Chapter 2

Production of Spineless Cactus in Brazilian Semiarid

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Abstract

The term "spineless cactus" is used in Brazil to designate cultivars of *Opuntia ficus indica* Mill and *Nopalea cochenillifera* Salm Dyck. The spineless cactus was consolidated in Brazilian semiarid as a strategic fundamental food resource in several production livestock systems, constituting a plant with enormous productive potential. Thus, the spineless cactus has been widely cultivated and used for several decades, by enabling the animal feeding in critical periods of year because of its characteristics, morpho-anatomical and physiological (CAM), which makes it tolerant to long droughts, being a crop that presents high productivity in droughts conditions, when compared to other forages. Nevertheless, the spineless cactus is a crop relatively picky about soil and climate characteristics of region, presenting greater growth in fertile soils, as well as in regions where nighttime temperatures are cool and the air humidity is relatively high. Although the crop be adapted to long droughts periods, many times it's necessary to perform irrigation in its production system, mainly in regions of low rainfall, for to supply its water needs, thus ensuring productivity and survival of crop. Therefore, the knowledge of characteristics of plant, as well as of appropriate management techniques to crop, is essential for the good performance of spineless cactus.

Keywords: *opuntia ficus indica*, *nopalea cochenillifera*, productivity, adaptability, requirements

1. Introduction

The spineless cactus is a native cactus of semiarid regions of American continent, specifically from Mexico, being cultivated for forage and fruits production. In other regions of the world, beyond to be used as forage resource, the spineless cactus is cultivated for medicinal purposes, cosmetics, dyes, vegetable production, fruit production [1], fences and landscaping, and in some countries of Africa, the spineless cactus is a part of humans' diet.

However, the spineless cactus has been consolidated in arid and semiarid regions of the world as forage strategic in various production livestock systems [2] for being a culture adapted to soil and climate conditions, in addition to presenting high dry matter production per unit of area [3].

The date its introduction in Brazil remains obscure, having multiple versions in literature, and most of it are not based on more rigorous historiographical study [4]. Even so, there are reports in literature of your likely introduction in Brazil during the colonial period, being introduced in Rio de Janeiro by Portuguese, aiming to preclude the Spanish monopoly about the red dye Carmine produced in Mexico [5]. The pragmatism of that movement manifested itself especially during the administration of Marquis of Pombal, where the Portuguese Crown encouraged the colonies to produce natural products and the study, especially of Botany [6]. Around 1880, Herman Lundgren introduced in Pernambuco spineless cactus originating in Texas, where they were studied by the botanist Burbanks [7].

At first, the forage value of spineless cactus in Brazilian semiarid region was not recognized, although, in North Africa, the cultivation of varieties of *Opuntia* for fodder purposes was widespread in the late nineteenth century [7]. The spineless cactus only aroused interest as feed in Pernambuco State and Alagoas State in 1902 [5]. In early twentieth century, after the drought of 1932, order of government began to spread the spineless cactus [8], realizing that the little established plantations were insistently searched for cattle, goats and sheep that ate. Thus, the plant began to be used by animal breeders [6].

From the late 1950s, that really started the deeper character studies on the species, for to improve your use. Between 1979 and 1983, during the prolonged drought in Brazil's northeast, the spineless cactus won your space in semiarid scenario [9]. From this date, numerous studies have turned to this forage.

In recent years, the spineless cactus went back to being cultivated on a large scale by the creators of dairy cows [10] and it is estimated that today there are about 600,000 hectares of spineless cactus in Brazil's northeast [2], and a large part of these hectares concentrated in States of Pernambuco, Paraíba, Alagoas, Rio Grande do Norte and Bahia [6, 11].

2. The spineless cactus in Brazilian semiarid

The Brazil's northeast is the region which is the largest cultivation area of spineless cactus throughout world, with about 600,000 hectares, and the most commonly used cultivars are the Gigante, the Redonda and the Miúda, being that the choice has been determined by soil and climate conditions of planting sites. The Miúda cultivar is planted on a large scale in State of Alagoas, while in other northeast states (Pernambuco, Paraíba and some regions of Ceará and Rio Grande do Norte) it predominates the planting of cultivars of *Opuntia ficus indica* [2, 12, 13].

The Gigante cultivar (*Opuntia ficus indica* Mill) is a plant well developed with stem little branched, which gives an aspect upright and vertical growth little leafy. It possesses characteristics like its arborescent size with 3–5 m of height, broad crown, glabrous and 60–150 cm of width of stem. Its cladode weighs about 1 kg, showing up to 50 cm long, oval-elliptic or suboval form and matte green coloration. The flowers are hermaphrodite, of medium size, bright yellow coloration and petal that stays open at anthesis. The fruit is an ovoid berry, large, yellow, changing to purple when ripe. This cultivar is considered the most productive and more resistant to drought regions; however, it is less palatable for animals and smaller nutritional value [14–16] (**Figure 1**).

The Redonda cultivar (*Opuntia* sp.), originated of Gigante cultivar, has medium size and stem many branched laterally, thereby reducing the vertical growth. Its cladode weighs about 1.8 kg, owning nearly 40 cm long, round and ovoid form. It presents great yields of a material more tender and palatable than the Gigante cultivar. Its lateral growth hinders the intercropping with annual crops, and thus, has been less common the planting with this cultivar [14–16] (**Figure 2**).

Figure 1. Morphological aspect of Gigante cultivar. Photo: Antônio Carlos Alves.

Figure 2. Morphological aspect of Redonda cultivar. Photo: Renaldo Araújo.

On the other hand, the Miúda cultivar (*Nopalea cochenillifera* Salm Dyck) has small size and stem quite branched. Its cladode weighs about 350 g, has almost 25 cm long, sharply obovate form (apex wider than the base) and intense bright green coloration. The flowers are red, and your petal remains half closed during the cycle. The fruit is a purple berry. Comparing with the previous two cultivars, this is the most nutritious and appreciated by animals (palatable), but offers less resistance to drought. It is a most demanding cultivar in soil fertility [14–16]. It is more demanding in humidity and temperature cooler to night when compared to the other cultivars [16, 17] (**Figure 3**).

