Chapter

Spinless Forage Cactus: The Queen of Forage Crops in Semi Arid Regions

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Abstract

Forage cactus is a perennial crop, which has been widely exploited for feeding ruminants in the semiarid region of different countries around the world. The main objective of this chapter is to describe the use and importance of spineless cactus as forage, desertification mitigation, source of water for animals and a source of income for producers in semiarid regions. The main species explored in Brazil are *Opuntia* spp. and *Nopalea* spp., due to characteristics such as resistance to pests, productivity, water-use efficiency and demand for soil fertility. The productivity of the species in a region will depend on its morphological characteristics, plant spacing, planting systems and its capacity to adapt to climatic and soil conditions. In other parts of the world, cactus species are the most cosmopolitan and destructive among invasive plants. However, the use of spineless forage cactus in areas where it can develop normally and may become the basis for ruminants' feed would increase the support capacity production systems. Thus, specifically for Brazil's semiarid region these species can make the difference as forage for animal feeding, cultivated as monoculture or intercropped, for soil conservation and desertification mitigation, source of water for animals, preservation of the Caatinga biome and be a potential source of income for producers if cultivated as vegetable for nutritional properties and medicinal derivative of fruits and cladodes for exports.

Keywords: livestock, smallholder, sustainability, energy

1. Introduction

Spineless Forage Cactus is no doubt a magic forage plant having potential to serve as a source of water bank and forage for animals under extreme environment, but it does not fall under the scope of book Grasses and grasslands: New perspectives. Due to its resistance to drought and high efficiency in the use of rainwater, the planting and use of Spineless Forage Cactus is neglected in semi-arid regions, which is a mistake. In these regions and suitable climatic conditions, it is an unbeatable crop in terms of productivity and quality as an energy food, which is why it has the power to be called the Queen of Forages in the Semiarid Region.

Scientific production around this forage crop dates back to the 1980s, with increasing interest in recent years, mainly in countries such as Mexico, Tunisia, the United States, Argentina, India and Brazil. Recently, it highlights scientific production related with crop productivity as a monoculture or intercropped, mineralization dynamics of differents sources of organic fertilizers, irrigation, its use as a food supplement or ingredient substitute and how ruminants supplement with spineless cactus can reduces drinking water ingestion.

This chapter is intended to describe a brief use and importance of spineless cactus as forage, desertification mitigation, source of water for animals and a source of income for producers in semiarid regions. As methodology, published papers on planting methods and cultural treatments were researched, aiming at the knowledge of those that allow greater productivity and also articles related to nutritional value that would allow its recommendation as the main alternative as a source of energy for ruminants in semiarid regions. Finally, simulations were carried out in order to demonstrate that the use of forage catus could help in environmental conservation. Papers are located from physical and virtual libraries.

2. Stand, productivity, and spacing

Forage cactos as *Opuntia* and *Nopalea* are a perennial crop, developed in several semiarid regions [1]. During periods of drought, it is used as forage in countries such as United States, Mexico, South Africa, Australia, Tunisia, Egypt, and Brazil [1–4]. In Brazil, It was introduced in 1880 and it is considered the main source of feed for herds, mainly in the semiarid region [1, 5, 6]. Its taxonomy is widespread among vascular plants and it is present in many succulent species from semiarid regions [7].

According to the Agricultural Census [8], the production of forage cactus in the semiarid region of Brazil is 3,581,469 tons, with productivity of 24.3 t/ha of dry matter in a harvested area of 147,439 ha. This production is concentrated in the states of Bahia (1,500,359 ton), Paraíba (742,982 ton), Pernambuco (481,932 ton) and Sergipe (431,468 ton).

