate amount of vitamins, mainly A and C (Cantwell, 1991, and Neri, 1991, cited by Pimienta, 1993). According to these figures, its fruits are high in carbohydrates (50-75% of DM) and moderate in protein content (12.5-25% of DM), minerals and vitamins.

South African measurements of nutritional quality of *Opuntia* of 4% CP, 64% TDN, 1.4% Ca, 0.2% P and 0.1% Na were similar to Texas data (De Kock, 1980). He indicated that in contrast to fertilized opuntia plantations, the protein content of the 'wild prickly pear' was so low that mineral and protein supplements were necessary.

The effect of cultivar is illustrated by a comparative study conducted in Brazil of fodder cultivars for milk production: the CP contents of *O. ficus-indica* cvs Gigante and Redonda, and *Nopalea cochenillifera* cv. Miúda were: 4.83, 4.21 and 2.55%, and their CF contents 9.53, 8.63 and 5.14%, respectively. *In vitro* dry matter digestibility (IVDMD) was 77.37% for Miúda compared with 74.11 and 75.12 for Redonda and Gigante, respectively; mean milk production and milk fat were not significantly different among treatments (Ferreira-dos-Santos *et al*., 1990).

Cladode age is an important factor for nutritional value. Young cladodes of *O. ficus-indica* grown for commercial fruit production in Spain had 10.6-15.0% protein, while mature cladodes varied from 4.4 to 11.3% protein (Retamal *et al*., 1987b). Similarly, Gregory (1988, cited by CFDP, 1994) reported that as the age of *O. ficus-indica* increased from one to four years, the CP content decreased: 11.53, 5.74, 5.5 and 5.65%, respectively in the four years, with an average of 7.10%. Compared to mature 12-year-old cladodes, 2-year-old cladodes had substantially higher N, K and Mn, but lower Na, Ca and Fe. This was attributed to age and to higher metabolic activity of young cladodes (Nobel, 1983). Concentrations of 15.3% protein and 0.3% P were reported in commercial *O. ficus-indica* fruit plantations in California (Nobel, 1983). In contrast, the chlorenchyma contained 9.6% protein and 0.12% P for 5-year-old plantations and 7.8% protein and 0.09% P for 12-year-old Chilean opuntia plantations. Young cladodes had significantly higher N, K and Mn, but lower Na, Ca and Fe. Epstein (1972) suggested that Ca and Fe are not very mobile so that both would be expected to accumulate in older tissues (Retamal *et al*., 1987b).

In contrast, Gregory and Felker (1992) reported that *O. ficus-indica* had similar protein contents in all age classes. Their results are unusual, as young cladodes are generally of better nutritional quality than older cladodes, which is attributed to the thickening of the cuticle of older cladodes and the increase in thickness due to the expansion of the water-storage parenchyma (which is very slowly degradable) at the expense of cell contents (Rodríguez-Felix and Cantwell, 1988). The latter authors reported the following composition values per 100 g for cladodes harvested when about 20 cm long: 91.7 g water, 1.1 g protein, 0.2 g lipids, 1.3 g ash and 1.1 g CF (13.3, 2.4, 15.7 and 13.3% on a DM basis, respectively). It was observed that total carbohydrates increased considerably during cladode growth, while protein and CF contents decreased.

Season has a profound impact on the chemical composition of *O. ficus-indica*. According to Retamal *et al.* (1987b), the highest values of moisture content, free reducing sugars, starch and CP were detected in spring (92.5%; 103 mg/g DW; 226 mg/g DW; 14.8% respectively) in young cladodes, while at the end of the season, ash content, ether extractive, crude fibre and calorific content presented the highest values (29.8%; 36 mg/g DW, 144 888 KJ/kg, respectively). Highest concentrations of N, P and K occurred in winter, with Ca showing the opposite pattern (Esteban-Velasco and Gallardo-Lare, 1994).

Compared to most agronomic plants, chlorenchyma levels of Ca and Mg (5.3% and 2.5% of DM, respectively) in cacti tended to be higher and Na level (0.11% of DM) lower (Retamal *et al.*, 1987b). They found that among the 11 elements tested, N was strongly correlated with the nutrient level and metabolic activity, where nocturnal acid accumulation (NAA) tended to be greater when the N level in the chlorenchyma was higher ($r^2 = 0.39$). In contrast, NAA was negatively correlated with chlorenchyma Na content ($r^2 = 0.32$).

The distinctive features of cacti: shallow root systems, leaves modified into spines, and shading of photosynthetic organs; could affect mineral relations. The shallow root enables them to accumulate elements from the upper part of the soil and shading results in accumulation of certain elements (Nobel, 1977). An important feature common to most cacti is the relatively high levels of Ca which may represent accumulation of calcium oxalate (Nobel, 1983).

Flachowsky and Yami (1985) studied composition, D and feed intake of *O. ficus-indica* by Ogaden sheep, where 70-75% (DM basis) was total carbohydrate and about 20% was crude ash. They indicated an apparent D of OM of 70.9%, corresponding to 35 and 467 energy feed units (cattle)/kg (72 MJ ME) in fresh material and DM, respectively. CP was 4.5-5.5% of DM, less than maintenance requirement.

Given free choice, rams preferred chopped fresh cactus to chopped dried cactus or whole fresh cactus (Flachowsky and Yami, 1985). In conditions where water is not a limiting factor for animal production, it could be difficult for animals to take enough fresh cactus to meet their requirements, as a level of water exceeding 780 g/kg fresh forage is claimed to have a detrimental effect on voluntary intake (John and Ulyatt, 1987, cited by Minson, 1990a). Fortunately, this effect may be small and of no disadvantage in arid and semi-arid areas where water is limiting for animal production.

In an experiment replacing alfalfa hay with *O. ficus-indica* cladodes as supplementary summer forage for milk goats, 50 goats were grazed on indigenous pasture alone (control); with lucerne hay (LH) *ad libitum*; and with three LH + cladodes (C) combinations (85% LH+15% C; 79% LH+21% C; 66% LH+34% C). Milk production increased by 55.4, 93.8, 103.6 and 12%, respectively, compared to the control ($p<0.05$) (Azócar and Rojo, 1991).

Gregory and Felker (1992) reported *Opuntia* to be high in moisture content (94.26%) and high in *in vitro* D (about 75%). Most workers have suggested that *Opuntia* is low in its CP (4%) content and P (0.2%) contents, and have recommended that supplements should be given to meet the requirements of animals (De Kock, 1980; Hanselka and Paschal, 1990). It is moderate in energy content measured as digestible nutrients, and high in water, vitamin A, fibre and ash (Hanselka and Paschal, 1990). Fortunately, there are ways of improving it. The application of low rates of N increases the percentage of CP significantly. It was proposed that high N treatment (224 kg/ha every two years) is needed to meet the requirements for lactating cows. Application of P (112 kg/ha) also doubles P content, which is normally low in *O. ficus-indica* (González and Everitt, 1990 cited by Pimienta, 1993).

Anti-nutritional characteristics, such as spines, may affect nutritional value by limiting palatability and digestibility and so utilization efficiency. The common method for removing the spines is burning. A device has been designed to mechanically remove the spines (Carmorlinga-Sales *et al.*, 1993). Another method is use of a chaff cutter (De Kock, 1980).

Given that *O. ficus-indica* is a Crassulacean Acid Metabolism (CAM) plant, the organic acid content varies during the day. Teles *et al.* (1984) found that levels of malonic, malic and citric acids in materials collected at 18:00 were: traces, 0.95 and 0.31 mg/g, respectively. In similar material collected at 06:00, concentrations were 0.36, 9.85 and 1.78 mg/g, respectively. The pH ranged from 5.2 in the evening to 4.4 in early morning, and the percentage of malic acid varied from >0.5% at 08:00 to <0.1% at 16:00 (Cantwell, 1991, and Neri, 1991, cited by Pimienta, 1993). However, the effect of organic acid variation during the day has not been studied with opuntia.

Nutritional changes after harvest have been noted, though not explained. Neri (1991, cited by Pimienta, 1993) observed reduction in the content of both total and reducing sugars, and an increase in pH and protein content. In production systems where water is not limiting, storing opuntia increases DM so that animals can consume more of it to meet their requirements. The increase in its protein content is more important and needs investigation.

ANALYSIS OF ETHIOPIAN OPUNTIA

Samples were taken from opuntia plants grown in a greenhouse on sandy soil, with no fertilization, representative of tropical poor soils in which *Opuntia ficus-indica* usually grows.

Four branches (A, B, C and D), as groups, each with three cladodes, as age groups, and their fruits (f) were separated. The cladodes on each branch were labelled as young (y), middle-aged (m) or old (o). They were six months, one year and two years old, respectively.

Dry matter, ash and mineral content determinations

Dry matter content was determined by drying chopped samples for four days in an oven set at 80°C. Ash content was determined by incinerating dried samples at 500°C until a greyish-white colour was attained. The solution for mineral determination was prepared as stated by Retamal *et al.* (1987b) except that the solution for Ca, Mg and K analysis was further diluted with distilled water (1:100) making the final dilution factor 1:1000. The concentration of Ca, Mg, K and Na in the solution was determined by atomic absorption spectrometry and the concentration of P was determined spectrophotometrically. The result for each element was calculated from the respective standard graphs (MAFF, 1986). Crude protein (CP), crude fibre (CF) and ether extract (EE) were determined by the proximate analysis method (MAFF, 1986). Nitrogen-free extract (NFE) was calculated as the DM not accounted for by the sum of CP, CF, EE and ash (NFE = DM -CP -CF -EE -ash) (Van Soest, 1982). A bioassay was performed using the faeces liquor technique (El Shaer *et al*., 1987) and used for *in vitro* dry matter digestibility (IVDMD) assay. IVDMD was calculated as: IVDMD = (A - (B - C))/A, where: A = dry weight of sample; B = dry weight of residue after digestion; and C = dry weight of reagent blank.

The mean proportional weight loss of the triplicates or duplicates for each sample was recorded as the IVDMD (Omed *et al*., 1989). Data were analysed by ANOVA (General Linear Model, GLM) test and the significance of difference between means detected using Fisher's least significance difference (LSD) test.

The relationship of chemical composition data with IVDMD was performed by simple linear regressions, and significance of correlation by ANOVA. For comparison, appropriate multiple regression equations using combinations of CP, CF, NFE, EE and ash as an independent variable and IVDMD as a dependent variable were used.

Mineral composition

The mineral composition of samples is summarized in Table 44. There was significant age effect on Ca, Mg and Na contents and a highly significant effect on P content. Age did not affect K content. It is well established that tropical legumes, tropical grasses and other roughages are low in minerals, particularly P (Fleming, 1973; Minson, 1988). The P content (Table 44) of the present samples was low in comparison to temperate pasture grasses (McDonald *et al*., 1995). Older cladodes had lower P contents than younger cladodes and fruits, which was in accordance with most previous results (De Kock, 1980; Nobel, 1983; Hanselka and Paschal, 1990; Gregory and Felker, 1992). All the results were within the range of 0.02 to 0.58% reported for 586 tropical grasses, whose mean was 0.22% (Minson, 1990b). In addition, all the P values were above the recommended level (0.17%) for cattle weighing 450 kg and gaining 0.5 kg/day (NRC, 1968).

O. ficus-indica has been reported to be high in Ca content (Nobel, 1977; De Kock, 1980; Retamal *et al.*, 1987b). The values obtained disagree with this (Table 44). This may be due to the young age of the samples having allowed less accumulation of calcium oxalate (Nobel, 1977). Fruits had significantly lower Ca content than other parts and Ca content of young cladodes was higher (but not significant; $p>0.05$) than either middle-aged or old cladodes. The significantly higher Ca content found in young cladodes also disagreed with other reports (Epstein, 1972; Nobel, 1983; Retamal *et al.*, 1987b), but the difference was small. Fruits had lower Ca content than cladodes, explained in part by the low mobility of Ca (Epstein, 1972).