The spineless cactus (*Opuntia* and *Nopalea*) is species that stand out in Brazilian semiarid region, having contributed significantly to livestock feed in prolonged droughts, since their anatomical and physiological features allow your productivity. In the three plants, the cladodes are covered by a cuticle which controls the evaporation, allowing the storage of water until the level of 90–93% [18].

In general, we can say that the cultivars of *Opuntia ficus indica* have shown more rustic when compared to Miúda cultivar, due to larger tolerance to intense droughts and pest attack *Diaspis echinocacti*, commonly known as "scale cochineal" [13]. However, the Miúda cultivar presents resistance to "carmine cochineal" (*Dactylopius opuntiae*), which is currently the main plague of spineless cactus culture in Brazil's northeast, and for this reason, there is a tendency to increase the planting area with this cultivar [7].

Regarding productivity [12], the Miúda cultivar has shown to be smaller than the Gigante and Redonda cultivars; however, when this production is considered in terms of dry matter, the results are equivalent, since the cultivar Miúda has higher dry matter content than the cultivars of genus *Opuntia*. Although it is considered as an excellent energy source (rich in non-fibrous carbohydrate, important source of energy and TDN) [2], the spineless cactus presents insufficient levels of neutral detergent fiber and crude protein for proper animal performance when provided as bulky food alone; therefore, the association with bulky foods of highly

Figure 3. Morphological aspect of Miúda cultivar. Photo: Agefran Costa.

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effective fiber content and non-protein nitrogen sources and/or true protein is required [19] (**Table 1**).

Because of its low dry matter content and high-water content, the use of spineless cactus in isolation in animal nutrition is not recommended and should be commonly used to compose the diet, replacing partially traditional forage [16]. Best result is achieved in fiber consumption by sheep when the spineless cactus was mixed to a diet of hay and concentrate [23]. Pessoa et al. [24] investigated the effects of different food strategies in spineless cactus-based diets, associated with sorghum silage and concentrated on the performance of dairy cows, and stated that the strategy of mixing the ingredients completely provided balance in the supply of nutrients for animals (protein, energy, effective fiber, minerals, etc.), because it made possible the decrease in the selection of ingredients, providing suitable relationship bulky/concentrate on diet and, consequently, the ruminal environment health, with gains in productivity.

Araújo et al. [25] evaluated the effect of use of two cultivars of spineless cactus (Gigante and Miúda) with and without the addition of maize in diet of lactating cows, noting that the

	Spineless cactus's cultivars		
Nutrients	***Opuntia ficus indica* Mill**	***Opuntia* sp.**	***Nopalea cochenillifera* Salm Dyck**
Dry matter (% as fed)	10.2	11.0	15.4
Organic matter (% DM)	89.8	89.1	93.0
Crude protein (% DM)	5.3	5.2	3.5
Neutral detergent fiber (% DM)	26.0	26.2	25.8
Acid detergent fiber (% DM)	22.4	22.2	23.0
Non-fibrous carbohydrate (% DM)	55.6	-	71.2
Total carbohydrate (% DM)	81.9	81.2	87.8
Total digestible nutrients (% DM)	64.3	-	-
Ether extract (% DM)	1.98	1.78	1.71
Mineral matter (% DM)	11.2	11.2	7.0
Crude fiber (% DM)	12.3	8.7	7.17
Non-nitrogenous extractive (% DM)	70.3	72.8	78.0
Calcium (% DM)	2.1	2.9	3.8
Phosphorus (% DM)	0.1	0.1	0.2
Potassium (% DM)	2.1	2.5	1.5

Table 1. Nutritional composition of different spineless cactus's cultivars. Source: Adapted from Refs. [20, 21, 22]

consumption of dry matter was not influenced by cultivars of spineless cactus studied, and, however, found higher consumption for diets with corn, which had higher dry matter content than those without corn, factor that possibly determined this difference. Wanderley et al. [26] evaluated the consumption of lactating cows fed with feed containing levels of spineless cactus + sorghum silage + concentrate, noting increase in dry matter intake, that according to authors was due to supply of food in form of complete feed, which provided, throughout the day, better supply of nutrients, favoring and conforming the ruminal fermentation, mainly to concentration of volatile fatty acids. The authors stressed the importance of animals has not been presented metabolic disorders, such as diarrhea, when spineless cactus was supplied under this food strategy, in association with fiber-rich food sources.

However, it is important to note that the high-water content of spineless cactus is an indirect way of promoting greater water consumption in diet [16], an important factor for the creation of animals in arid and semiarid regions [27], because in a region where water is scarce and often of bad quality, this characteristic must be framed among the positive aspects of forage [28].

In arid and semiarid regions, the spineless cactus has been the basis of ruminant feed because it is a culture adapted to soil and climate conditions, in addition to presenting high dry matter production per unit of area [3].

Recently, studies have been developed, seeking the intensification and efficiency in the use of spineless cactus to reduce the time and labor costs for harvesting and daily supply of animals. Thinking about this, the research has been focused on production of silage, since it would allow the maximization of the use of this forage, as well as improve operational logistics in supplying food diary to animals. In this way, the spineless cactus ensilage would allow harvest of all the plantation, standardizing and increasing regrowth capacity and, consequently, the productivity, beyond to reduce labor with harvest and periodic supply, throughout the dry season.

Although spineless cactus presented some unfavorable characteristics to ensilage, such as low dry matter content and highly soluble carbohydrate concentration, favoring growth of undesirable microorganisms, it has features that distinguish it from other foragers. The mucilage of spineless cactus is constituted by hydrocolloids which are distributed throughout the plant and have the property of water absorption [29, 30]. The hydrocolloids are compounds formed by highly hydrophilic polysaccharides that minimize the movement of the water, providing the increased viscosity of material and thus the formation of mucilage.

