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.

Djalma CORDEIRO DOS SANTOS

Estação Experimental de Arcoverde IPA
Petrolina
Brazil

Severino GONZAGA DE ALBUQUERQUE

CPATSA–Empresa Brasileira
do Pesquisa Agropecuaria
Petrolina
Brazil

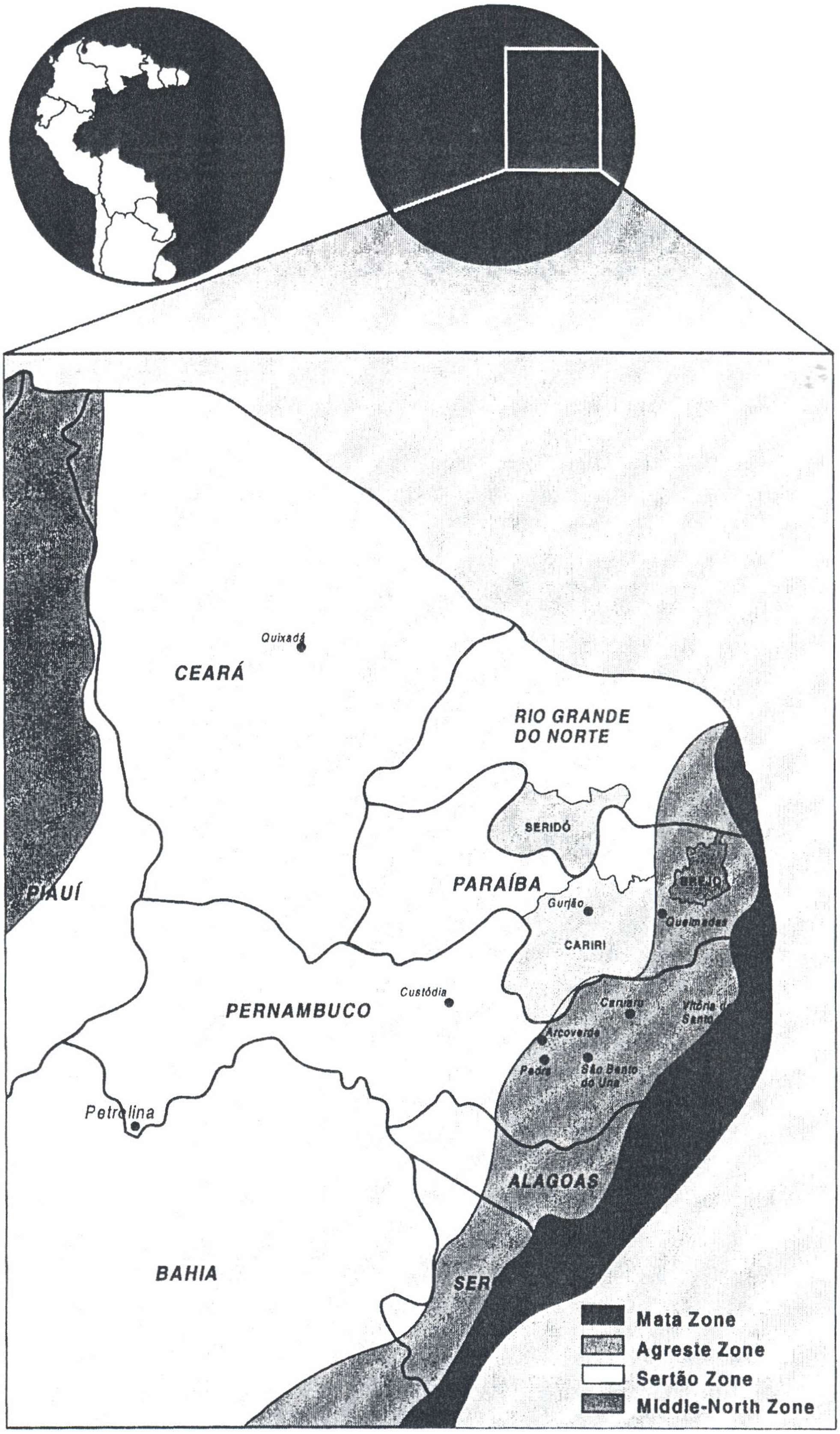

Figure 3. The agroclimatic zones of eastern Brazil

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 × 1 × 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)