Ca content of 390 tropical grasses varied from 0.14 to 1.46% (Minson, 1990b), a range containing most of the values obtained. All samples contained sufficient Ca to meet the required 0.17% recommended by NRC (1968). Most samples were within the high range of temperate pasture grasses (>0.6%) (McDonald *et al.*, 1995).

O. ficus-indica has been reported as high in Mg content (Retamal *et al.*, 1987b). Mg content of these samples was high and significantly ($p<0.05$) increased with age. All the values were within the range reported by Minson (1990b). In addition, the results were above the 0.11% Mg level recommended by the ARC (1965). Though there is less likelihood for Mg to be deficient, as most tropical grasses and legumes have enough of it (Norton, 1982), these results showed that *Opuntia* had a sufficiency of Mg.

Table 44. Mean mineral composition (% of DM) of fruits and cladodes of *Opuntia ficus-indica*

	Element				
	Ca	Mg	K	Na	P
Fruits	0.45^{c}	0.14^{c}	0.40	0.07	0.37^{a}
Young cladodes	1.03^{a}	0.20^{a}	0.37	0.06	0.33^{a}
Middle-aged cladodes	0.94^{b}	0.19^{a}	0.38	0.05	0.25^{b}
Old cladodes	0.73^{b}	0.22^{ab}	0.17	0.05	0.23^{b}
Probability	$p<0.05$	$p<0.05$	ns	ns	$p<0.001$
Grand mean	0.79	0.19	0.33	0.06	0.30
Standard deviation	1.177	0.147	0.927	0.004	0.014

Notes: (1) Different superscripts indicate significantly ($p<0.05$) different means. (2) ns = Non-significant.

The low K content of the older cladodes (Table 44) may reflect the high metabolic rate of fruits and younger cladodes (Nobel, 1983). Retamal *et al.* (1987b) observed that younger cladodes had substantially higher K content, which was not found in this study.

The Na content of both fruits and cladodes was very low (Table 44) as reported by De Kock (1980) and Retamal *et al.* (1987b). Retamal *et al.* (1987b) reported that younger cladodes had lower Na contents, which was not observed in the results reported here (Table 44). The values indicate that the low Na content of cacti was probably due to the low genetic capacity for accumulation, low requirements for growth or low availability in the soil (Norton, 1982; Retamal *et al.*, 1987b). The latter authors reported that Na content was negatively correlated with nocturnal acid accumulation (NAA), confirming the above claim.

It is firmly established that tropical plants have low Na contents (Fleming, 1973), though its deficiency is related to particular species (Minson, 1990a). The results were within the range of Na contents typically found in tropical grasses, i.e. 0.01 to 1.8%. All the samples contained less than 0.08%, which is the recommended level (ARC, 1965). However, in the arid and semi-arid areas, salinity of drinking water may be high (McDowell, 1985), which could compensate for any deficiency.

Chemical composition

Both fruits and cladodes had low DM contents (9.17%), with the lowest values observed in young cladodes (Table 45). Average ash percentage of the DM was 8.67%. CP declined with age (r = -0.79) in the cladodes, though the pattern was inconsistent. Fruits and young cladodes had significantly (p<0.05) higher CP content than middle-aged and old cladodes (Table 45) while there was no significant differences between fruits and young, middle-aged and old cladodes. Young cladodes had the lowest mean CF content (Table 45). CF content was negatively correlated with CP contents (r = -0.33), and NFE contents (r = -0.53). However, the differences between CF contents were not significant at the 0.05 level. NFE was positively correlated with age (r = 0.64), and negatively correlated with EE (r = -0.42) and ash (r = -0.77).

In vitro dry matter digestibility

Average IVDMD (Table 45) was highest for fruits (p<0.01), followed by young cladodes, and significantly declined with age in the older cladodes. IVDMD was negatively correlated with age (r = -0.95), and NFE (r = -0.80), and positively correlated with CP (r = 0.76) and ash contents (r = 0.73). A relationship between IVDMD and chemical composition, including age was calculated:

$$\text{IVDMD} = 74.1 - (4.12 \times \text{Age}) - (0.009 \times \text{CP}) + (0.482 \times \text{CF}) - (0.91 \times \text{EE}) + (0.989 \times \text{ash})$$

$$(r^2 = 0.93; p<0.001).$$

Table 45. Mean *in vitro* dry matter digestibility (IVDMD), estimated digestible energy (DE) and total digestible nutrient (TDN) contents and chemical composition of fruits and cladodes of *Opuntia ficus-indica*

	DM %	IVDMD % DM	DE MJ/kg DM	TDN % DM	CP % DM	CF % DM	NFE % DM
Fruits		82.92[a]	15.57[a]	77.78[a]	13.10[a]	10.39	65.78
Young cladodes		77.88[b]	13.98[b]	73.48[b]	13.42[a]	7.96	66.78
Middle-aged cladodes		71.14[c]	13.14[c]	67.63[c]	10.76[b]	8.03	72.15
Old cladodes		69.64[c]	12.99[c]	66.32[c]	9.15[b]	10.72	70.85
Probability		p<0.01	p<0.001	p<0.001	p<0.01	ns	ns
Grand mean	9.17	75.40	13.92	71.33	11.61	9.28	68.89
Standard deviation		1.651	0.226	0.312	0.366	1.238	1.281

Key: DM = dry matter. IVDMD = *in vitro* DM digestibility. DE = digestible energy. TDN = total digestible nutrient. CP = crude protein. CF = crude fibre. NFE = nitrogen-free extract

Notes: (1) Different superscripts indicate significantly (p<0.05) different means. (2) ns = Non-significant.

Table 46. Mean DM and chemical composition of *Opuntia ficus-indica* fruits and cladodes from 16 locations in Ethiopia (% on DM basis)

Sample	DM	CP	CF	EE	Ash	NFE
Af	7.5	12.07	9.05	1.94	9.10	67.84
Ay	6.8	12.42	8.68	1.53	10.40	66.97
Am	8.7	9.18	8.40	1.49	7.25	73.68
Ao	10.6	7.95	13.32	2.18	6.90	69.65
Bf	7.7	11.63	7.73	1.12	10.25	69.18
By	6.8	9.78	21.54	2.18	10.95	55.63
Bm	8.7	8.62	8.12	1.77	6.90	74.59
Bo	8.6	10.46	9.37	1.40	9.45	74.59
Cf	7.9	13.11	14.12	1.78	9.35	61.64
Cy	6.9	13.83	7.62	1.91	9.50	67.14
Cm	10.3	12.35	8.16	1.47	8.75	69.27
Co	11.3	9.83	12.30	1.03	9.05	67.79
Df	8.6	14.13	8.00	1.20	8.80	67.87
Dy	6.9	14.00	7.58	1.34	10.85	66.23
Dm	11.6	10.75	7.53	0.92	7.30	73.50
Do	12.9	10.47	6.54	1.09	6.80	75.10

Key: DM = dry matter. CP = crude protein. CF = crude fibre. EE = ether extract. NFE = nitrogen-free extract

CHEMICAL COMPOSITION

CP content

Opuntia ficus-indica was reported to be low in CP content (De Kock, 1980; Glanze and Wernger, 1981; Flacowsky and Yami, 1985; Ferreira-dos-Santos *et al*., 1990). In contrast, some authors reported *Opuntia ficus-indica* as a moderate CP source (Nobel, 1983; Retamal *et al*., 1987b; Rodríguez-Felix and Cantwell, 1988; Cantwell, 1991, and Neri, 1991, cited in Pimienta, 1993). The results obtained (Table 45) agreed with the last-named authors. However, most of their samples were from cultivated plantations, while the opuntia used for this study was treated as a wild plant. Age and conditions of cultivation may explain the difference (De Kock, 1980; Retamal *et al.,* 1987a; Hanselka and Paschal, 1990).

As is the case in most plants, age significantly affected CP content. The mean CP contents of all the fruits and cladodes of all ages (grand mean = 11.61%) were greater than the average CP content of all fibrous crop residues (6.1%) (Kossila, 1984) and tropical grass samples (7.7%) reported by Butterworth (1967) or the 10.6% of Minson (1990b). However, it was less than the average CP content of 340 tropical legumes: 17.2% reported by Minson (1988) or 16.7% reported by Minson (1990b), while most were comparable to the average CP content (13.3%) of 470 temperate grasses (Minson, 1990b). All values were above the level (6-7%) reported as the limit to microbial activity, and thus productivity and feed utilisation efficiency (Minson, 1990b).

Crude fibre content

CF content is usually taken as a negative index of feed quality (Van Soest, 1982). In this study, *Opuntia ficus-indica* was extremely low in CF. Similar results were previously reported by Rodríguez-Felix and Cantwell (1988) and Ferreira-dos-Santos *et al.* (1990).

As plants mature there is a significant increase in CF content (Van Soest, 1982). In cacti, however, there were no significant differences in CF among age groups ($p>0.05$). Rodríguez-Felix and Cantwell (1988) even reported a decrease in CF in older cladodes, suggesting that the significant decrease in IVDMD values of older cladodes (Table 45) was not due to the increase CF content.

All the samples reported here were below the range of CF contents determined for either tropical legumes (12.4 to 43.4%, with a mean of 30.6%) and tropical grasses, with a mean of 33.4% (Butterworth, 1967). They were lower than the mean CF content of temperate grasses (20.0%) and temperate legumes (25.3%) reported by Norton (1982).

Nitrogen-free extract content

The NFE content, which represents the highly digestible carbohydrates (Van Soest, 1982), of all the samples was relatively high (Table 45). The high NFE values of the older cladodes indicated that they had the highest soluble cell contents. The increase in NFE with age ($r = 0.64$) agrees with the observation that total carbohydrates increased during cladode development (Rodríguez-Felix and Cantwell, 1988), which could, to some extent, buffer the decline in IVDMD as cladodes get older (Radojevics *et al*., 1994). The negative correlation between NFE content and IVDMD ($r = -0.80$) might be due to changes related to other factors.

In vitro dry matter digestibility

Low digestible energy and protein contents are the two most important features of a diet that imposes physical restriction on feed intake (Van Soest, 1982). Consequently, energy and protein are usually given first consideration in any feeding system, and thus there is a real need for a digestible feed resource (Yilala, 1989).

The data in Table 45 showed that *Opuntia ficus-indica* was highly digestible, agreeing with the values reported by Ferreria-dos-Santos *et al.* (1990). Although there were relatively small differences in CP and CF contents between fruits and young cladodes, the IVDMD was significantly higher for fruits. Their high digestibility was attributed, in part, to the translocation of soluble carbohydrates (Norton, 1982). Younger cladodes were more digestible than middle-aged and old cladodes. This seemed to be related to the lower CP contents of older cladodes (r = 0.76). However, none of the CP contents was below 6-7% – the limiting level for microbial growth (Minson, 1990b) – or below the DMD/CP ratio (>10:1) that was noted as limiting for microbial synthesis and fermentation conditions (Hogan, 1982).

It was less likely that CF content of old cladodes had significantly affected their digestibilities. This suggestion was confirmed by the extremely low CF contents (Table 45), which had no correlation with age (r = -0.04). When compared with other grasses and legume forages, it might be argued that *Opuntia ficus-indica* with such low CF content had a lower IVDMD than might be expected. The degree of lignification was also unlikely to cause significant reduction in D because non-legume dicotyledenous plants, to which *Opuntia* belongs, are chiefly unlignified and have a high cell wall recovery (Van Soest, 1982). The extremely low CF content might, however, have caused a high rate of digestion and affected digestibility due to acid accumulation in the bottles, which is difficult to buffer (Van Soest, 1982).

A proportion of the decline in digestibility values for the old cladodes could be associated with the indigestible cutin, which prevents microbial attack (Monson *et al*., 1972) Cutin is present in the cuticle of cacti (Hanna *et al*., 1973; Uden, 1984). Differences exist in the ability of cuticle to crack under stress (Hanna and Akin, 1978), which has not been investigated in *Opuntia ficus-indica*.