It should be noted that spineless cactus has bioactive compounds, such as organic acids (malic, citric, oxalic, malonic, succinic and tartaric acid) found in their cladodes [1]. The presence of these substances buffers can control the growth of yeasts through buffering of ensiled mass, directing the fermentation to produce lactic acid, thereby minimizing losses during ensilage [31].

Beyond these characteristics presented by spineless cactus, the silage additives are added to forage for to correct characteristics unfavorable during the ensiling process.

About the exposed, studies [32] showed the efficiency of spineless cactus for ensilage. This author evaluated the potential of spineless cactus for ensilage without additives or additive with wheat bran and urea, noting that pH values varied between 3.7 and 4.2, values considered ideal for well-fermented silages [33]. Really, they found lactic acid production close to 100 g/kg in silages with or without additives—content considered normal for fermented silages by acid lactic acid bacteria [33]. It should be noted that spineless cactus used in this work presented 12% of dry matter, soluble carbohydrates content of 120 g/kg of dry matter and a buffer capacity of 22 mEq/100 g DM. The combination of these three characteristics can result in a high fermentative capacity, without, however, trigger alcoholic fermentations.

Recently, Sá et al. [34] evaluated silages of five complete feed based on spineless cactus in three opening times (7, 15 and 60 days), and noted that all silages showed pH values indicative of normal fermentation, no difference between the feed in each open, decreasing significantly to 60 days, with an average of 3.98. In this study, the concentrations of lactic acid of feed significantly increased to 60 days, reaching 17.34% based on DM.

Brito et al. [35] evaluated the spineless cactus silage with chemical additives (2% urea based on DM) and microbial (*Lactobacillus buchneri*), as well as the association of both (2% urea + *Lactobacillus buchneri*) in four opening times (7, 15, 60 and 120 days) and observed that all silages showed values of pH considered suitable for silage well fermented, around 4.0. In these silages, lactic acid levels increased significantly from 60 days, reaching 8.49% based on DM to 120 days.

However, despite the excellent quality of spineless cactus silage, the performance assessment studies of animals consuming such silage are virtually nonexistent in Brazilian semiarid region. Nevertheless, unpublished data on performance evaluation of sheep getting complete feed silage based on spineless cactus showed satisfactory results. Therefore, more studies are needed to behold the performance of animals consuming spineless cactus silage in Brazil's semiarid region.

3. Adaptive characteristics of spineless cactus

The spineless cactus is considered a xerophyte plant due to the fact that its adaptive features allow your survival in hot and dry environments.

Xerophytic plants are characterized by structural modifications (physiological and morphological) that help these plant species survive in the more complicated climatic conditions that are hot and dry climates, which often does not have the ideal amount of water to grow a plant. In Brazilian semiarid region, especially in drought periods, water is a rare item, including for the human beings themselves. So, the xerophytic plants needed to develop mechanisms to make them support these adverse conditions and they could survive. Among the mechanisms and adaptations, morfoanatômicas developed by plants xerophytic are:

- Dense nerves; epidermal cells small; bristle coating; external walls of the epidermis thickened; very developed sclerenchyma; thick cuticle; cutinized layers; presence of wax, tannins, volatile oils, resins, mucilage and various layers of palisades [36, 37];

- Trichomes and many small stomata per unit of surface, inside of crypts formed by cutine layers on the epidermis [7];
- Small-size leaves that are waxy and, often, the leaves these plants are modified to thorns, as adaptation, that cause smaller loss of water, making the plant survive any longer;
- Stems and roots that can store water for the vital needs of the plants; strong roots that grow up and enter the soil to reach the underground water sheets [38].

Another adaptive mechanism of xerophytic plants is the ability to maintain high-water potential in the tissues, which is achieved by the absorption of water or decreasing water loss by transpiration. For maintenance of the water absorption, the plant can present a deepening or comprehensiveness of the root system, increased hydraulic conductivity and osmoregulation in the roots. And for the reduction of water loss by transpiration, the plant can promote the reduction of epidermis conductance through the thickening of cuticle, reducing the amount of radiation absorbed by production of bristle and wax, and reduced leaf area and stomata [37, 39, 40].

Another very important aspect of xerophytic plants when subjected to water stress is the osmotic adjustment, in other words, active fotossintetizados product buildup inside the cell [36, 37], which are used to promote the development of adaptive features of plant.

Unlike other xerophytic plants, spineless cactus presents a shallow root system and distributed horizontally, fleshy that exploring almost the entire surface of the soil (10–20 cm), with high-water absorption capacity of the light rain and even the dew, featuring an advantage in places of low rainfall [37, 41]. The distribution of spineless cactus roots may depend on ground conditions. Under favorable conditions of soil, moisture develops an elongated root. On the other hand, under dry conditions develop lateral fleshy roots from the main root to thus absorb water at shallow levels [42].

The root system of spineless cactus is very complex, and it can have four types of roots [42]:

The structural roots, formed by a primary with little fibrous roots skeleton of 20–30 cm in length, forming quickly a periderm, but keeping many latent and active gems, distributed from the base until the apical region without a regular pattern of distribution. When the structural roots remain dry for a while and suddenly are moistened, in a few hours if restarts the formation of absorbent roots that respond quickly to moisture.

The absorbing roots form within few hours after the side buds respond to moisture and are called "rain roots." These roots die as soon as the soil dries.

The spur roots are formed as the most voluminous mass of roots and can be short, thick and fleshy, with many fine bristle roots, and long, like the system of absorbent roots.

The roots of areolas develop when the areolas are in contact with the ground. At the beginning of its development are thick and without bristle and have a kalyptra with the cells of the epidermis forming appendages like bracts. The growth of young roots is very fast, and they become soft with a shell of three to four cells thick and are covered with many bristle roots. Over time, all roots that originate from areolas form a real root system.

The fine roots (<1 mm) are considered as the main in processes of absorption of water and nutrients for plant, being observed wide variation in your distribution in the soil profile, depending on the genotype and sampling period [41].