The main species explored in Brazil are *Opuntia* spp. and *Nopalea* spp. For decades, the varieties of *Opuntia ficus-indica* have been considered among those the best establishment, after introduction into a new area, more resistant to drought or adverse conditions, long shelf life, and most productive [9, 10]. However, they are the most sensitive species to attack by the cochineal insect [*Dactylopius opuntiae* (Cockerell)]. As a result, more resistant varieties are expanding, the clones are IPA Sertânia [IPA; *Nopalea cochenillifera* (L.) Salm-Dyck], Miúda (*N. cochenillifera*), Mexican Elephant Ear [OEM; *Opuntia stricta* (Haw.) Haw.] and African Elephant Ear (OEA; *Opuntia undulata* Griffiths; [10–12]. There are still many plantations with the variety *O. ficus-indica* in Brazil [13]. However, the authors highlight the need to diversify the genetic base, introducing new genotypes, mainly due to the occurrence of the cochineal insect.

In many cases, despite belonging to the same genus, forage cactus species present different responses under different growing conditions. Thus, the productivity of the species in a region will depend on its morphological characteristics [14] and its capacity to adapt to climatic and soil conditions (**Table 1**) [6, 15].

The variety OEM is an imported clone native from Mexico which has been highlighted by its greater tolerance to drought, resistance to *D. opuntiae,* and high productivity [6, 10, 20]. More recently, it has been highlighted by its higher forage productivity, water accumulation, water use efficiency, and carrying capacity [18].

The recommended plant spacing for forage cactus varies according to the production system and the environment, and it can be planted as a single crop or

Clone	Plants/ha	Spacing	Harvest frequency	DMP (t/ha)	Reference
Ipa Sertânia[1]	28,000	1.6 × 0.2 m	2 years	10.7	[6]
Miúda[1]	20,000	1.0 × 0.50 m	2 years	7.35	[16]
Miúda[1]	29,875	1.6 × 0.2 m	2 years	11.5	[6]
OEM[2]	30,938	1.6 × 0.2 m	2 years	15.6	[6]
OEM[2]	33,333	2.2 × 0.2 m	234 days	13.7	[17]
OEM[2]	25,000	1.0 × 0.4 m	330 days	16.4	[18]
Gigante[3]	20,000	1.0 × 0.5	600 days	21.5	[19]
	20,000	3.0 × 1.0 × 0.25m	600 days	14.7	

[1]*Nopalea cochenillifera (L.) Salm-Dyck.*
[2]*Orelha de Elefante Mexicana [Opuntia stricta (Haw.)].*
[3]*Opuntia ficus-indica Mill; DMP: dry matter production.*

Table 1.
Productivity of forage cactus clones under dryland condition.

intercropped with commercial crops [21]. In a single crop, there is greater proximity between plants, especially in double rows, which can favor greater competition for nutrients, damaging growth [19]. However, according to [22] it is possible to obtain greater productivity in dense crops due to the increase in the number of plants per hectare and, consequently, the increase in the cladode area index. However, depending on the genotype-environment combination, there will be a limit where light interception and photosynthetic efficiency can be affected. If mechanization is available, this must also be taken into account when choosing the optimal spacing [21]. Less dense plantings facilitate cultural treatments and reduce the risk of pests such as cochineal insect [22]. According to [23] it is possible to use planting arrangements in triple or quadruple rows that favor the mechanization of the forage cactus *O. ficus-indica* Mill. Although, this can affect sustainability, since the increase in the area covered by plants reduces erosion processes, favoring the maintenance of the most fertile layers in the soil [24]. Some examples of the importance and variability of the productive response to planting spacing and density are highlighted in **Table 1**.

Intercropping planting systems can also affect the productivity and harvest timing of forage cactus [14]. Some of the crops considered in these intercropping systems have been, *Vigna unguiculata* (L.) Walp, *Sorghum bicolor* L. [14, 25], *Spondias* spp. [26], *Leucaena leucocephala* (Lam.) by Wit., and *Gliricidia sepium* (Jacq.) Steud. [27]. Different responses were observed highlighting clone importance. In *O. stricta* (OEM), the cutting season of forage cactus was anticipated (17 months), indicating that competition with sorghum did not reduce its monthly growth rate [14]. While for *Nopalea cochenillifera* (L.) Salm-Dyck., there was no difference in production (20.5–24.5t/ha) concerning the single crop [27]. For all referenced works on cactus intercropped with grasses or legumes, morphophysiological and productive changes were verified in relation to the growth dynamics of both cultures. However, recommendations for resilient production systems can be useful under semiarid conditions.