C_4 plants are photosynthetically more efficient than C_3 plants, but they exhibit low nutritive value (Van Soest, 1982). The morphological characteristics (Norton, 1982); temperature of growth (Minson, 1990a); the well-developed, more slowly degradable, parenchyma sheaths of C_4 plants (Akin, 1982); and the few mesophyll cells (Van Soest, 1982) might limit the digestibilities of fruits and cladodes. However, any impact of these must be small, as the samples were highly digestible (Table 45). These high IVDMD values were related to the high cell contents, which are roughly represented by nitrogen-free extract (NFE) contents and low CF contents (Table 45) (Van Soest, 1982).

Regression analyses of IVDMD against separate chemical composition data (CP, CF, NFE, EE and ash) confirmed that CF and EE contents are not related to digestibility (r^2 = 0.0%), although combination had a highly significant ($p<0.001$) effect. IVDMD was best predicted by regression including age (r^2 = 93.6%).

The IVDMD of almost all the fruits and the cladodes were above the mean values reported for tropical grasses (30-75%, with a mean of 54%) (Minson and McLeod (1970) in Minson, 1988), temperate grasses (45-85%, with a mean of 67%), tropical legumes (36.0 to 69.3%, with a mean of 54%) and temperate legumes (mean of 60.7%) (Minson, 1988). None of the IVDMD values was below the digestibility level recommended for different ruminants kept for different production purposes. For example, for higher performance levels of larger animals, forage digestibility over 66% is required (Burns, 1982); a lactating beef cow producing 10 kg milk/day requires forage of 67% D, and a cow producing 5 kg milk/day, high yielders of Ethiopian indigenous breeds, requires 53% D (Burns, 1982). Thus, *Opuntia ficus-indica* can be a feasible forage in the tropics where even applying N to grasses does not appear to improve D (Minson, 1973).

Higher IVDMD is obtained by drying samples at 100°C for one hour followed by a moderate temperature of 70°C (Burns, 1981). However temperatures above 80°C causes thermo-chemical degradation of non-structural parts. Content of water-soluble carbohydrates (WSC), *in vitro* digestibility (IVD) and percentage of nitrogen insoluble in neutral detergent are affected most by drying temperature. Thus, prolonged heating at high temperature promotes loss of sugar through the Mailliard reaction. The reaction is favoured by high temperature, moisture content and soluble carbohydrates in the plant material: all these requirements were met for opuntia. Oven-drying at high temperature can also increase structural constituents. Therefore, Mailliard products were produced and structural constituents increased, limiting digestion as they are totally unavailable or very slowly degradable (Van Soest, 1982).

CONCLUSIONS

O. ficus-indica was moderate in CP, high in Ca, normal in Mg and low in Na, K and P contents in relation to ruminant requirements from a diet, and similar to common temperate or tropical grasses and legumes. It was highly digestible. *Opuntia ficus-indica* may serve as a link between crop residues, legume forages and NPN sources by supplying readily available organic matter.

Extremely high water content may affect total DM intake by animals, especially during wet seasons and where water is not a limiting factor for animal production. Therefore, research must gear to silage production in combination with coarse crop residues.

This study has evaluated some feed quality parameters at one point in time. For any true evaluation and in order to incorporate *Opuntia ficus-indica* into feeding systems, its effect on animal performance must be investigated. Likewise, further work on its combination with other feeds is needed.

THE USE OF OPUNTIA AS A FODDER SOURCE IN ARID AREAS OF SOUTHERN AFRICA

Gerhard C. DE KOCK

INTRODUCTION

Drought is a natural and normal attribute of the arid lands of arid and semiarid climates. Agricultural drought may be defined as a deficiency of rainfall with respect to the median or to the mean, that seriously impairs agricultural production for a period of several months to several years, extending over a large geographical area. Drought should not be confused with aridity, which rather refers to the average long-term relationship between rainfall and potential evapotranspiration, although it may occur in non-arid zones as well.

Southern Africa, with its variable and limited rainfall, is arid, and seasonal and severe droughts normally occur. During droughts, considerable stock and stock-product losses occur due to the lack of fodder.

CLIMATE

Southern Africa is subject to the most complex bio-climatic conditions on the African continent (Le Houérou *et al*., 1993). This complexity results from a combination of various geographic conditions, among which are the following:

* Large variation in latitude between Messina in Northern Transvaal (22°30' S) and Cape Agulhas (34°50' S), a distance of approximately 1350 km north-south.
* Large variation in elevation, from sea level to about 3 500 m, with a direct effect on rainfall and temperature.
* The presence of the oceans to the east and west. These are associated with the influences of warm currents (Mozambique and Agulhas) in the east, and a cold current (Benguela) to the southwest.
* Mean annual precipitation varies from 40 mm at the mouth of the Orange River, to over 2500 mm on the eastern slopes of the Drakensberg and the upper and western slopes of the Cape mountains.

The rainfall regime may be tropical summer mono-modal; Mediterranean winter mono-modal; spring and autumn bimodal; or completely amodal (without a regular dry season). The mean potential evaporation may vary from a little less than 1000 mm along the Cape and Natal, to over 2 500 mm in the Upington-Pofader-Pella area on the southwest border with Namibia.

OPUNTIA CULTIVATION

Cacti perform well on deep, light textured soils, including coarse sands, but clay should be avoided. Shallow soils tend to give low yields. Cacti are tolerant of pH up to 8.5, and maximum electrical conductivity at soil saturation should not exceed 5-6 mS/cm (Le Houérou, 1992).

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Cacti respond to application of nitrogen and phosphorus fertilizer. A production increase of 200 to 300% has often been observed following moderate nitrogen and phosphorus application. Manuring also increases yield even with very low precipitation of 150-200 mm (Monjauze and Le Houérou, 1965; Le Houérou, 1992; De Kock, 1980). Cacti cannot withstand waterlogging.

WATER REQUIREMENT AND USE

Cacti and other drought tolerant fodder crops use water more efficiently than conventional fodder crops. According to De Kock (1980), opuntia uses 267 kg H_2O/kg DM, or 3.7 mg DM/g; *Atriplex* sp. uses 304 kg H_2O/kg DM, or 3.3 mg DM/g; and *Agave* sp. uses 93 kg H_2O/kg DM, or 10.7 mg DM/g.

The productivity of opuntia is also very high if compared to most native vegetation under similar conditions. Opuntia produces up to 10 t of aboveground DM/ha/yr in arid zones, 10-20 t in semi-arid zones and 20-30 t in sub-humid areas under appropriate or close to optimum management (Monjauze and Le Houérou, 1965; De Kock and Aucamp 1970; Steynberg and De Kock 1987; Nobel 1988; Le Houérou 1991b, 1992).

Such high yields, however, demand careful crop management and good deep soils. Under such conditions, productivity is about ten times that of standard rangelands under common management conditions. With neither cultivation nor fertilization, yield is still three to five times that of rangeland (De Kock, 1980; Le Houérou, *et al*., 1988). The rain use efficiency (RUE) and water use efficiency (WUE) under rainfed and irrigated conditions are summarized in Table 47.

Table 47. Rain use efficiency (RUE) and water use efficiency (WUE) under rainfed and irrigated conditions for several crops

Crop	RUE (kg DM/mm/yr)	WUE – Transpiration coefficient (kg H_2O/kg DM)	WUE (mg DM/g H_2O)
Agave	45.0	93	10.7
Opuntia	40.0	267	3.7
Atriplex nummularia	28.0	304	3.3
Pearl millet	25.0	400	2.5
Barley	20.0	500	2.0
Sorghum	15.0	666	1.6
Wheat	13.3	750	1.3
Alfalfa	10.0	1000	1.0
Rangeland	5.0	2000	0.5

Using the WUE characteristic of an opuntia in an area with 200 mm mean annual precipitation, the yields of cactus material presented in Table 48 were produced under various systems of limited irrigation (De Kock and Aucamp, 1970). In arid and semi-arid areas with limited supply of irrigation, irrigating spineless opuntia is more efficient than irrigating a small area of alfalfa.

Table 49 summarizes the fodder yield and the amount of digestible nutrients produced by spineless cactus (*Opuntia robusta*), oldman saltbush (*Atriplex nummularia*) and alfalfa per unit of water received (25 mm).

Table 48. Yield of spineless opuntia (2920 plants/ha) under limited irrigation at the Carnarvon Station (average rainfall: 200 mm/yr) (Two seasons: 1965-66; 1967-68)

Irrigation + rainfall (mm/yr)	**Number of times irrigated**	**Irrigation schedule**	**Fresh weight yield** (t/ha)	**Dry weight yield** (t/ha)
No irrigation + 178 mm rainfall	0	-	24.89	3.27
75 mm irrigation + 178 mm rainfall	1	September	38.61	4.21
152 mm irrigation + 178 mm rainfall	2	September and November	66.49	6.11
229 mm irrigation + 178 mm rainfall	3	September, November and January	97.60	9.09
305 mm irrigation + 178 mm rainfall	4	September, November and January and March	106.68	10.57

Table 49. Comparison between fodder yield and digestible nutrients (kg/ha) produced by three fodder crops per unit of water received

Season	**Spineless cactus**		**Oldman saltbush**		**Alfalfa**	
	Fodder yield	Digestible nutrients	Fodder yield	Digestible nutrients	Fodder yield	Digestible nutrients
1	161.6	100.4	578.3	235.6	247.5	137.0
2	3001.0	1746.3	944.8	397.2	367.4	208.4
3	3551.8	2081.0	1229.4	555.8	394.9	210.5
4	2169.1	1279.5	752.6	303.2	316.4	180.5
5	2220.9	1301.8	876.3	373.0	331.5	182.0

PRODUCTION

In South Africa, there are three species of spineless cacti utilized for fodder production:

(ix) *O. robusta*. This cactus has large, circular, bluish cladodes, almost spineless. It was first introduced into South Africa in 1911 from the selection programme of Luther Burbank in California. This tetraploid is tolerant to *Dactilopius opuntia*. It does not produce marketable fruit and so is mainly used as fodder.

(x) *O. fusicaulis* has narrow, lanceolate, green cladodes with an upright growth habit.

(xi) *O. ficus-indica* f. *inermis* is a green, oblong type, with dense growth habit.

O. fusicaulis and *O. ficus-indica* cannot produce both fodder and fruit in the same stand in fruit orchards (unless pruning waste is considered). Fodder plantations are harvested every two to three years, before they produce fruits.

In South Africa, opuntia cactus is propagated vegetatively by placing pads flat on the ground with a shovelfull of soil or a stone on top, to improve contact with the soil. Alternatively, double joints can be planted in a furrow, burying the lower end with soil drawn from an adjacent furrow. Roots will develop from the areolas within a few weeks.

Rows are laid out following contour lines. Deep furrows or trenches are made with a heavy ripper and partially filled with manure, which in turn will be covered by soil, planting cladodes on top. The method is more expensive than simple planting, but it yields better growth in the first two to four years, implying earlier production and higher productivity. Rows are usually established 2 to 6 m apart with 1 to 2 m between plants. Planting density may vary from 850 to 5000 plants/ha. The best time for planting in South Africa is September and October, when the pads are fully-grown and ready to sprout. The resulting plants will be well established before the first frost of the following winter. It is preferable to use one-year-old cuttings as planting material.

The selection of a planting layout depends on the type of use envisaged. For direct browsing, dense stands (3 000 to 5 000 plants/ha) with short plants are used. In contrast, the cut-and-carry system requires a wider space to allow a tractor and a trailer to collect the harvest. In this case, a 1 m × 6 m layout is preferred, giving a mean planting density of about 1 666 plants/ha.

CROP MANAGEMENT

Under rainfed condition, yield may vary from 2 to 10 t DM/ha/yr, if harvested every 2 to 3 years. Yield rates from irrigated opuntia are presented in Table 48. Yield is increased if weed competition is reduced. Contour planting to reduce rainfall runoff can also improve yield. The protein content of fodder opuntia can be raised from 3.5 to 4.5% crude protein to 8 to 10% through application of nitrogenous fertilizer.