In addition to these features, the physiology of spineless cactus is characterized by the photosynthetic process named Crassulacean Acid Metabolism (CAM). The CAM metabolism allows plants to improve efficiency in the use of water. Typically, a CAM plant loses 50–100 g of water for each gram of CO_2 obtained, whereas plants with metabolism C_3 and C_4 lose 400–500 and 250–300 g, respectively. Thus, CAM plants have a competitive advantage in dry environments [43].

A key feature of CAM plants is your juiciness due to its thick cladodes and large vacuoles filled with water in the photosynthetic cells, as well as of several layers of cells' water storage. The mature cladodes of spineless cactus usually have 1–5 cm thickness, and most of it is a whitish water-retentive tissue. The greenish chlorenchyma, which contains chlorophyll and where occurs photosynthesis, has a layer of 2–5 mm thickness on each side of cladode; it consists of 15–40 layers of compact cells. The water storage parenchyma also has compact layers of cells, slightly larger than the chlorenchyma. During drought, the water is preferentially lost from the parenchyma, allowing the chlorenchyma to remain well hydrated and allowing the continuity of photosynthesis [44].

Plants of CAM metabolism, unlike other plants of C_3 and C_4 metabolism, open their stomata at night and close during the day, which means the capture of atmospheric CO_2 takes place in the dark. This is considered a mechanism for adaptation of these plants to arid and semiarid regions, to minimize water loss. The clamping mechanism of CO_2 in these plants is very like the mechanism of C_4 plants; however, in CAM plants, the fixation of CO_2 occurs two-way [Rubisco and phosphoenolpyruvate (PEP) carboxylase], being separated in both time and spatially. Initially, the CO_2 is captured at night, via PEP carboxylase enzyme in cytosol, using the phosphoenolpyruvate (PEP) as acceptor and forming oxaloacetate which is then reduced to malate. The malate is stocked in large vacuoles, anatomical characteristic typical of leaf cells of CAM plants, acidifying them. The next day, with the stomata closed, the malate is transported to the chloroplast and decarboxylated by the enzyme NADP-malic to pyruvate and CO_2. Since the stomata are closed, the CO_2 released internally cannot escape, being refixed via Calvin-Benson cycle, by Rubisco, and converted to carbohydrates (**Figure 4**). The high inside concentration of CO_2 favors activity carboxylative of Rubisco [39, 43].

The key to water conservation by CAM metabolism plants is the opening of stomata at night, resulting in less water loss. The water loss from a CAM plant is much smaller than that of other species (plants C_3 and C_4) due to the lower proportion of surface area open to the atmosphere. In addition, the cooler temperature at night makes you reduce the difference of the water vapor content between the plants and the air around them (**Figure 5A**). Thus, during a period of 24 h, the spineless cactus can transpire 11.3 Moles (203 g) of water per m^2 of surface, while plants C_3 and C_4 can lose about 4.7 and 2.9 times more, respectively [44].

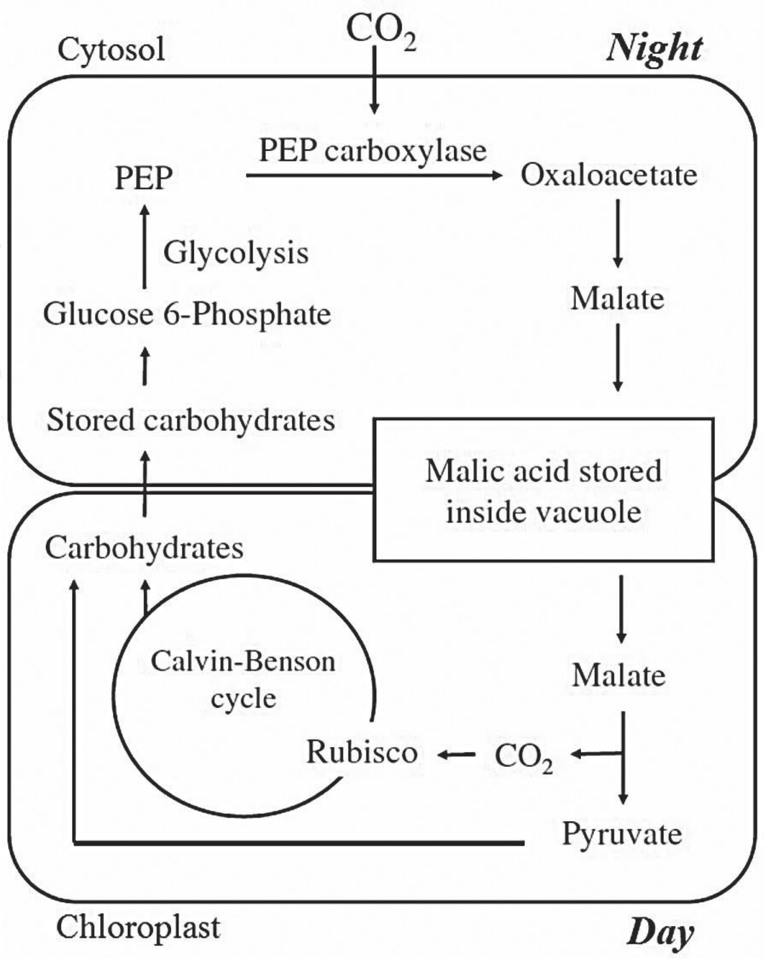

Figure 4. Crassulacean acid metabolism schema (CAM).

Previous studies [44] discuss evaluation of plants with different types of photosynthetic metabolism (C_3, C_4 and CAM), irrigated and fertilized without shade on bright days with maximum temperatures of 30–35°C and minimum night temperatures of 15–20°C; Nobel [44] noted that the capture of atmospheric CO_2 per hour between representatives of the three types of photosynthetic system is like the daily loss of water per hour. According to the author, the net speed of atmospheric absorption of CO_2 by nearly horizontal sheets of plants C_3 and C_4 gradually increases during the morning, as the sun rises, and reduces similarly in the afternoon, as the incidence of light on the leaves decreases, with a near zero catch at dawn (**Figure 5B**).