The consortium of forage catus and the use of appropriate management practices can contribute to improve soil fertility, increase crop productivity and the sustainability of livestock production systems. Northeastern semi-arid region. The introduction of Leucaena (*Leucaena leucocephala* (Lam.)) or Gliricidia (*Gliricidia sepium* (Jacq.) Steud.) intercropped with forage cactus, along with the application of manure, is a relevant alternative for production systems in the semi-arid

Clone	Dry matter production (t/ha)[1]			Plants/ha	Harvesting frequency	Reference
	Basal	Primary	Secondary			
Miúda[2]	11.03	17.5	23.04	50,000	12 months	[32]
Gigante[3]	8.62	14.83	19.64	50,000	12 months (year 1)	[30]
	14.9	22.3	34.7		12 months (year 2)	
Gigante[3]	—	3.9	—	—	12 months	[33]
	—	13.2	—	—	24 months	
OEM[4]	20.9	37.5	33.2	43,478	12 months	[34]

[1]*Preserving corresponding cladode.*
[2]*Nopalea cochenillifera (L.) Salm-Dyck.*
[3]*Opuntia ficus-indica Mill.*
[4]*Orelha de Elefante Mexicana [Opuntia stricta (Haw.) Haw.].*

Table 2.
Forage cactus production under different cutting intensities and harvest time.

region, in order to increase soil organic matter and soil nutrients because deposition of litter with low C: N ratio. Such improvements imply the maintenance of soil fertility, cactus productivity, and the sustainability of these systems. The forage cactus can be intercropped with several crops, whether annual or perennial, such as corn, sorghum, beans, sunflower, pigeon pea, gliricidia among others [28], but researches with forage catus intercropped with other cultures are recent and are not conclusive.

A decrease in dry matter production of 22.7% and 39.2% of forage cactus and sorghum, respectively, when they were cultivated in intercropping [29].

The cutting intensity and harvest management of forage cactus are two other factors that affect crop productivity. The efficiency of plants in converting light energy via photosynthesis depends, among other factors, on the area of the cladodes remaining after cutting and the reserves for the next cycles [30, 31]. However, this response will be conditioned by the plant structure and the relationship between genotype, crop agroecosystem, and adopted management [31].

Regardless of harvest management and genotype, it is consistent to observe higher yields when primary or secondary cladodes are preserved (**Table 2**). This fact is related to a larger photosynthetic area that can provide faster growth and consequently higher productivity [30, 34]. In different states of the semiarid region of Brazil, it is common to observe harvest managements that preserve only the main cladode in search of a greater amount of cladodes per plant in the first harvest [31]. However, the plant will have fewer reserves for the next growth cycle, affecting later production.

Related to the ideal time for harvesting, [33] comment that the annual cut can be used as a management practice for forage cactus since the sum of fresh matter production and dry matter production can be greater when the annual harvest is adopted. However, it will also depend on other managements and cultural treatments adopted in addition to the selected genotype.

3. Cultural treatments (weeding, irrigation, fertilization)

3.1 Weeding and irrigation

The forage cactus planting in production units has been purposed for animal feed as forage in 98.5% [13]. When properly managed (improved varieties, density, organic fertilization, weed control, irrigation), forage cactus (*Opuntia* or *Nopalea*) will be able to produce enough forage to support 4–5 adult cows per ha/year [35].

Weed control, as an agronomic practice to reduce competition for nutrients, moisture, and light, is important to increase both green and dry biomass and crop water accumulation. Thus, it is possible to obtain a greater amount of forage, carrying capacity, and water reserve in the plants [21, 24]. The recommended control can be chemical or mechanical, but the most used control method in the Northeast of Brazil is cleaning with a hoe or mowing during the dry season. Chemically, the control is recommended from the early growth stage to minimize competition, although, in Brazil, there are no products registered for weed control for forage cactus [36]. There are few references regarding this topic (**Table 3**).

The use of irrigation for forage cactus is another of the agronomic practices considered. It is not a common practice, but in some regions where low precipitation associated with high night temperatures limits crop development, the application of small amounts of water can improve results in the planted area [21]. Thus, it is a technology that should be strategically used based on local rainfall, thermal regimes, and available clone [38]. The diversity of responses has been observed over time.