UTILIZATION

Fresh spineless cladodes contain approximately 90% moisture. The energy requirement for the survival of a 35-kg sheep is approximately 350 g of TDN per day; therefore, the ingestion of 538 g of dry cactus is enough to obtain sufficient energy. This means that 5 to 6 kg of fresh cactus must be ingested daily. However, a sheep eats an average of 4 kg a day.

For cattle, to provide the daily energy requirements for the survival of a 400 kg beast, 2 850 g of TDN are required per day. Therefore, such an animal will require approximately 4 385 g of dry cactus to meet its requirements. That means a daily ingestion of 44 to 45 kg of fresh cladodes. However, an animal only eats an average of 40 kg of cactus per day.

One of the reasons why animals (especially sheep) do not eat sufficient amount of fresh cactus cladodes is the high moisture content. Although the high water content limits consumption by animals, this moisture can be valuable during droughts, to reduce the need for drinking water. Penned sheep could be kept alive for 500 days without drinking water, provided they had free access to fresh cactus cladodes. The intake of TDN can be increased if the fresh cladodes are wilted or dried before feeding.

Cactus cladodes are very low in crude protein in general, but any ration for non-reproductive sheep and cattle should contain at least 8% of crude protein. Rations or feeds with low protein content are poorly ingested by animals. A sheep with a liveweight of 35 kg requires approximately 50 g of crude protein per day. The average 500 g of dry material from the daily ration of cactus cladodes contains only 20 g of crude protein, so cactus cladodes must be supplemented with some form of crude protein. Cactus cladodes are low in phosphorus and sodium, requiring supplementation of these elements as well. In general, cactus cladodes are not a balanced feed but rather a good, inexpensive source of energy.

Grazing

The easiest way to utilize cactus is by direct grazing, which requires little labour and therefore is cheaper. There is a risk of overbrowsing and destruction of the plantation if strict control of stock and grazing is absent. Grazing or harvesting should take place every two to three years. The pads reduce in feeding value after the third year (Walters, 1951). For efficient grazing, the plantation can be divided into small paddocks, which are then used intensively for a short period each. Large loses can occur during grazing due to wastage.

Chaffing

Increased intake by animals and better utilization can be obtained by chopping the cladodes. To limit waste, it is preferable to feed the chaffed material directly in the trough.

Meal

Chaffed cactus cladodes can be dried on any suitable surface, and then milled. A supply of cactus meal can thus be stored for use during droughts and/or for supplementing fresh cactus pads to increase dry matter intake.

Silage

Good silage can be made from cactus cladodes by chaffing them with oat straw, low grade alfalfa or any other dry roughage on the basis of 84 parts mass of cactus cladodes and 16 parts of roughage, with the addition of molasses meal. When cladodes bearing fruit are used for silage, the addition of molasses is not necessary. The silage is then made and used in a conventional manner.

Opuntia fruit and cladodes – even the spiny types – can be made into silage with low quality hay, cereal straw or veldt hay, and supplemented with protein feed (cotton or sunflower seed meal, and urea) and a mineral supplement of phosphorus and sodium (bone meal, salt and lime) and this can sustain dairy production in arid and semi-arid rural areas during dry seasons and drought periods.

Supplementary feeding

In an emergency, where nothing else is available, cactus cladodes can be fed alone in any form, and sheep and cattle can survive on it for many months. Wool sheep were kept for 500 days on cactus cladodes alone and survived.

For optimal utilization, however, cactus cladodes should be supplemented. As protein is the most important deficiency of cactus, a protein-rich supplement should be supplied. A supplement comprising one-third bone meal, one-third common salt and one-third urea can be used. Another possibility is a ration consisting of cactus meal and 6.5% of fishmeal, which will supply the needs of sheep.

The most suitable supplement for cactus meal is alfalfa, either meal or hay. It is recommended to provide 100 g of alfalfa in summer and 200 g in winter, with cactus *ad libitum*. Any other hay legume with a reasonably high protein content could be used instead of alfalfa. Cactus cladodes are an excellent succulent supplement on dry Karoo range (shrub type veldt, high in protein), or in dry grass range during winter, with a protein-rich supplement.

LAXATIVE ACTION

A problem experienced when cactus cladodes are fed in any form to sheep and cattle is the severe laxative action. This laxative action is not a disease symptom and has no detrimental effect on the animal’s health. It is the result of a fast passage through the digestive system. The laxative effect can be curtailed by:

* Feeding fodder lime (approximately 3% of the total intake), to counteract acidosis. The high acid content of cactus cladodes is related to the Crassulacean Acid Metabolism of the plant.
* Limit access of the animals to drinking water.
* Feed hay with cactus cladodes. Hay as a supplement retards the laxative effect. Alfalfa hay is regarded as an exceptional supplement to spineless cactus cladodes in any form.

CULTIVATION OF OPUNTIA FOR FODDER PRODUCTION: FROM RE-VEGETATION TO HYDROPONICS

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INTRODUCTION

Opuntia or nopal is cultivated for fresh fruit production in Chile, Italy, Mexico and the USA, and interest is also growing in many other countries. The main physiological advantage of opuntia is its high water use efficiency, with production of 1 kg DM per 162 kg water intake in *Opuntia ellisiana* (Han and Felker, 1997). However, adoption of fruit production in countries without a tradition of consumption or with no immediate access to export markets is slow and difficult. The experience of Brazil has demonstrated that utilization of opuntia as a forage is easier to integrate into the farming systems of semi-arid regions, where the cultivation of cactus for forage dates back to the early 1900s, and at present there are more than 300 000 ha planted (Russell, 1990). No appreciable use of fruits is reported.

Plantations of opuntia for specialized forage production are not widespread in Mexico, as wild populations provide reservoirs of forage for livestock. However, these wild stands are endangered due to intensive exploitation and severe frosts. Plantations of opuntia for forage production could reduce the pressure on the natural stands while improving the profitability of dairy and meat operations.

Opuntia tolerates a variety of growing conditions, but productivity in its natural habitat is limited by drought and poor soils. When *O. ficus-indica* was irrigated in Chile, yields were reported of 1.3 kg DM/m^2/yr, including 0.3 kg/m^2/yr as fruit (Acevedo *et al.*, 1983). Assuming 10% moisture content, the yield of fresh pads for animal consumption reaches 100 t/ha/yr.

Computer models indicate that productivity could be increased by 40% by modifying planting layouts (García de Cortázar and Nobel, 1986).

In this chapter, some of the physiological bases for forage production are reviewed. Three production systems differing in cultivation intensity are discussed:

(xii) extensive, low-cost plantations aimed at reducing desertification and producing forage;
(xiii) small, intensively managed orchards, demanding high labour and inputs; and finally
(xiv) hydroponic production.

These systems have been studied in Mexico for growing opuntia under rainfed or limited irrigation conditions for forage, fruit or vegetable production. For vegetable production, crop management practices have been adapted to produce mature cladodes for fodder. This information could be applicable with minor adaptation to other semi-arid regions of the world in which opuntia has shown promise.

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FACTORS ASSOCIATED WITH OPUNTIA FODDER PRODUCTION

The cladode as a water reservoir

Anatomically, the opuntia plant has a jointed succulent pseudostem, with cladodes differing in water content according to age. Younger cladodes have the highest moisture content, with mean values of 90.8, 89.1 and 83.4% for young, mature and older cladodes, respectively (Flores *et al.,* 1995). Minerals show a similar trend, with N, P, K, Mn, Zn and Na decreasing, and Mg increasing, in older cladodes of *O. amyclaea* Tenore (Lopez *et al*., 1988). Young cladodes are more palatable due to their low fibre content.

Cladode shape has evolved to store the maximum amount of water with minimum loss (Nobel, 1994). A cross section of this organ shows that the innermost tissue is spongy, with large cells adapted to store water. During drought, water is preferentially lost from the water-storage parenchyma rather than from the photosynthetic chlorenchyma (Nerd and Nobel, 1991). The chlorenchyma is also protected by a waxy epidermal layer that restricts water loss. Opuntia is a Crassulacean Acid Metabolism (CAM) plant (Gibson and Nobel, 1986), associated with built-in features to save water during the photosynthetic process, including, *inter alia,* nocturnal stomata opening for CO_2 intake.

Length of growing season

Disregarding the planting season – early spring or late autumn – opuntia produces at least one flush of new cladodes arranged in layers. Rainfed conditions common in semi-arid central Mexico, with 300 to 450 mm of rainfall annually, induce the formation of a single layer of new shoots during early spring, which continues until the end of summer. Adequate water and nutrient supply combined with suitable temperatures may induce the formation of three new layers of cladodes per season, as observed by Mendéz *et al.* (1999) in the hydroponic cultivation of spineless varieties.

If the plant is not managed or disturbed, these cladodes will be mature at the end of the growing season. Lower temperatures in autumn and winter induce dormancy. Throughout the winter season the cactus loses some water as a result of drought and transpiration losses, and can be used advantageously as a forage. Cladodes can remain on the plant and be either browsed by the animals, or “harvested” according to needs (using the plant as *in situ* live storage), or collected and stored for latter use. Fibre and dry matter content increase with age, but, if properly cleaned and chopped, cladodes up to three years old can be utilized to feed livestock.

Propagation

The basic meristematic unit in opuntia (and the cacti in general) is the areole (Gibson and Nobel, 1986). They are helically positioned on the cladodes (Sudzuki Hills, 1995) and can develop either branches or flowers (Boke, 1980) or roots. The cladodes can initiate the rooting process soon after they come in contact with soil. Soil moisture is important – but not limiting – for rooting, because the root initials are supported by the water stored in the cladode.

If the cladodes are detached from the mother plant they undergo a healing and suberization process, which seals the potential sites of additional water loss. The immediate release of mucilage by wounded cells enhances and accelerates healing. Once suberized, each piece can act as an independent propagule. The water stored will support transpiration, and the formation of new shoots and root initials if placed in the ground. The cladode can sustain water loss for a long time: up to six months without losing viability if stored in a shaded location.

According to Nobel and Castañeda (1998), the unrooted cladodes of *O. ficus-indica* remain alive for at least 12 months. This feature is particularly useful for animal feeding, as cactus cladodes can supply and partially substitute the water needs of livestock for a long period. Any other traditional source of fodder available during the dry season in semi-arid zones (cereal straw, maize, sorghum or millet stubble) is stored dry, requiring additional water to be ingested. Consumption of 40 kg of opuntia per day by cattle provides 35 litre (85%) of water (Felker *et al.*, 1977)

Initiation of new organs on cladodes of *Opuntia ficus-indica* maintained unrooted in a glasshouse was greatest when the cladodes were detached in winter (Nobel and Castañeda, 1998). The response to cladode excision is very rapid, and enables the cutting to establish rapidly a relationship with the soil. The stimulus to cell differentiation and multiplication may occur within the first 48 hours, and root primordia emergence may take as little as two weeks (Fabbri *et al*., 1996).

The size of the cladode does not affect the ability to form shoots or roots (Mondragón and Pimienta, 1995), but the size of the cladode is correlated positively to the number and size of the new shoots. Luo and Nobel (1993) found that, under greenhouse conditions, growth of new cladodes is markedly influenced by the dry weight of basal cladodes, which act as a carbon source for the new shoots. Whole cladodes are able to produce at least one layer of new shoots a year, depending on cultivar and the soil moisture available during the growing season. A new plant can be formed as long as there is an areole at the top and at the bottom of the cutting, and the first layer can have anywhere from 2 to 6 pads.

Better establishment and shorter time between planting and the first harvest are achieved with large cuttings composed of more than one cladode. However, the investment in handling and transportation of this type of material increases accordingly. This is a reasonable alternative only in those areas in which opuntia cultivation is traditional, and there is a continuous supply of planting material. Healthy, vigorous branches with two to three pads are the best choice.

New plantations can be undertaken even if there is no soil moisture available, using entire cladodes or fractions according to availability of planting stock. In extensive, low maintenance plantations this is a unique feature that confers advantage to opuntia over some trees and shrubs commonly used against desertification (e.g. *Eucalyptus* spp., *Casuarina* spp. and *Atriplex* spp.), which rely on soil moisture at planting for successful establishment.