Many plants C_3 tend to a partial closure of stomata close to noon, which results in the reduction of water loss, but also in reducing atmospheric capture of CO_2. The maximum speed of atmospheric capture of CO_2 tends to be greater in cultures C_4 and smaller in CAM species, although its speeds of absorption may be significant during the night. In addition, CAM plants well irrigated usually absorb some CO_2 in the morning and in the late afternoon, while the plants C_3 and C_4 do not absorb nothing during the night [43, 44].

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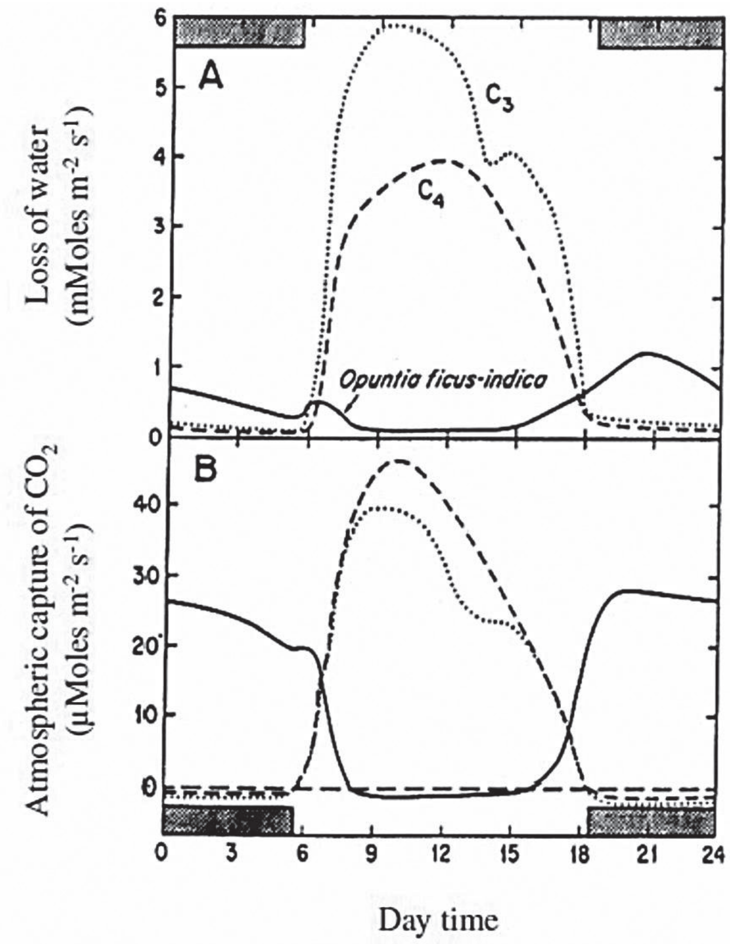

Figure 5. Daily loss of water (A) and atmospheric capture of CO_2 (B) for plants of type C_3, C_4 and for the species *Opuntia ficus indica* (CAM) (shaded area indicates the night). Source: [44].

4. Soil and climate requirements of spineless cactus in Brazilian semiarid

The semiarid region of Brazil's northeast is characterized by irregular rainfall, with rainfall between 300 and 500 mm/year, concentrated on a few months of year, consequently leading to long periods of drought. However, the spineless cactus is a plant adapted that has a good development in regions with little rainfall. Nevertheless, information about air and soil humidity, average temperature of day and night are crucial for production [16].

Climatic conditions exert a strong influence on growth and development of this plant [14]. Knowledge of phenology and the characteristics of cultures, when associated with the climatic conditions of their regions of origin and commercial dispersion, allows to establish the limits of climate requirement of species [45]. Thus, Souza et al. [46] have elaborated an agricultural zoning, using as essential tools, the information of phenology and the characteristics of the culture associated with the climatic conditions of the regions of origin and commercial dispersion of spineless cactus (**Table 2**).

	Aptitude		
Climate parameter	Ideal	Restricted	Inadequate
Average temperature (°C)	16.1 ≤ AverT ≤ 25.4	AverT < 16.1 and AverT > 25.4	-
Maximum temperature (°C)	28.5 ≤ MaxT ≤ 31.5	MaxT < 28.5 and MaxT 31.5	-
Minimum temperature (°C)	8.6 ≤ MinT ≤ 20.4	MinT < 8.6 and MinT > 20.4	-
Thermal amplitude (°C)	10.0 ≤ TA ≤ 17.2	TA < 10.0 and TA > 17.2	-
Precipitation (mm)	368.4 ≤ P ≤ 812.4	812.4 ≤ P ≤ 1089.9 and P < 368.4	P > 1089.9
Moisture index (-)	−65.6 ≤ MI ≤ −31.8	−31.8 ≤ P ≤ −7.7 and MI < −65.6	MI > 7.7

Source: Adapted from Ref. [46].

Table 2. Climatic indicators of agricultural zoning of spineless cactus.

Moura et al. [47] performed the agricultural zoning of spineless cactus for Pernambuco State based on climatic indicators presented by Souza et al. [46], as well as rainfall precipitation and climate data belonging to the Northeast Development Superintendence (SUDENE) and the National Institute of Meteorology (INMET), respectively. The authors observed that with respect to thermal amplitude, the favorable conditions for the cultivation of spineless cactus cover virtually the entire state. However, there may be thermal limitation for the cultivation of species in coastline, because of decreased of thermal amplitude in this territorial range. Also, it is observed that with respect to moisture index, approximately half of Pernambucan territory offers favorable conditions for the cultivation of spineless cactus, covering rural regions and part of Hinterland of State. However, when approached of arid region of São Francisco, it was verified restriction to cultivation, since this region has low values of MI, resulting, mainly from low levels of rain precipitation and greater evaporative demand, that condition the reduction in water content of soil. In contrast, the transition regions and the coastline were restricted and inadequate, respectively, which is associated with the excess rains resulting in increased moisture index. Finally, the results show that, under the climatic point of view, about 42.3% of state present conditions suitable for the cultivation of spineless cactus, while 54.4% are of territorial scope feature restrictions. In these areas, spineless cactus cultivation can be carried out; however, there may be restrictions regarding thermal amplitude or moisture index, which can result in a reduction in productivity.