For species *Opuntia stricta* (Haw.) Haw., authors report irrigation depths of 355 mm to ensure fresh and dry matter production of forage cactus in the first production cycle [39]. However, irrigation depths between 1048 and 1090 mm can promote better crop responses in successive cycles [40]. Both cases in environments with an air temperature of 26.5 °C, and reference precipitation and evapotranspiration (ETc) of 354.7 and 2,072 mm, respectively. According to [41], *O. stricta* (Haw.) irrigated with up to 40% ETc (849 mm/year) and *Nopalea cochenillifera* (L.) Salm-Dyck (IPA-Sertânia and Miúda) with 80% ETc (1076 mm/year), can anticipate the harvest time of the crop concerning cultivation under rainfed conditions.

3.2 Fertilizing

The cacti grow in various types of soils and regions with rainfall between 300 and 600 mm annually, however, they are sensitive to high rainfall [42]. Saline soils are another limitation to the cultivation of the *Opuntia* and *Nopalea* because the growth of roots and shoots is reduced. [21] added that stress is caused when the concentration of sodium chloride (NaCl) reaches 25 mM reducing root development.

Clone	Control type	DMP (t/ha)	Reference
Gigante[1] Harvest 2 years	Chemical	11.9	[37]
	Manual labor (summer weeding and hoe)	4.93	
	No control	3.03	
Miúda[2] (0.5 × 0.5 m) Harvest 1 year	Manual labor	11.1	[24]
	No control	9.5	
Miúda[2] (1.0 × 1.0 m) Harvest 1 year	Manual labor	3.9	
	No control	4.5	

DMP: dry matter production
[1]*Opuntia ficus-indica Mill.*
[2]*Nopalea cochenillifera (L.) Salm-Dyck.*

Table 3.
Control of weeds used in forage cactus production.

Due to drought resistance and high efficiency in rainwater use, forage cactus planting is neglected in terms of soil fertility; which is a mistake. In semiarid regions and adequate climatic conditions, it is an unbeatable crop in terms of productivity and quality as an energy feed, for that it can be called The Queen of Forages in the Semiarid Region [43]. So, it must occupy the best fertile soil on the property.

As with all crops, the fertilization of forage cactus is conditioned to the fertility of the soil where it was or will be planted. Therefore, the first step to cultivate the forage cactus is the choice of the planting place, and the second to carry out the soil analysis. When the soil is submitted for analysis, the recommendation of fertilization for forage cactus is required. Or, with the analysis result, a professional can make the calculations to quantify enough limestone to correct soil acidity if necessary, and quantify the amount, formulate the planting and maintenance fertilizers for the crop.

In the nutritional aspect, it has long been recognized that forage cactus responds well to organic and chemical fertilization, as shown by [21, 42, 44, 45]. Also known the effect of the interaction between the level of fertilization, spacing, and environmental conditions of the crop influence the nutrients replacement. The higher population of plants more extraction of nutrients from the soil, and the greater requirement.

According to [42] forage cactus has a low nutritional requirement, but nutritional deficiency causes losses in yield and plant health. They report a quick response to the application of manure and chemical fertilizer in the production of new cladodes and fruits. Under greenhouse conditions, the application of 3–5 g/l of NPK (19:19:19) after fruit harvest was beneficial to the production of new cladodes. Another point reported by authors was the positive response to fertilization with tanned corral manure, which improves soil structure, nutrient availability, and soil water storage capacity. Thus, they recommend 6–10 t of barn manure/ha incorporated into the soil before planting.

In soil conditions, their recommendation is the application of 20 kg of N after harvesting cladodes, either for the production of *"nopalitos"* or forage, which indicates the need for constant nutrient replacement for the plant.

The recommendations above are for India and are contained in ICAR's Technical Bulletin No. 73, which still shows the recommendation by [46] with the combination of five tons of tanned corral manure and NPK (60:30:30)/ha at planting.