The succulence of the propagule is a disadvantage when establishing large plantations, due to its weight compared to ordinary budwood or stem cuttings in other species (Fabbri *et al*., 1996).

Response to pruning

Opuntias can endure heavy and continuous pruning. In frost-free locations, pruning can be performed at any season. Orchards devoted to fruit production are pruned after harvest, at the end of the growing season. Bud emergence is heavier if plants are pruned during the growing season. In most cultivars, the vegetative growth overwhelms the reproductive growth. The plant can be maintained in the juvenile stage indefinitely by continuous pruning, which is the basic crop management tool for vegetable opuntia production. If not pruned, the cladodes will continue growing until autumn, giving rise to flowers at the beginning of spring. Development of floral buds is mostly observed in mature cladodes that are at least six months old (Pimienta, 1990).

Disregarding the planting system, plants can be pruned down to the initial cladode if needed. However, pruning intensity should be adjusted in the light of rate of recovery, future plant productivity and fodder quality. Efficiency of animal utilization of pruning waste of different ages and quality should also be balanced against fodder needs.

The number of buds available to form new cladodes depends on the number of pads. Planting systems using bushy plants at low planting densities are more productive (on a per-plant basis) than high-density (using short plants) systems. High density planting systems therefore can withstand heavier pruning.

In locations with mild winter temperatures, the plants can be induced to continuously bud if winter protection of some sort is provided, along with irrigation and fertilization. This interesting feature is the basis of out-of-season production of vegetable opuntia across central Mexico and southern Texas. Application of high manure rates to soil and pruning are responsible for the high yields observed in vegetable production in Milpa Alta, Mexico, which can reach 400 ton/ha/year (Nobel, 1994). In general for cladode production, either tender or mature, the productivity of the crop should be tightly regulated by pruning practices.

Growing opuntia for forage production needs careful timing of pruning practices. Cladodes stored "on the plant" maintain a higher water content than the detached ones, while labour and storage needs are reduced. However, it is advisable to remove them just before the start of the next growing season, to avoid sprouting of new buds.

Response to fertilization

Cacti in general present low productivity due in part to the limitations imposed by the natural environment in which they grow. Wild opuntia stands are usually found in poor soils with low contents of dry matter, in regions with a short growing season that does not allow the full expression of their growth potential.

Fertilization trials conducted in Mexico and other countries (Mondragón, 1994; Karim *et al*., 1996) showed that fertilizers induce higher yields of fruits and cladodes. Combining manures with synthetic fertilizers gave the best results in fruit orchards. The reactivation of buds and the increase in size of the cladodes are immediate effects of fertilization, which can be advantageously manipulated for forage production. Higher N application (from 0 to 160 kg/ha) increased the number of new cladodes of *O. engelmannii* in Texas. The individual cladodes were slightly thicker, leading to 12% dry weight enhancement per cladode at the high-N level (Nobel *et al*., 1987).

Fertilization increases yield as well as nutrient content, according to González (1989). *O. lindheimeri* (Engelm) fertilized in the spring for three consecutive years showed increased protein levels of 3.1, 4.2 and 4.4 percentage units in response to applications of 67, 135 and 224 kg N/ha, respectively.

The efficiency of fertilizers and manures in semi-arid environments, however is strongly influenced by soil moisture. Therefore, fertilization should be spared for those years and seasons in which the amount of rain can guarantee its efficacy.

Response to high planting densities

High inter-plant competition reduces the reproductive ability of opuntia plants, leading to extended juvenility and generation of new cladodes, which is the objective in forage production. This effect is enhanced in the broad-bed system, which allows minimum space for individual plants. The basis of productivity from high planting densities is the total biomass production, even though individual plants may have a small yield. In contrast, a row layout allows higher individual yields with a fairly low planting density and facilitates mechanization.

Opuntia is affected by shading at any stage of growth. The thickness of the cladodes as well as the plant architecture tends to reduce photosynthetic efficiency. The most important limiting factor in high density plantings is photosynthetic active radiation (PAR), as found by García de Cortázar and Nobel (1986) using computer simulation models validated with field studies conducted under irrigated conditions in Chile. Water and temperature were found to be of secondary importance for plant productivity. Increasing Stem Area Index (SAI) or cladode area per unit ground up to 4.0 for plants that are 5 cladodes tall, productivity could be increased by up to 40%. Orientation of initial cladodes had no significant effect.

Typical plantations for vegetable production in Milpa Alta Mexico are done in furrows, training the plant to obtain a compact low height (<1.5 m) bush, with around 40 000 plants per hectare (80 × 40 cm). Similar planting methods in rows are used in Brazil to grow opuntia for fodder. Empresa Pernambucana de Pesquisa Agropecuaria (undated) recommends two planting layouts: 100 × 25 cm (40 000 plants/ha), which are more intensive than the traditional planting method using 2 m between rows and 1 m between plants. Two years after planting, the reported yields were 246 ton/ha for the high density planting versus 100 ton/ha for the low density plantation. Both systems were supplemented with fertilizers or manures. These observations support the trend of using higher planting density in Brazil.

EXTENSIVE CULTIVATION OF OPUNTIA FOR FORAGE IN ECOLOGICALLY-ORIENTED PROGRAMMES

Opuntia has been the plant of choice for socio-ecological-oriented plantations in northern Mexico. It has been used as a government employment strategy in semi-arid areas, justified by the potential ecological impact in areas depleted of their natural opuntia vegetation. The extent of over-exploitation of opuntia for fodder in northern Mexico was highlighted by Lopez *et al.* (1997), indicating that in the 1970s, opuntia was collected from sites located within a radius of 20 km around the main cities, while in the 1990s the distance had increased to more than 120 km.

Flores and Aranda (1997) reported that there were 3 million ha of scattered wild opuntias in northern Mexico, with another 150 000 ha planted by ranchers with government support, with the aim of increasing the availability of forage, providing refuge for the local fauna, and countering desertification. Plantation sites occupy areas where wild opuntias formerly grew. Attempts to introduce selected genotypes have been unsuccessful, so native species are preferred. Cultivation of cuttings from frost-tolerant selections has been also reported (Borrego *et al*., 1990). Extensive plantations of wild *O. engelmannii* Salm-Dick and *O. rastrera* Weber were reported by Medina *et al.* (1987).

Soil and crop management are kept to a minimum; flat terrain is preferred, without removal of initial vegetation. The opuntia is planted in furrows following contour lines, laid out with a disk. Once cactus is established – after 2-3 years – undesirable vegetation is removed and pasture grasses are seeded.

MINIMUM REQUIREMENTS FOR EXTENSIVE PLANTATIONS

Opuntia plantation on an extensive scale (>1000 ha) should be undertaken applying the same technical criteria as for smaller, commercial orchards. However, due to the limitations of the criteria used for conservation and land reclamation projects, such projects usually suffer from careless planning, deficient operation and lack of basic horticultural principles. A few points to consider are listed in the sections below.

Site selection

Even though it is imperative to reclaim all areas affected by desertification, new projects should to be directed to the least affected spots, and then gradually move onto more problematic areas. This strategy allows users to obtain faster results, while the costs of reclamation are reduced.

Select sites with the least restrictions for implementation of simple water harvesting and soil conservation techniques, soil preparation of light-slope terrain (<4%) can be done with standard agricultural machinery. Contour planting is the simplest and cheapest technique, which can be enhanced by drawing furrows close to the plants to collect rainwater to the benefit of the opuntia.

Opuntia is a perennial plant, and so it deserves care to obtain fast and sustainable yield of either cladodes or fruits. Projects that include opuntia should regard at least three years as the minimum period to assess genotype adaptation and forage productivity. The final length of this period should be adjusted according to local climatic criteria, such as the precipitation recurrence period.

Site protection

During the establishment period (1 to 2 years), opuntia needs protection from predators, and controlled livestock consumption should not start until after this period. Protection of the site is required to avoid overgrazing and destruction of the newly planted cladodes.

Planting material

Native species are to be preferred. Species that have been extensively used represent a resource that is vanishing and needs the opportunity to recover. Its suitability as animal feed is already proven by depletion! Select plants that are indigenous to the region. Mature and old plants that have survived unusual frost and drought events should be multiplied and reintroduced. Spiny species are more resistant to herbivore predation.

Collection of planting material from wild stands

Even under limiting conditions there are spots where water and soil collect; abandoned anthills and rodent burrows also provide better growing conditions for cactus plants, promoting vigour and cladode production. These spots are the best for selection of planting material. Pre-conditioning of planting material (partial dehydration) can be eliminated when planting in dry soil.

Planting techniques

Using two cladodes per planting spot increased the success of plantation to 95% in a reforestation trial conducted at Coahuila, Mexico, using *O. rastrera* and *O. lindheimeri* (Tores *et al*., 1990). Manually building an individual micro-catchment around the plant improved utilization of the scarce rainwater available in the region (mean annual precipitation of 327 mm).

Fertilization

Save the application of synthetic fertilizers for those years with above-average rainfall. Utilization of manure from local sources is the best choice, due to its long-term effect. The rate of manuring is limited only by local availability; responses to extremely high doses of manure have been reported in Milpa Alta, Mexico, where rates exceeding 200 ton/ha every other year are common.

Utilization

Use rotational, controlled harvesting according to site productivity. Avoid methods that lead to total destruction of the plant, such as non-selective burning and uprooting. Leaving a high number of branches allows faster plant recovery.

INTENSIVE CULTIVATION OF OPUNTIA FOR FORAGE PRODUCTION

Some of the developments intended to improve *nopalitos* (tender cactus pads used as a vegetable) production can be adapted towards similar systems for forage production.

Opuntia is a plant that tolerates competition and heavy pruning. The entire aerial part can be utilized as a forage if needed. It also shows a notable response to manure and chemical fertilizers. Manipulation of planting densities and plant nutrition allow large yields of fresh pads. The broad-bed planting system takes advantage of all these features. It was proposed for use in small plots (<0.5 ha) in the backyard or near the household. These spots are usually more productive than the open fields (due to the accumulation of domestic waste), and in some places they have access to limited irrigation. Both these factors benefit plant productivity. The labour needed to maintain the plot is provided by the family.

The system can produce fresh tender pads (an advantage where there is a tradition of consumption) and/or mature pads for forage. Production is higher during the summer season (the rainy season in Mexico). Longer production periods are feasible in frost-free places or by providing some sort of frost protection.

Site selection

Planting sites are more convenient if located near to the household or in a backyard, which allows for continuous care and protection. If plantations are to be located in the open field, then select the plot with easiest access. Fresh opuntia pads are heavy feedstuff, therefore it is necessary to ensure quick access to roads in good condition at any season of the year.

The site should be preferably flat, but slopes up to 3% can be handled with simple soil and water conservation practices, such as contour planting, without increasing cost of site preparation.

Land preparation

Eliminate perennial weeds or shrubs. Till the soil to facilitate broad-bed formation. Depending on the soil type, it is advisable to plough it twice. Slight terrain imperfections can be reduced by grading. Levelling the planting site improves water distribution, ensuring more uniform growth.

Rainfall management is a key issue for effective plant growth. Simple techniques that improve rainfall management have been tried successfully, the aim being to reduce runoff and impound the water *in situ* to allow better infiltration and extended availability for the crop. Rainwater can be collected on the site prior to planting if the field is ploughed in advance. After planting, the furrows that separate the beds can be "tied up" every 2 to 3 m to distribute rainwater evenly.

Cultivars

Spineless cultivars are most preferred for forage production in this system because they are easier to handle and process. They also present fewer problems during feeding. In Mexico, the cultivars Pabellón and CPF1 are the most suitable. Both are highly productive and posses large spineless pads. Pabellón has ovoid, thick, dark green pads, and the adult plants produce red, tasty fruits. CPF1 produces long, thin, green pads, suitable for consumption as a vegetable when tender. The fruits of this cultivar are white, with thin pericarp and slight blush. Under rainfed conditions, at least one flush of pads per growing season is produced.