For the cultivation of spineless cactus in low-risk climate conditions, in State of Rio Grande do Norte was elaborated an agricultural zoning, establishing the following criteria: average annual temperature (16–27°C), maximum temperature (28.5–33°C), minimum temperature (8.5–22°C) and average annual precipitation (360–800 mm/year). The municipalities that presented in at least 20% of its areas, thermal and water conditions within of the criteria established in at least 80% of the evaluated years were considered suitable for the cultivation of spineless cactus [48].

Bezerra et al. [49] determined the agricultural zoning of spineless cactus' cultivars for the municipality of Paraíba based on climatic indicators presented by Souza et al. [46] and in each of the meteorological stations in the State of Paraíba. The authors concluded that the mesoregion of Borborema and part of west-center mesoregion of region Agreste are the areas that present the most favorable climatic conditions for the cultivation of spineless cactus in state, in accordance with the ideal aptitude observed in **Table 2**. On the other hand, the coastline region of Paraiba and swamp of altitude around the municipality of Areia present the most unfavorable climatic conditions for the cultivation of spineless cactus. The mesoregion of Agreste and the arid region feature restrictions to precipitation and/or temperature.

Under conditions of excessive moisture in the soil accumulates water in quantities exceeding the transpiration capacity of plant, which facilitates the occurrence of rot, tipping and only then becomes highly vulnerable to diseases, especially those caused by fungi [49].

Accordingly, [14] the good yield of crops in semiarid northeast Brazil is associated with fact they need far less water than other conventional crops. The spineless cactus uses 100–200 kg of water to produce 1 kg of dry matter and produces well in areas with annual precipitation of up to 750 mm. It grows best where the average relative humidity of the air is above 40%, and day and night temperatures oscillate around 25 and 15°C. In some semiarid regions, low relative humidity and high nighttime temperatures are the main factors for the lower productivity or even death of plants [22].

Spineless cactus growth is favored in the higher altitudes, due to the reduction in air temperature and increasing relative humidity at night (55–60%) [13].

The spineless cactus is a culture relatively picky about physical and chemical characteristics of soil, showing greater growth in fertile soils. Therefore, if they are fertile, spineless cactus cultivation can be realized in areas of texture sandy to clay, but more often recommended the clay-sandy soils. In addition, fertility is also important that soil is well drained, since very moist soils do not lend themselves to the cultivation of spineless cactus [22], because it does not tolerate disabled drainage areas. The cultivation is also impossible in regions whose annual rainfall exceeds 1100 mm [46]. In addition, the spineless cactus does not tolerate high levels of salts [7]; therefore, it is not recommended to your cultivation in saline soils.

The spineless cactus is found in a wide range of soils, where the soil pH range is subacids to subalkalines, showing a good adaptation of species. Soils with 60–70 cm depth are good for the development of shallow root system of culture. However, soils with little drainage capacity, shallow groundwater and/or surface layer waterproof should not be regarded as adequate. The clay content must not exceed 15–20%, to avoid putrefaction of the roots [50].

5. Productivity of spineless cactus in Brazilian semiarid

5.1. Nonirrigated soil

Forage production in dry soil conditions means that the crop is cultivated without irrigation in regions where annual rainfall can be less than 500 mm. The cultivation will depend, in addition to precipitation, on specific techniques that allow an efficient use of the limited soil moisture. However, the spineless cactus is a plant which features high productivity in non-irrigated conditions, compared to other fodder, especially when subjected to appropriate agronomic practices and when used plant with high production potential, and being able, the production of dry matter varies from 12 to 47 tons every 2 years [25].

This productivity of spineless cactus can be observed in the study by Silva et al. [51] with *Opuntia ficus indica* and *Nopalea cochenillifera*, fertilized (130 kg N/ha/2 years) in drought conditions. The authors checked most green biomass (163.0 t MV/ha) for *Opuntia ficus indica*, differing of *Nopalea cochenillifera* (124.3 FM tons/ha). However, when this productivity was considered in terms of dry biomass, the incomes were equivalent, showing an average of 12.6 tons DM/ha/2 years.

Almeida et al. [52] evaluated the productive performance of *Opuntia ficus indica* and *Nopalea cochenillifera*, subjected to organic fertilization treatments (30 tons manure/ha), chemistry (100 kg P/ha and 300 kg N/ha) and the association of both in dense planting (1.0 × 0.25 m) in Semiarid Bahia. The data showed that, regardless of treatments, the fresh and dry biomass productions were equivalent among the species. However, when compared individually, the biggest productions were observed when there was association of organic fertilizer with the chemical.

Silva et al. [53] evaluated the dry matter production of spineless cactus cultivated under different types of chemical fertilizer (150 kg P/ha; 200 kg N/ha + 150 kg P/ha; and 200 kg N/ha + 150 kg P/ha + 100 kg K/ha) and spacing (1.00 × 0.50 m; 2.00 × 0.25 × 1.00 × 3.00 and 0.25 m), to 620 days after planting. The average productivity of dry matter was 17.1 mg/ha. The plants under 1.00 × 0.50 spacing with NPK, NP and P produced more dry matter than plants without fertilization. In spacing 2.0 × 0.25 m and 3.0 × 1.0 × 0.25 m dry matter production was similar for different fertilization.