The five soil nutrients that may influence the *Opuntia* performance are N, P, K, B, and Na [47]. For [48] N, P, K, Ca, B, Mg, Fe, and Mn are the nutrients with the greatest effect on forage cactus growth in descending order, cited by [21].

Some research results for the states of Pernambuco and Paraíba prove the positive effect of fertilization with cattle manure on the *O. stricta* (Haw.) Haw and *N.* cochenilifera cv. "Miúda" yields (**Table 4**).

[51] suggested for South Africa the correction of the soil before the forage cactus planting intended for fruit production in dryland during summer rains. They indicated the ideal soil pH range of 6.5 to 7.5 and the fertilization indicated by soil analysis to obtain the soil nutrient levels as shown in **Table 5**.

Whereas the recommendation for forage cactus nutrition to produce fruits or "nopalit*os*" is inconsistent and contradictory, physiologically and morphologically different from many other crops [51], and discussed in other countries. The fertilization of forage cactus would be no different in Brazil. The indication of nutrients levels in the soil contained in **Table 5** can be used as an indicator to forage cactus fertilization in Brazil, where high dry matter productivity per area is expected. What is common where forage cactus is produced as an agricultural crop for fruit or forage is the use of fertilization to maintain productivity and perenniality.

Location	Plants/ha	manure (t/ha)	Increment (t/ha/2 years)	%	Reference
Parari, PB	20,000[1]	20	70.3 → 191.9(FM)	173	[49]
Bonito de Santa Fé, PB	20,000[2]	20	74.8 → 299.8(FM)	300	
Caruaru, PE	40,000[2]	30	9.6 → 42.6 (DM)	443.7	[50]

[1]*Orelha de Elefante Mexicana [Opuntia stricta (Haw.) Haw.].*
[2]*Nopalea cochenillifera (L.) Salm-Dyck cv Miúda; FM: fresh natter: DM: dry matter.*

Table 4.
Indicating that forage cactus responds positively to organic fertilization.

The great level of element in soil (mg/kg)			
P	K	Ca	Mg*
20–30	80–100	> 400	100–150

**Mg levels should not be bigger than Ca. Source: [52, 53] (adapted).*

Table 5.
Suggested optimal soil nutrient levels for forage cactus fruit production in dryland summer crops in South Africa.

In Brazil, research about forage cactus retakes to the 1950s with agronomic trials on fertilization, planting spacing, and later on animal feed [21], and nowadays on irrigation, water salinity, and chemical weeding. Some studies indicate the composition and morphology of Brazilian Semiarid soils show diversity; they are vulnerable to degradation, due to the decrease in organic matter content and loss of fertility, and in arid, semiarid, and dry sub-humid climates it is characterized as desertification [28]. Data from INSA show that 9% of the Brazilian semiarid region is already desertified and 85% in a moderate process of desertification, a condition that makes the management of this soil more difficult and the need to use soil conservation and fertilization management techniques.

This diversity consists of shallow, stony, and sandy soils generally with low fertility in contrast to deeper soils with greater fertility. In some situations, saline soils are already found. [21] reported 19.2% of the soils in the Brazilian semiarid range from Litholic Neosols, shallow with an “A” horizon directly on the rock, to Latosols (21%), deep, well-drained, and with low organic matter content.

As we know the scope of forage cactus fertilization is generally neglected by producers. The reasons are many and generally, the areas chosen by the producers are characterized by their little agricultural vocation and usually with low fertility. [54] developed research with producers from Taperoá, PB, Brazil, and found that only 10% of producers performed soil analysis before planting forage cactus. However, 74% of the plantations were implanted in clayey soils, 20% in sandy-clay textured soils, and 6% cultivated cactus in sandy textured soils.

The search for greater productivity in the forage cactus crop has led researchers and producers to increasing plant density, increasing the number of plants per ha under cultivation. [55] indicate extraction of 0.9; 0.16; 2.58 and 2.35%, for N, P, K, and Ca, respectively by forage cactus cultivation indicating partial agreement with [42]. However, [56] cited by [21] demonstrated the positive effect on forage cactus production with increasing levels of organic fertilization and numbers of plants per ha in the state of Pernambuco. Even with a low level of nutrient requirement by forage cactus, the increase in dry matter production per area promotes high nutrient extraction per cultivated area causing the need for nutrient replacement after each harvest, whether annual (**Table 6**) or biannual. Logically, the amount of fertilizer needed to increase production will reach its limit.