Irrigation and fertilization can induce more than one layer of pads per season and increase yield. Recorded yields of fresh mature pads without irrigation in central Mexico are 75 and 118 ton/ha for Pabellón and CPF1, respectively.

Propagation material

Planting material should be collected from robust, productive and healthy plants. The pads can be collected at the end of the growing season and subjected to slight dehydration to induce suberization of the joints. Collect pads of medium to large size, devoid of suspicious dark spots or discolorations. After collection, they are stored in a shaded dry place for 2 weeks. Pad portions can also be used when planting material is scarce, but the smaller the portion, the longer the time new shoots will require to reach full size. The smallest portion that can be planted should have at least two to three areoles in each face.

To reduce rotting, the pads are treated with Bordeaux mixture prepared on the same day as treatment. Mix 1 kg of copper sulphate in 5 litres of warm water until completely dissolved, then add 1 kg of lime, stirring until the mixture is homogeneous, and then dilute to 100 litres (enough to treat up to 2000 pads).

Plantation layout

The broad-bed system provides high planting density and productivity per unit area. Several options are possible, according to the machinery available. In the authors' experience, the best dimensions of the broad-bed are 150 cm wide with a 120 cm top, and the length is adjusted as needed. Broad-beds are built using a small (120 HP) tractor or animal-drawn device. Three or four rows of pads are aligned on top of the broad-bed with a separation of 30 cm between rows and 40 cm between pads in the row. Eliminate any buds or roots that have sprouted during storage, which most likely will be misplaced as they can interfere with the planting operation. The pads are buried halfway into the ground. Using these dimensions, 20 pads are needed for each 2-m broad-bed length.

Planting date

Tender shoots are highly susceptible to frost damage, and they start emerging 2-3 weeks after planting. Therefore planting should be done after risk of frosts is over. A safe lower limit temperature would be 5°C for most cultivars.

Fertilization

To ensure high yields, it is convenient to apply manure prior to planting. Manure can be broadcast and ploughed in prior to planting. The best results are obtained when manure is supplemented with synthetic fertilizers. Chemical fertilizers are a quick source of nutrients, while manure represents a longer-term, steady supply. A minimum of 20 ton/ha of cow manure every other year, supplemented with 90-40 (kg of $N-P_2 0_5$) supplied annually are suggested. These rates have to be adjusted according to the source. Chemical fertilizers can be applied during the rainy season, providing half of the nitrogen fertilizer early in the season and the rest 45 days later. The product is spread along the rows and lightly covered with soil (Mondragón, 1990).

Weed control

Once planted, opuntia can serve as a nurse plant for many weed species, so periodic weeding becomes an integral element in crop management. Maintain the plot free of perennial weeds and shrubs to eliminate competition with opuntia. Weed control between the beds can be accomplished either manually or by using herbicides. Felker (1988) reported the use of glyphosate at 20 g/litre of the commercial formulation ("Roundup") used as a broadcast post-emergence spray to control Johnson grass (*Sorghum halepense*) and Bermuda grass (*Cynodon dactylon*).

Management of pests and diseases

Pests that thrive inside the pads are the most destructive and difficult to control. However selective pruning can help to maintain a healthy plantation. Some rotting problems can also be solved by pruning. Some pests that live on the surface of the pads, such as mealy bugs and thrips, can be controlled with contact insecticides. Effective control has been achieved by spraying with dithiocarbamate at 1 kg/200 litre of water.

Harvesting

Mature pads can be collected at the end of the growing season. They are detached from the plant using a sharp knife, with a clean stroke right in the joint. Avoid unnecessary chopping of the harvested pad or the plant, to reduce risk of rotting. The number of pads to be harvested varies with cultivar and age of the plant. During the first year, 2-4 pads per plant can be collected. In order to get steady yield, the plants are left with only two branches ("rabbit ears") oriented along the broadbed. Cactus pads can be consumed directly on the plants, but uncontrolled browsing can cause damage. It is more efficient to collect and store them close to the livestock yard until needed.

Storage

Fresh pads should be stored in a shady dry spot. They can be either stacked or arranged in rows sitting on their sides. Avoid spots that collect runoff in order to minimize rotting or sprouting. Those pads in close contact to the ground need to be flipped over every 4 to 6 weeks to avoid rooting. Some relief from direct sunshine can be obtained with a thin layer of dry straw spread on top of the stored pads. Direct sunshine induces pad deformations and chlorophyll degradation on the exposed area, thus reducing nutritional quality. Under the semi-arid cool conditions of central Mexico, the authors have stored pads for up to six months without appreciable losses.

HYDROPONIC CULTIVATION

Although water has been considered to be a renewable resource in some areas, population growth and urbanization are changing the scenario. Initiatives to improve water management in urban as well as agricultural lands are increasingly required. Hydroponics is perhaps the last frontier for opuntia fodder production: it can be adapted to arid areas where the availability of water for irrigation is restricted and there is strong pressure on grasslands. Hydroponics also improves nutrient use efficiency.

Hydroponic modules could allow the efficient utilization of limited volumes of water to produce food or forage crops, improving rural income. Some systems are relatively easy to handle and could be quickly adopted. The size of the hydroponic operation can be adjusted to other farm operations, and farmers could consider it as a part-time occupation and self-employment strategy.

In Mexico, some of the most traditional growers are hesitant to use hydroponics, although commercial modules to produce export-quality vegetables are becoming fashionable in central and northwest Mexico.

Small-scale hydroponics possesses special significance for arid and semi-arid zones, where agricultural production is limited by low water availability. In many of these areas, there are shallow artesian wells and intermittent water sources that can provide enough water to irrigate plant species such as opuntia, characterized by its high water use efficiency and productivity. Opuntia can produce up to 47 t/ha/yr as irrigated high-density plantations in open fields, which is higher than C_3 and some C_4 plants (Nobel, 1998).

Exploratory trials conducted in central Mexico showed that hydroponics may play an important role in fodder production in extreme climates. The results of three of these trials are discussed below.

HYDROPONICS: ADVANTAGES AND DISADVANTAGES

Hydroponics literally means "waterworks," and includes all methods and systems to grow plants without soil (Steiner, 1977; Douglas, 1985; Gómez 1995). According to Durany (1982), the most common hydroponic systems are:

Cultivation in liquid media. In this system, the plants have their roots immersed in the nutrient solution and the type of support depends on the crop.

(iii) Cultivation on solid, inert and porous substrates. In this case, the plant anchors to the substrate and acquires the nutrient solution by percolation.

Sub-irrigation belongs to the latter type: the nutrient solution is provided and drained through the same inlet (Steiner, 1977). The system is "closed" and recycles the nutrient solution every two to six weeks (Resh, 1987). Numerous variants of this type have been developed using the latest technological advances.

Hydroponics promotes efficient water and nutrient use. Compared to traditional agriculture, hydroponics uses only an insignificant fraction of the water. Hydroponics allows the use of poor quality water, either moderately saline or alkaline. Some disadvantages are: high energy input (gas, gasoline, oil and electricity) and initial investment. Basic water-quality analysis and some training are needed to prepare and maintain the nutrient solutions. The availability of simple instruments to determine pH and electro-conductivity should also be considered.

Hydroponics ensures better stand establishment, leading to higher densities, saves water and nutrients, and provides some protection against limiting climatic factors such as drought and light frosts. Well-fed plants tolerate cold temperatures better and recover faster from frost damage.

THE SYSTEM

The system utilized to grow opuntia was sub-irrigation, using lava as growing media. The system includes :

(xvii) Storage tank for the nutrient solution.

(xviii) Planting benches. Rectangular shaped and arranged in five pairs, they covered 18 m^2 each (15×1.2 m) and were 30 cm deep.

(xix) Growing medium. Red volcanic gravel, with a granulometry between 5 and 20 mm. Gravel, crushed lava, basalt gravel, porous or non-porous or any other rocky inorganic material can also be used.

(vi) Distribution tanks. Built of mortar and bricks, they distribute and drain the nutrient solution.
(vii) Hydraulic network. A gasoline pump (4 HP) provides the power, and is connected to a network of 50 mm PVC pipes.

The nutrient solution is prepared from commercial sources (Table 50). Two methods of preparation can be used: stock solutions or a dry mix of commercial fertilizers. In both methods, the fertilizers of low solubility are dissolved in advance, then added first to the solution. The products with acid reaction are added next, followed by the micronutrients in solution.

The pH is maintained at around 6.5 by adding either phosphoric or nitric acid, according to the pH readings, with mean values of 3.5 dS/m electro-conductivity. The nutrient solution is replaced every 15 days, after plants have consumed about two-thirds of the initial volume.

Table 50. Composition of nutrient solution

Source	**Concentration** (g/m^3)	Nutrient
Potassium nitrate	150 – 250	N
Phosphoric acid	40	P
Potassium sulphate	289.4 – 350	K
Calcium nitrate	210	Ca
Magnesium sulphate	40	Mg
Ferrous sulphate	12	Fe
Copper sulphate	0.1	Cu
Zinc sulphate	0.2	Zn
Boric acid	0.6	B

Source: Calderón, 1995

The nutrient solution moves out to the storage tank due to the suction exerted by the pump, then it is deposited in the check tanks to feed the distribution network and fed to the growing benches. The same negative pressure forces the solution up to the surface of the planting medium. Once the solution floods the medium, the pump stalls and drainage begins by gravity. The growing benches are fed in pairs. The nutrient solution is briefly in contact with the roots, reducing evaporation and potential rotting problems. The key mechanisms of the system are the recirculation and efficient drainage of the solution.

Planting material. Spineless accessions from central Mexico with previous records of high productivity under open field conditions were selected for the trials. They were provided by INIFAP (National Institute of Agricultural, Forestry and Husbandry Research). The plants were allowed to grow freely and a single yield evaluation was performed after six months. The variables included cladode length and width, plant diameter and number of shoots, and fresh and dry weights. The tissue was sampled and sent for nutrient analysis.

Effect of irrigation schedule and planting method. Two cladode orientations – NS and EW – as well as two planting positions – vertical buried vs. horizontal on top of the soil – were studied. Once the plants were established they were subjected to four irrigation schedules: twice a day every day; twice a day every other day; once a day every day; and once a day every other day. Recorded variables were establishment percentage; days to budding; number of shoots; and yield on a fresh (FW) and dry weight (DW) basis.

The tissues collected from the 15 most productive accessions were analysed for bromatological parameters, neutral and acid detergent fibre (according to Goering and Van Soest 1970), as well as *in vitro* digestibility.

GENOTYPE PERFORMANCE

All accessions responded well to cultivation in hydroponics and a positive correlation between number of shoots and weight was detected. No reduction was observed in dry weight associated with higher number of shoots. After six months, the average number of mature pads was 10.2 (ranging from 1 to 18 pads per plant), 97% of the accessions presented two or more layers of pads and cv. Valtierrilla yield was larger (Table 51). The morphological and phenotypic features did not change significantly in hydroponic cultivation. An interesting observation was that *O. robusta* initiated budding at the same time as in the wild. Average fresh weight per pad was 475 g, reaching a yield of 5 kg of fresh pads per plant in six months.

Considering the maximum values of number of cladodes per plant (18) and cladode weight (845 g), the experimental yields could reach 15 kg fresh weight per plant with cv. Selection 34 and cv. Milpa Alta. If a hydroponics module has a planting density of 30 000 plants/ha, the potential yield could reach 450 ton/ha on a fresh weight basis in six months: sufficient volume to be the sole feed source for a herd of 30 cows for 180 days, or 523 pregnant sheep for 3 months. The authors' observations confirmed the findings of Calderón (1995).

The N content in cladode tissue ranged from 1.73 to 4.02% on dry basis (Table 52), supporting the report that N content in opuntia is higher than the best grass, Nobel (1998). According to the analysis, cv. Valtierrilla and cv. Tapón Hembra showed an N content above 4%. If this value is converted to protein content, then opuntia can be compared to other valuable forage crops, such as alfalfa (Table 52).