The spineless cactus extracts large amounts of nutrients from soil. Considering an average annual productivity of 20 tons DM/ha, this plant extracts, approximately 180 kg of N, 32 kg of P, 516 kg of K and 470 kg of Ca per hectare. Considering an average productivity of 40 tons biennial DM/ha and average levels in DM of N, P, K and Ca as being of 0.9%, 0.16%, 2.58% and 2.35%, respectively, the spineless cactus extracts about of 360 kg of N, 64 kg P, 1032 kg of K and 940 kg of Ca per hectare every 2 years, without considering the other macros and micronutrients [54].

Dubeux et al. [55] observed influence of population of plants in spineless cactus productivity in several municipalities in semiarid region of State of Pernambuco. Dry matter production varied from 6 to 17 tons/ha in density of 5000 plants/ha and from 17.8 to 33.7 tons/ha in density 40,000 plants/ha, when spaced 2.00 m × 1.00 m and 1.00 m × 0.25 m, respectively. When assessing the spineless cactus growth in four spaces (1.00 m × 1.00 m; 1.00 m × 0.50 m; 2.00 × 1.00 m; 2.00 m × 0.50 m), Ramos et al. [56] concluded that the spacing influenced the production of biomass per area and that efficiency of use of rain by spineless cactus is incremented with higher population densities, being the best results observed in the spacing of 1.00 m × 0.50 m, resulting in a greater quantity of forage produced per area and per unit of rain. According to Ref. [22], the spineless cactus dense cultivation, with up to 40,000 plants/ ha, has been used in the Brazilian semiarid region, resulting in high productivity (320 tons FM/ha).

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5.1.1. Management of spineless cactus in nonirrigated soil

Choice of species or cultivar—In Brazilian semiarid region predominate three cultivars of spineless cactus, of which two belong to the species *Opuntia ficus indica* Mill (Gigante and Redonda) and one belongs to the species *Nopalea cochenillifera* Salm Dyck (Miúda). The Gigante and Redonda cultivars have shown greater rusticity due to its resistance to drought, when compared to Miúda cultivar, not being recommended its use in drought conditions. Therefore, in choice of species, one should opt for the more adaptable to region to be cultivated. On the other hand, the Miúda cultivar has larger palatability in relation to others, though more demanding on soil and lower nighttime temperature [17, 57].

Planting area—Contrary to popular belief, the spineless cactus has requirements for the physical-chemical characteristics of soil. For your cultivation can be indicated the soil of sandy to clay texture, being most recommended mixed texture soils (clay sandy). The most fertile soil of property for planting is recommended, preferably deep and free of acidity, salinity and stones. The soil must be well prepared and mainly already corrected. It is very important that the soil has good drainage. In practice, such as the planting of spineless cactus is normally in final third of the drought period, and the mechanized soil tillage, mainly in conventional ways, can generate many clods of land, due to low soil moisture in that period. The clay terrain is the most conducive to form clods. Therefore, more care should be spent on fixing the seedlings in grooves of planting, if there are many clods [57].

Choice of cladodes and forms of planting—The cladodes must be obtained from young plants, preferably the most productive, stain-free, clinical signs of disease and pest-free (especially the cochineal). Must make planting of cladodes of good development, preferably located in the middle of plant. The cladodes should be cut and separated at the junction of cladodes, with the aid of a knife sharp and clean, to avoid possible contamination. The cladodes should be stored in shade for a period of about 10–15 days for healing of wound caused by cutting. In Brazilian semiarid region, many forms of spineless cactus planting are found: cladodes in vertical position; positioning to 45° of inclination; and planting with overlapping cladodes, referring to a deck of cards open, bilateral alignment in groove referencing aligned domino pieces, among others. However, regardless of the form of planting, one must prioritize one east-west orientation to maximize uptake of solar radiation [17, 57].

Fertilizing—As for the fertilization of establishment has been studied the addition of organic fertilizers, minerals and the joint addition of these, obviously depending on factors, such as level of soil fertility, availability of financial resources, among others. If to add manure in groove, put a layer of land on the manure or spread the manure between planting lines avoiding the contact with the basis of plants. These measures ensure the reduction of plant mortality by rot of base cladode. It is valid to note that in forage use, the spineless cactus extracts considerably some specific soil nutrients (for 10 tons DM/ha/year: 90 kg N/ha, 16 kg P/ha, 258 kg K/ha and 235 kg Ca/ha), which need to be restored [57].

Planting spacing—The planting spacing to be used varies according to soil fertility, amount of rainfall, size of property, forage need and purpose, among other factors [57]. However, it should be chosen according to the preferences and the availability of capital from the producer [58].

The practice of dense cultivation makes it possible to achieve greater forage production by area; however, the costs of establishment of plantation also are larger, and the cultural practices become more difficult and do not allow cultivation with other crops [59]. It is worth mentioning that spineless cactus extracts large amounts of nutrients from the soil. By adopting a system of dense planting, there will be greater extraction of nutrients from the soil, so it must have greater care with fertilizing, because it can cause yellowing of the cladodes by nutrient deficiency [60]. Moreover, it can affect the light interception and photosynthetic efficiency, influencing on the development and productivity of the plant. In Brazilian semiarid region, usually if it adopts the spacing of 1 m between rows and 0.25 m between cladodes, while in other countries it used 3 m or more, which facilitates the mechanization. Thus, less dense plantations facilitate cultural practices with animal traction, important for family agriculture [61].

Care with crops—The control of invasive plants is of fundamental importance in cultivation of spineless cactus. In addition to competition for light, competition from invasive plants for water and nutrients, due to shallow root system of spineless cactus, reduces the productivity of this crop and increases the risk of fire [12].

Pest and disease control—About the pests and diseases, in Brazilian semiarid region, although there are records of diseases, the problems are small and localized [12]. With respect to pests, scale cochineal (*Diaspis echinocacti*) and carmine cochineal (*Dactylopius opuntiae*) are the main today. In relation to first, the biological control by predator insect (*Coccinella septempunctata*) known as "Joaninha" has been shown to be efficient, but the chemical control with mineral oil is also recommended when massive infestation occurs. In relation to second, the use of resistant cultivars, like the Miúda cultivar, has been shown to be very efficient [7].