Productivity (t DM/ha/year)	Nutrient annual removal (kg/ha)				
	N	P	K	Ca	Ratio t DM:Nutrient amount
5	45	8	129	117	1:1:1:1
10	90	16	258	235	2:2:2:2
20	180	32	516	470	4:4:4:4
40	360	64	1032	940	8:8:8:8
55	495	88	1419	1292	11:11:11:11
80	720	128	2064	1880	16:16:16:16

Calculated from [55]: extration of 0.9; 0.16; 2.58 and 2.35% for N, P, K e Ca from soil, respectively.

Table 6.
Nutrient extraction by forage cactus according to productivity.

Soil analysis	Implantation[1] (kg/ha)			Fertilizing[2] (kg/ha)		
Content in soil	**Planting**	**Growth**	**After cutting**	**Planting**	**Growth**	**After cutting[2]**
		Nitrogen (N)				
Do not consider		100	100		222	222
		Phosphorus (P_2O_5)				
P						
< 11 mg/dm^3	80	60	60	445		445
K		**Potassium (K_2O)**				
< 0.12 cmol$_c$/dm^3	100	60	100	167		167
Organic fertilization						
Cattle manure[3]	20,000					20.000

[1]*Fertilizing recommendation for the State of Pernambuco, Guide [58].*
[2]*Urea, Single superphosphate (P_2O_5) e potassium chloride (K_2O)*
[3]*Based on [50].*

Table 7.
Example of chemical and organic fertilization association for forage cactus based on hypothetical soil analysis and recommendation for the state of Pernambuco, Brazil.

Research by [57] showed the efficiency of organic fertilization decreased when using a low amount of cattle manure for planting with 160,000 plants/ha of forage cactus and recommended a minimum application of 40 t/ha every two years for this density. Greater productions occurred with the increase in population density and application of 80 t of cattle manure every two years, with values of 61; 90; 117 and 139 t DM/ha/two years, respectively, for planting densities of 20, 40, 80 and 160 thousand plants/ha.

Taking as an example a forage cactus planting in low fertility soil (P and K; **Table 7**), we used the fertilizer recommendation for forage cactus in Guide recommendation for crops in the state of Pernambuco.

4. The forage cactus as a invasive plant

[59] reported to have little information on the subject but asserts several occurrences of cactus becoming a problem as invasive plants in several countries around the world. According to him, species of commercial value such as *Opuntia*

ficus-indica and *Opuntia monacantha* have become invasive in several countries, requiring their control.

In Brazil, this is still not a problem be considered for cactus cladodes, however, [60, 61] cited by [62] comment cactus species are the most cosmopolitan and destructive among invasive plants in any parts of the world. Briefing, informative material from ICARDA – International Center for Agricultural Research in the Dry Areas reports after 150 years cultivation of *Opuntia ficus-indica* in South Africa reverted to its thorny form becoming an invasive plant and forming dense, impenetrable bushes with more than two million hectares invaded at the beginning of the 20th century, although, in the colder parts of the country, forage cactus was less aggressive and producers used it more extensively. Countries where the climate is more favorable such as Eritrea, Ethiopia, Yemen, Saudi Arabia, and Madagascar occurred a similar invasion.

The number of invasive species in South Africa has increased from 13, all *Opuntiae,* in 1947 to 35 in 2014, including at least eight *Cactoideae,* and some of them had to be subjected to chemical control followed by biological control if necessary [59].

5. Spinelles Cactus as forage and desertification mitigation

The semiarid in the world land structure is almost entirely characterized by a large number of small and medium sized family-owned establishments. In Brazil, 70% of the consumed food is produced by small producers [63]. Although family farming is economically in these regions crucial, producers in the semi-arid region are most vulnerable to the impacts of climate change. The combination of an adverse environment and economic activity that is dependent on nature leads to extreme vulnerability of the production systems, represented by virtual collapses under climatic conditions that are unfavorable to production. This, in part, results in economic fragility.