Considering plant productivity, absence of spines and early budding, 17 genotypes were outstanding. Some of the accessions qualify as dual use: vegetable and fodder; or fruit and fodder. They can and do represent an important fodder source for the driest part of the year (April-May).

Reports from Lopez *et al.* (1988) indicated a phosphorus range of 0.1 to 0.5 % on dry basis as influenced by cultivar, cladode age and planting site. Under hydroponics, the average content was 0.55 %, with a maximum of 0.84% for cv. Tapón Hembra. K was the nutrient that showed the highest accumulation (mean 3.89%). Six cultivars – Pabellón, #75, Redondo, RSR, RDR and #70 – showed above average K concentrations, with 5.96, 5.75, 5.72, 5.50, 5.37 and 5.24%, respectively.

Calcium is found mostly in the cell wall of cacti, providing mechanical support to the cell. It also participates in ATP and phospholipid hydrolysis. In cacti, Ca is mostly found as oxalate crystals and druses (Gibson and Nobel, 1986). The average content of calcium in opuntia tissue varies from 2 to 9.5%, depending on plant age and soil type. Cladodes produced in hydroponics had an average calcium content of 2.66% (Table 52), with a maximum of 6.4 in cv. #V-3. A study of the chemical form in which calcium is present in opuntia is needed in order to understand its significance for animal or human nutrition.

Ash content ranged from 18.68 to 30.31%, higher than any other regional forage. Reported values (NRC, 1984) are only 7.6, 7.2 and 6.4 for oat hay, maize stover and sorghum stover, respectively. Fodder production with hydroponics could be an important source to cover maintenance and production levels of Ca, P, K and Zn.

Protein content is one of the most limiting factors for cattle raising in semi-arid rangelands (Fuentes, 1992). Wild opuntia has a range of 2.72 to 5.8% of crude protein, insufficient to provide for the needs of cattle and sheep (Table 53), leading to weight loss. Protein content in cactus fodder obtained with hydroponics ranged from 11.72 to 18.07% for cv. LCNF and cv. Pabellón Amarillo, respectively (Table 54).

These values cover the minimum requirements for grazing cattle, sheep and goats (McDonald *et al.*, 1981). The nutrients content found in some of the accessions tested are similar to those reported for good quality fodder such as alfalfa, maize silage and orchard grass (12-20, 8.4 and 15% CP, respectively (NRC, 1984)) and higher than maize stover and wild opuntia (Table 53).

Table 51. Growth features of opuntia accessions from central Mexico, cultivated in hydroponics

Accession	Cladode DW (g)	Number of cladodes/plant				DW (g/plant)
		1st layer	2nd layer	Total	Average	
Redondo	16.6	8	10	18	6.0	99.6
ACNF	27.5	8	9	17	5.6	154.0
70	21.8	13	37	40	13.3	289.0
Milpa Alta	37.1	6	13	19	6.3	233.7
Tehuacán	22.4	11	9	20	6.6	147.8
44	29.7	9	18	28	9.3	276.1
Rosalito	22.3	9	21	30	10.0	223.0
RSA	26.8	13	33	46	15.3	410.0
40	14.9	16	34	50	16.6	247.3
Villanueva	20.9	15	17	32	10.6	221.5
RSR	33.2	7	26	35	11.6	385.1
RDR	12.6	7	17	24	8.0	100.8
34	17.5	15	40	55	18.3	320.2
LCNF	28.7	7	18	25	8.3	238.2
75	13.5	9	22	31	10.3	139.0
Italiano	12.9	10	23	33	11.0	141.9
V-3	13.2	7	6	13	4.3	56.7
T-L	10.6	10	35	45	15.0	159.0
Valtierrilla*	7.6	17	4	21	13.3	101.0
V-1	13.2	11	29	40	13.3	175.5
RSB	8.9	12	32	44	14.6	129.9
R-7	19.4	11	22	33	11.0	213.4
F-1	29.5	3	19	22	7.3	215.3
AGO	29.1	8	23	31	10.3	299.0
R-72	15.2	9	25	34	11.3	171.7
Pabellón	15.2	13	24	37	12.3	187.0
COPENA	13.0	9	21	30	10	130.0
Pabellón Amarillo	23.7	8	15	22	7.3	173.0
Tapón Hembra	10.4	7	9	16	5.3	55.1
Tapón macho	4.5	3	0	3	1.0	4.5
S-34	21.5	12	29	41	13.6	292.0
S-35	7.0	5	10	15	5.0	35.0
Tezontepec	5.4	10	7	17	5.6	30.20
Irapuato	8.0	11	5	16	5.3	42.0
Control	5	0		5	1.6	8.0

Note: * = Produced more than three layers of cladodes.

Table 52. Nutrient content of 30 accessions of opuntia from Central Mexico

Accession	N %	P %	K %	Ca %	Mg %	Fe ppm	Mn ppm	Cu ppm	Zn ppm	B ppm
Redondo	2.68	0.38	5.72	1.65	1.28	135	39	3	38	42
ACNR	3.39	0.32	4.79	1.16	0.93	54	26	0	23	32
70	2.60	0.53	5.24	2.07	1.84	177	206	3	45	44
Milpa Alta	3.31	0.36	4.18	2.06	1.24	305	14	0	32	57
Tehuacán	3.15	0.67	4.58	2.00	1.71	178	24	2	50	49
44	3.70	0.24	2.20	2.70	0.87	102	153	0	20	36
Rosalito	3.23	0.56	4.59	2.32	2.15	160	56	3	53	60
RSA	3.62	0.56	4.42	1.89	1.95	159	115	0.61	41	55
40	3.62	0.71	4.81	2.91	1.83	144	331	4	63	53
Villanueva	1.73	0.43	3.12	4.95	1.65	293	92	1	34	87
RSR	2.99	0.62	5.50	1.97	2.01	233	102	3	101	58
RDR	3.15	0.48	5.37	2.99	2.27	152	363	1.27	51	67
34	2.60	0.50	3.76	2.65	1.70	149	163	1.34	49	56
LCNF	3.23	0.54	4.30	2.36	1.55	168	366	2	48	56
75	3.15	0.74	5.75	2.12	1.78	126	304	3	48	61
Italiano	3.54	0.73	4.80	2.59	1.82	105	23	0	45	92
V-3	2.99	0.60	4.11	6.40	1.84	116	300	0	42	77
T-L	3.07	0.75	4.09	2.74	1.87	152	46	3	50	62
Valtierrilla	4.02	0.59	3.42	3.68	1.72	231	307	0.74	47	98
V-1	3.39	0.53	4.77	2.31	1.59	144	32	1.40	37	63
RSB	2.91	0.66	3.92	2.77	1.84	103	136	1.19	49	74
R-7	3.62	0.60	2.75	3.09	2.00	138	65	1.78	49	64
F-1	3.54	0.58	3.33	2.35	1.51	104	95	0	42	53
AGO	3.86	0.55	2.18	3.29	1.41	108	71	0	50	50
R-72	3.39	0.50	2.47	2.43	1.63	116	370	0.91	36	69
Pabellón	3.15	0.56	5.96	2.25	1.85	114	442	1.90	46	74
COPENA	2.76	0.37	3.01	2.59	2.03	91	29	0	47	69
Pabellón amarillo	3.15	0.62	4.87	2.31	1.70	133	37	0	42	72
Tapón hembra	4.02	0.84	2.78	3.08	2.05	103	60	0.06	53	83
Tapón macho	3.62	0.46	2.98	2.23	1.54	89	64	0	48	82

DM digestibility *in vitro* varied from 84.9 to 95.5% (Table 54), above values reported elsewhere (e.g. Flores and Aguillar, 1992; Lastra and Pérez, 1978; De Kock, 1998). NDF or cell wall values were below those reported for most of the forages used in the region to feed cattle (NRC, 1984). It means a higher potentially digestible rate of cell contents, which might explain the high *in vitro* digestibility observed in cv. Pabellón Amarillo and cv. Villanueva.

Table 53. Analysis of opuntia (*Opuntia* spp.) and some common feedstuffs used in semi-arid zones compared to nutritional requirements of cattle and sheep(1)

	ME (Kcal/kg DM)	Protein (%)	Ca (%)	P (%)	Na (%)	DMC(4) kg
Alfalfa	2.10	17	1.41	0.24	0.12	
Corn stover	1.81	6.6	0.57	0.10	0.07	
Opuntia		4	1.4	0.2	0.1	
Nutritional requirements(1)						
Cow(2)	2.21	10.32	0.29	0.21	0.1	9.66
Sheep(3)	1.92	9.55	0.37	0.23	0.1	1.3

Notes: (1) Nutritional requirements based on NRC, 1984. (2) Cow of 450 kg liveweight producing 3 kg milk/day. (3) Sheep of 45 kg liveweight in the last third of pregnancy. (4) DMC = Dry matter consumption.

Table 54. Nutrient content and *in vitro* digestibility of opuntia grown in hydroponics

Accession	DM (%)	Ash (%)	Crude protein (%)	ADF (%)	NDF (%)	Cellular content (%)	Hemi-cellulose (%)	DM *in vitro* digestibility (%)
Italiano	94.61	24.01	17.78	18.67	29.42	70.58	10.75	88.4
40	92.90	25.44	16.25	23.01	35.71	64.29	12.70	87.2
34	92.79	26.37	15.28	19.66	27.63	72.37	7.97	89.9
RDR	93.17	26.28	15.21	23.6	26.71	73.29	3.11	86.7
LCNF	92.59	28.59	18.07	24.78	30.35	69.65	5.57	87.8
Villanueva	92.96	30.31	15.55	21.17	39.27	60.73	18.10	84.9
Tehuacán	93.75	22.35	15.77	14.45	32.26	67.74	17.81	91.3
75	92.65	27.37	15.25	16.20	32.23	67.77	16.03	87.2
70	92.94	22.51	13.67	20.08	37.42	62.58	17.34	84.8
RSR	93.19	23.52	15.91	20.21	37.23	62.77	17.02	91.5
Rosalito	92.75	28.40	15.58	20.78	34.98	65.02	14.20	92.4
AGD	92.32	26.01	16.41	21.97	33.97	66.03	12.00	90.6
44	93.17	28.07	15.86	21.00	33.36	66.64	12.36	22.6
COPENA	92.39	24.59	16.55	18.53	33.08	66.92	14.55	91.9
P. Amarillo	92.77	18.68	11.72	18.37	37.10	62.90	18.73	95.5

Key: ADF = acid detergent insoluble fibre. NDF = neutral detergent insoluble fibre.

Wild opuntia is an important source of water during the dry season; there are reports of cattle feeding on opuntia for 400 to 525 days using opuntia as the only source of water. However, moisture content of forage obtained in hydroponics ranged from 90-92%, which could limit usefulness. DM requirements would be difficult to meet because of the associated high volumes of consumption, as cattle would have to consume 90-100 kg/day of fresh opuntia fodder. An interesting possibility is the use of dehydrated opuntia, or its combination with other sources with low moisture content, like maize and sorghum stover, dry bean straw, etc. Considering agronomic as well as nutritional criteria, the best selections were "34", "70", "40" and "LCNF."

Nutrient accumulation value is obtained by multiplying DW by the nutrient concentration and dividing into 100, which is the nutrient content in grams accumulated in the cladode during a specific period. In this study, it corresponds to six months (Table 55). The extraction order for the main elements was K, N, Ca and P, with mean values of 0.77, 0.60, 0.48 and 0.09 g, respectively. High extraction results from high DM production and high concentration. Regarding N accumulation in cvs Milpa Alta (1.22 g), AGO (1.12 g) and Selection 44 (1.09 g) had the highest values, while for P cvs RSR (0.20 g) and F-1 (0.17 g) had the highest values. In the case of K, the genotypes with the highest accumulation were Milpa Alta (1.55 g), LCNF (1.23 g) and Pabellón Amarillo (1.15 g). Significant Ca accumulation was recorded for cvs Villanueva (1.03 g) and AGO (0.95 g).