In dry areas around the world, periodic droughts have a major impact on rural properties, leading to serious socio-economic losses [29]. In these regions, biomass production is typically low (<5 tons of DM per ha per year), with low forage potential (<1 ton of DM per ha per year), leading to a low support capacity (12–15 ha to sustain an adult cow; Dubeux et al., 2015). However, producers should make efforts to identify and implement strategies to deal with these adversities, which can reward them with long-term resilience [64]. For this reason, [65] suggested corn crop for silage production. [66] evaluated five short cycle corn cultivars, recommended for silage production in semi-arid regions, and observed a productivity of 8.04 tons of DM/ha (6.12 to 9.68 tons of DM/ha).

However, the use of cactus, notably cactus cladodes (*Opuntia* and *Nopalea*), for ruminant feeding in dry areas has been increasing, as, for example, in North Africa [67] and northeast Brazil [68, 69]. Cactus is chosen for its high efficiency of water use, rapid dissemination, high water and energy content, and high biomass yield [70]. Recently, [71] suggested cactus *Opuntia stricta* (Haw.) Haw. cladodes as a new option for milk production in smallholder systems in semi-arid regions. In addition, [58] published productivity data of this cactus cladodes' clone in different semi-arid areas in Brazil and reported a minimum production of 40 tons of DM/ha and a maximum production of 60 tons of DM/ha, achieved every two years.

In general, energy is the most limiting "nutrient" for animal production. [72] showed that *O. ficus-indica and N. cochenillifera* has an average ME content of 2.34 Mcal/kg DM. In **Table 8** presents the estimates of DM productivity/ha of various forages that are commonly recommended for semiarid regions. Thus, they are equal

Item	Forages					
	Forage cactus	Sorghum silage	Alafafa	Leucaena	Buffel grass	Corn silage
ME (Mcal/Kg DM	2.34	2.28	2.13	2.67	1.52	2.29
DM (ton/ha)	23.69	24.31	26.03	20.76	36.47	24.21

Table 8.
Metabolizable Energy (ME) content and productivity expectation of different forages.

to the potential for ME production/ha of forage cactus, which was 55,434 Mcal/ha (23,690 kg DM; 2.34 Mcal/kg DM). The average productivity of the forage cactus species was considered in the paper of [43]. The ME values of the various forages were taken from the Brazilian Tables of Feed Composition for Cattle [73].

It is impossible to achieve the productivity of the selected forages in semiarid conditions (**Table 8**) under low rainfall without irrigation. However, they should not be discarded, because they could be used, to a lesser extent in the diet, as a source of fiber.

Some other advantages justify spineless forage cactus use; for example, cows producing 15 kg of milk/day, fed with a diet contenting 50% of forage cactus, practically do not need water via a drinking fountain [74]. Spineless forage cactus is a perennial crop that allows for a reduction in implantation costs over time.

Due to its crude protein content (5.4%), CNF content (54.3%), and NDF content (24.8%), cactus cladodes combined with a cheap source of fiber (sugarcane bagasse, wheat straw) and NPN (urea), as a feeding strategy for ruminants, show very satisfactory results, including a reduction in the required amount of concentrated feed. [75] evaluated diets for crossbred lactating cows, with 61% forage cactus, 34.2% roughage, 1.7% urea, and only 3.1% soybean meal. They reported an average production of 11 kg milk/day. In another study, Holstein heifers, with an average weight of 243 kg, received a basal diet consisting of spineless forage cactus (69.8%), sugarcane bagasse (27.6%), and urea (2.6%), supplemented with 1 kg wheat bran per day. They showed an average gain of 0.71 kg/day [76]. Spineless forage cactus is an excellent feed for small ruminants. [77, 78] reported a positive performance for sheep with an average daily gain of 251 g/day, and lactating goats with average milk production of 2.97 L/day, respectively, when the animals were fed with spineless cactus.