Effect of irrigation schedule and planting method

Plant survival varied from 70.2 to 88%; the failures were attributed to rotting, probably due to origin of propagules, as planting material was collected from a previous hydroponic unit and was more succulent than regular material collected from commercial orchards.

Bud emergence started in February, simultaneously with late frosts, but a second flush was observed in March, except for cv. Río Verde and cv. Tapón Hembra, which generated vegetative buds until April. There were large differences in FW and DW among irrigation schedules ($p<0.05$), irrigating twice a day every other day was significantly superior to the rest of the irrigation treatments: the yield differences were attributed only to cladode size (Table 56). Cladodes planted in the vertical position and N-S oriented presented a higher number of shoots and higher yield (Table 58).

It is feasible to produce high quality fodder under hydroponics during the dry season when other sources of fodder are scarce. The best results are obtained by irrigating twice a day every other day. We detected four outstanding genotypes, namely "34," "70," "40" and "LCNF," which produce tender cladodes of good quality for consumption as vegetables, and mature cladodes for fodder. The system allowed an efficient use of water and nutrients, making it competitive with other, traditional systems.

Table 55. NPK and Ca accumulation in 30 accessions of opuntia grown in hydroponics

Accession	**DW** (g)	**Accumulation** (g)			
		N	P	K	Ca
1. Redondo	16.6	0.44	0.06	0.94	0.27
2. ACNF	27.5	0.93	0.08	1.31	0.31
3. 70	21.8	0.56	0.11	1.14	0.45
4. Milpa Alta	37.1	1.22	0.13	1.55	0.76
5. Tehuacán	22.4	0.70	0.15	1.02	0.44
6. 44	29.7	1.09	0.07	0.65	0.80
7. Rosalito	22.3	0.72	0.12	1.02	0.51
8. RSA	26.8	0.80	0.15	1.18	0.50
9. 40	14.9	0.53	0.10	0.71	0.43
10. Villanueva	20.9	0.36	0.08	0.65	1.03
11. RSR	33.2	0.99	0.20	1.82	0.65
12. RDR	12.6	0.39	0.06	0.67	0.37
13. 34	17.5	0.45	0.08	0.65	0.46
14. LCNF	28.7	0.92	0.15	1.23	0.67
15. 75	13.5	0.42	0.09	0.77	0.28
16. Italiano	12.9	0.45	0.09	0.61	0.33
17. V-3	13.2	0.39	0.07	0.54	0.84
18. T-L	10.6	0.32	0.07	0.43	0.29
19. Valtierrilla	7.6*	0.30	0.04	0.25	0.27
20. V-1	13.2	0.44	0.06	0.62	0.30
21. RSB	8.9	0.25	0.05	0.34	0.24
22. R-7	19.4	0.70	0.11	0.53	0.59
23. F-1	29.5	1.04	0.17	0.97	0.69
24. AGO	29.1	1.12	0.16	0.63	0.95
25. R-72	15.2	0.51	0.07	0.37	0.36
26. Pabellón	15.2	0.47	0.08	0.90	0.34
27. COPENA	13.0	0.35	0.04	0.39	0.33
28.Pabellón Amarillo	23.7	0.74	0.14	1.15	0.54
29. Tapón Hembra	10.4	0.08	0.06	0.35	0.38
30. Tapón Macho	4.5	0.16	0.02	0.13	0.10

Table 56. Effect of irrigation schedule on number of shoots, dry weight and yield of forage opuntia

Irrigation frequency	**Shoots/plant**	**FW** (g)	**DW** (g)
Once a day	4.65	875.85 b	65.73 b
Twice every other day	5.07	1401.4 a	84.20 a
Twice a day	4.1	1080.8 b	75.11 b
Once every other day	5.1	574.7 c	52.07 c

Note: Different letters in the same column indicate significantly ($p<0.05$) different means

Water use efficiency

All genotypes tested presented higher WUE compared to the control (Table 59). RSA, Villanueva and 43 appeared superior. The WUE values observed are lower than the data reported by de Kock (1998) for irrigated opuntia.

Table 57. Biomass yield of opuntia grown in hydroponics

Accession	**FW** (g/plant)	Accession	**FW** (g/plant)
34	1559.02	75	803.36
70	1398.47	Copena	772.77
40	976.34	Acnf	710.08
Villa Nueva	956.50	Pabellón	692.14
Milpa Alta	883.79	Tehuacán	685.84
Pabellón Amarillo	873.84	Irapuato	679.10
RDR	870.27	TL	588.05
44	858.18	LCNF	528.26
F5	823.40	Mayero	520.51
S36 V8	822.04	Italiano	476.96
RSR	821.54	RSB	325.41
Rosalito	809.36	Redondo	300.90

Table 58. Effect of cladode position and orientation on the number of shoots/plant and DW yield

Position and orientation	**DW** (g)	Shoots/plant
Vertical (N-S)	757.0	4.9
Horizontal	596.2	2.7
Vertical (E-W)	355.9	4.6

Table 59. Water use efficiency of fodder opuntia cultivated in hydroponics

Genotype	**Yield** (g DM/yr/m^2)	**WUE** (g/DM/l)	Genotype	**Yield** (g DM/yr/m^2)	**WUE** (g/DM/l)
70	1531.70	1.77	V1	930.15	1.07
Milpa Alta	1238.61	1.43	RSB	688.47	0.79
Tehuacán	783.34	0.90	R7	1131.02	1.31
44	1463.33	1.69	F1	1141.09	1.32
Rosalito	1181.90	1.36	AGO	1584.70	1.83
RSA	2173.00	2.51	R72	910.01	1.05
40	1310.69	1.51	Selección Pabellón	991.10	1.14
Villanueva	1173.95	1.35	COPENA	689.00	0.80
RSR	2041.03	2.36	Pabellón amarillo	916.90	1.06
RDR	534.24	0.62	Tapón hembra	292.03	0.34
34	1697.06	1.96	Tapón macho	23.85	0.03
LCNF	1262.46	1.46	S34	1547.6	1.79
75	736.70	0.85	S35	185.50	0.21
Italiano	752.07	0.87	Tezontepec	160.06	0.18
V-3	300.51	0.35	Irapuato	222.60	0.26
Tl	842.70	0.97			
Valtierrilla	535.30	0.62	**Control**	42.40	0.05

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ANNEX 1 – SOME OPUNTIA WEBSITES

FAO – Cactus Pear as Forage (Technical Bulletins)

http://www.fao.org/WAICENT/FAOINFO/AGRICULT/AGP/AGPC/doc/pasture/CACTUS.HTM

Cactusnet Newsletter 2000

http://www.data.fao.org/WAICENT/FAOINFO/AGRICULT/AGP/AGPC/doc/publicat/Cactusnt/cactus0.htm

Development of Sustainable Agriculture in Arid Regions of Chile – Paper on "Prickly pear (*Opuntia ficus-indica*) utilization as a feed for ruminants"

http://ag.arizona.edu/OALS/oals/proj/linkages/cactus/feed.html

IPGRI - An ethnobotanical inventory

http://www.ciat.cgiar.org/ipgri/fruits_from_americas/frutales/Ficha%20Opuntia%20ficus-indica.htm

Paper on "Controle de plantas daninhas na cultura da palma forrageira (*Opuntia ficus-indica,* Mill.)"

http://www.sbz.org.br/eventos/PortoAlegre/homepagesbz/For%5CFOR146.htm

FAO Electronic Conference – Paper on "The Prickly Pears (*Opuntia* spp., Cactaceae)".

http://www.fao.org/ag/aga/agap/FRG/ECONF95/HTML/OPUNTIA.HTM

Paper on Biological Control of *Opuntia stricta* in the Kruger National Park

http://www.parks-sa.co.za/knp/scientificservices/hoffmann%20opuntia.html

Environmental Affairs Office, Washington State USA - *Opuntia fragilis*

http://www.wsdot.wa.gov/eesc/environmental/programs/culres/ethbot/m-p/Opuntia.htm

Arizona – Index of Prickly Pears

http://arizona.cacti.home.att.net/cacti02.htm

Paper on "Evaluation of leucaena and cactus pear as forage resources for rabbits"

http://www.asas.org/jas/papers/1997/mtgabs/rabbitsym.pdf

Value and Use of *Opuntia polyacantha*

http://www.fs.fed.us/database/feis/plants/cactus/opupol/value_and_use.html

FAO electronic conference – Paper on "Opuntia-based ruminant feeding systems in Mexico"

http://ces.iisc.ernet.in/hpg/envis/doc97html/envfoo24.html

Paper on "Plains Prickly pear: relation to grazing intensity and blue grama yield on central great plains"

http://jrm.library.arizona.edu/data/1968/212/6beme.pdf

Native cultivars of cactus pear in Mexico

http://www.hort.purdue.edu/newcrop/proceedings1996/v3-446.html

FAO – a paper on "Opuntiae: a strategic fodder and efficient tool to combat desertification in the WANA region

http://www.fao.org/ag/AGP/AGPC/doc/PUBLICAT/Cactusnt/cactus2.htm

Cactus homepage of Texas A & M University, including use as forage

http://www.tamuk.edu/webuser/cactus/

Paper on "Efeito da adubação e de nematicida no crescimento da palma forrageira cv. Gigante

http://www.sbz.org.br/eventos/PortoAlegre/homepagesbz/For%5CFOR172.htm

Prickly Pear Cactus Control

http://www.aginfonet.com/agricarta/content/grazing_pasture_technology/prickly_pear.html

Famine Food Field Guide – *Opuntia ficus-indica*

http://www.telecom.net.et/~undp-eue/faminefoodweb/category1/cat1_Opuntia_sp_ok.htm

Programa de investigación y servicio en nopal

http://www.chapingo.mx/ciestaam/directorio/nopal.htm

ANNEX 2 – COLOUR PLATES

A) J.J.Lopez

B) A. Nefzaoui

C) C. Flores

D) C. Flores

Plate 1. Opuntia is the plant of choice for reclamation of eroded and degraded lands in Mexico and several countries of North Africa. It is also planted to improve productivity of overgrazed areas.

A) Opuntia plantation in a semiarid area of Northern Mexico intended for vegetative cover recovery.

B) Soil conservation in Tunisia takes advantage of Opuntia tolerance to drought and its high productivity.

C) Opuntia planted in a subtropical area of south central Mexico to reinforce simple soil conservation works.

D) A grassland recovery project in Central Mexico includes rainwater collection and spiny Opuntia for fruit and fodder production.

A) D. Cordeiro

B) J.J. Lopez

C) D. Cordeiro

D) A. Nefzaoui

Plate 2. Opuntia pads are chopped before feeding to cattle.

A) Small electrical chopper from Brazil.

B) A machine from Northern Mexico designed for a medium size dairy operation.

C) Delivering of whole pads in Brazil.

D) Manual chopping of spineless Opuntia pads in Tunisia. The mechanical devices are of local design and are usually built to order in small metal shops.

A) C. Mondragon

B) D. Cordeiro

C) A. Nefzaoui

D) C. Guevara

Plate 3. Cultivation of Opuntia can be adjusted to the needs and possibilities of the area.

A) High density plantation in broadbeds in central Mexico for intensive production and fodder Opuntia. Plants can be harvested annually or every other year, limited irrigation is sometimes provided.

B) Rainfed plantation in Northeastern Brazil. Plants are harvested in the third year.

C) Barley inter-cropped in rows of Opuntia, increasing land use ratio and the number of products obtained from a single piece of land: cereal grain and stover, as well as fresh Opuntia pads suitable for animal feeding.

D) Spineless Opuntia planted in rows for fodder production in Mendoza, Argentina.

A) C. Mondragon

B) C. Mondragon

C) C. Mondragon

D) C. Mondragon

Plate 4. Spineless Opuntia selected for fodder production.

A) CPF1, obtained by the late F. Barrientos at Chapingo, Mexico.

B), C) and D) Many of the spineless O. ficus-indica can have more than one use, fruit and fodder production is an interesting combination. “Amarilla Grande” selected for its big juicy fruits and spineles cladodes “Selección Pabellon” which produces red fruit are some examples.