A major issue that affects the global society is desertification, which is the process of land degradation in arid, semiarid, and sub-humid areas stemming from factors such as climatic variations and human activities [79]. Due to climatic conditions, soil characteristics, the inadequate exploitation of natural resources, and overgrazing, the Caatinga, a specific biome in Northeast Brazil, has become fragile and vulnerable [80]. In general, the causes of desertification in Northeast Brazil are not different from those typically found in other areas around the world. They are related to the exploitation of natural resources, to improper practices of land use (overgrazing and over-cultivation), and above all, to models of immediatism regional development [80].

It is necessary to consider the notorious contribution of livestock activity to the acceleration of the desertification process, along with the aforementioned climatic factor. According to [81], the use of semi-extensive or extensive livestock in semi-arid areas becomes a factor in environmental changes due to the excessive stocking of animals in limits above the ecosystem's support. In the medium term, it exerts strong pressure on the floristic composition of the native vegetation due to the high palatability that is causing the extinction of species. It also exerts pressure on the soil due to the excessive trampling that causes compaction (in the rainy season)

Manipulation Level	DMY** (kg/year)	Available for animal intake	Forage cactus area (ha)
Nativa	4.000	400	0.02
Rebaixada	4.000	1600	0.08
Raleada	4.000	2400	0.13
Enriquecida	4.000	3600	0.18

*20 tons of dry matter/year was considered.
**Dry matter yield.

Table 9.
*Caatinga management and biomass production vs. forage cactus.**

and disintegration (in the dry season), which has negative effects on soil physical, chemical, and biological properties. In the long term, it contributes to the irreversible degradation of soils and vegetation, thus generating areas that are susceptible to the process of desertification.

The use of spineless forage cactus in areas where it can develop normally and may become the basis for ruminants' feed would increase the support capacity production systems. This would avoid the indiscriminate use of natural vegetation, mitigate desertification, and improve coexistence with the adverse conditions of the semiarid region. Taking Caatinga as an example that is an exclusive Brazilian biome with semiarid weather, vegetation with a few leaves and adapted to dry season, presents great biodiversities, but it is quite degraded by man.

According to [82], there are techniques for handling the Caatinga that can significantly increase the forage supply in that biome and contribute to its preservation. The main techniques used are thinning, lowering, and enrichment of the caatinga, with possible combinations between them. The thinning consists of making selective cuts in species of little forage and timber value, reducing the density of these plants in the area, thus allowing other species to develop and serve as a source of feed for the animals. Lowering is cutting the highest part of trees and shrubs to increase the forage supply for grazing animals. This practice makes forage in the pasture accessible, but it is not easily available because it has two meters high, becoming indicated for use in goat production systems or that combine goats and cattle. On the other hand, enrichment is a technique to improve forage production conditions by introducing perennial species. In addition to the benefits for herds, these management techniques help to regenerate native vegetation and optimize the use of forage resources (**Table 9**). There is a considerable increase in forage availability, from 400 (native caatinga) to 3600 kg of dry matter/ha/year (enriched caatinga).

Despite the increase verified with the manipulation of the Caatinga, it could be preserved using more productive species such as *Opuntia* and *Nopalea*, which would will produce much more in less area used fill less space. A comparison was made between the amount of dry matter in a hectare of native Caatinga or different management systems can make available to the animal and how much this would represent if forage cactus were used (**Table 9**). According to the simulation carried out, it can be seen that thousands of hectares of Caatinga could be preserved with the use of forage cactus. We must not forget that the forage cactus must be supplemented with fiber and nitrogen sources according to animal requirements.

6. Conclusion

Opuntia spp. and *Nopalea* spp. are cultivated and have been income sources for farmers as fruit, nutrition, medicine and forage use. Cultural treatments such as weeding control, irrigation and fertilization; stand and spacing are extremely important factors to consider in the planting of forage cactus in order to increase productivity.

Specifically for Brazil's semiarid region these species can make the difference as forage for animal feeding, cultivated as monoculture or intercropped, for soil conservation and desertification mitigation, source of water for animals, preservation of the Caatinga biome and be a potential source of income for producers if cultivated as vegetable for nutritional properties and medicinal derivative of fruits and cladodes for exports.

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