Harvest—Usually, spineless cactus harvesting is made every two years. However, the cut-off frequency can vary depending on the need of producer and of the climatic conditions. Nevertheless, as well as for other forage, there is the need to preserve a residual cladode area to promote vigorous regrowth and increased longevity of plant [7, 12].

5.2. Irrigated soil

Despite all morpho-anatomical and physiological adaptability, growth and development of spineless cactus varies with the weather conditions, where often necessary irrigation events in its production system so that it can meet its water need [62].

It very common to irrigate it in areas with long periods of drought, where the spineless cactus is used for fruit production and human food (Mexico, Chile, Italy and Israel) [44, 63] for to supply its water need, especially in periods of low rainfall levels to ensure productivity and survival of crop [64].

The water deficit in soil negatively influences on growth and development of plants, since it reduces your water potential, resulting in loss of turgidity, closing of stomata, reducing growth and, consequently, reducing the final output [65].

In this way, the knowledge of how spineless cactus responds to different levels of water availability is considered as indispensable for the establishment of management strategies, which are aimed at better use of water reserves in soil by crop. Information, such as these are fundamental to the management of spineless cactus, in search of more efficient use of available water, considering that this is a very cultivated forage in areas of low water availability [62].

In State of Rio Grande do Norte was conducted a study with spineless cactus dense (50,000 plants/ha), fertilized (organic, 50 tons manure/ha; and chemistry, 500 kg superphosphate/ha in foundation and 225 kg of nitrogen/ha/year) and irrigated (7.5 liters per linear meter every 10 days, 3.75 mm) in municipalities of Apodi, Cruzeta and Pedro Avelino for to improve the performance of spineless cactus in these regions of State where it suffers severe wilting due to inadequate climatic conditions (high temperatures and low relative humidity) (**Table 3**). The published results proved the effectiveness of irrigation of salvation as enabling technology of spineless cactus production in semiarid Brazilian, where traditionally were not obtained productions on dryland cultivation system [66].

In general, researches developed by EMPARN [66] with spineless cactus irrigated and dense (50,000 plants/ha) achieved productivity average of 250–350 tons FM/ha in cuts with annual frequency. Dry matter yields are variable and dependent on the concentration of crop dry matter.

In Rio Grande do Norte, the first studies with spineless cactus cultivation under irrigation were performed by Wanderley in 1996, in municipalities of Lajes, Angicos e Pedro Avelino. After testing several alternatives, he defined a system with use of high densities of planting with 50,000–100,000 plants/ha and drip irrigation in simple rows with low intensity, 5 liters of water/linear meter (2.5 mm) every 15 days (5 mm/month), as well as organic and chemical fertilization. Even when it comes to empirical data, high productivity was obtained in a region where the spineless cactus had never previously succeeded [63].

It is also important to point out that those were the yields obtained by EMPARN in its experiments, which is not to say that yields larger or smaller cannot be obtained. Indeed, Queiroz et al. [67] evaluated the effect of application of different irrigation blades (976, 1048, 1096, 1152 and 1202 mm) on the productive performance of spineless cactus cultivated in semiarid environment and check that there were no differences in number of cladodes and in fresh and dry annual biomass between treatments, revealing that the increase of irrigation has not contributed to increase the yield of crop. Flores-Hernández et al. [68] also found that supplemental irrigation (740, 1060 and 1380 mm) did not provide increments cladodes production and dry matter productivity.

		Productivity (tons of forage/ha)	
Municipality	**Cutting period**	***Opuntia ficus indica* Mill**	***Nopalea cochenillifera* Salm Dyck**
Apodi	2 years	500	400
Cruzeta	2 years	215	200
Pedro Avelino	1 year	200	220

Source: Adapted from Ref. [66].

Table 3. Productivity of spineless cactus dense, fertilized and irrigated in Rio Grande do Norte State, Brazil.

Oliveira et al. [41] reported that regions with rainfall above 1000 mm/year can result in low productivity of spineless cactus, possibly due to excessive rainfall. Thus, the good yield of crops in semiarid is associated with fact that they need far less water than other conventional crops. In this case, spineless cactus produces well in areas with annual precipitation of up to 750 mm [14]. These results lead to the understanding that the productive benefits of increased of water blade for spineless cactus are more apparent in regions with very low rainfall levels compared to regions where the rainfall values exceed 750 mm [67, 68].

5.2.1. Management of spineless cactus in irrigated soil

Irrigation—For the choice of an irrigation system, some aspects should be considered, such as the quantity and quality of water, climate, topography, soil and crop to be irrigated; in other words, there is no irrigation system and yes, the one that more fits the conditions of resources available on the property [63]. In general, the most widely used irrigation system is located by drip, with a line per row [62, 67, 68]. The origin of water can be from various sources, from the dam to the wastewater or saltwater, where positive results were obtained on productivity [69]. Whatever the source of available water, to irrigate one hectare of spineless cactus, you will need a volume diary minimum of 5000 liters [63].

Planting area—The spineless cactus is a relatively demanding crop about physical-chemical characteristics of soil. Fertile soils, plants, and deep with sandy to clay texture should be selected, being most recommended clay-sandy soils. In the old days, it was common for the producers to choose the worst soils to plant the spineless cactus for being a very tough plant. However, for spineless cactus plantation irrigated the thought should be exactly the opposite, due to the high cost of the system, the high density of planting, and nutrient extraction, and to be a permanent crop, one must choose the best soil possible [63]. However, since provided that the soil is decompressed and organic matter is added, other types of soil can be used [2]. To do this, it must carry out an analysis of soil of area chosen, avoiding acid and salinized soil, choosing preferably light soils of gentle topography, and avoiding those shallow and stony. The analysis shall include both physical-chemical characteristics soil [63]. It is very important that the soil has good drainage, since very moist soils do not lend themselves to cultivation of spineless cactus [22].

Choice of cladodes—To select the cladodes in middle of the plants, avoid very small cladodes, young and very thin, as they have high mortality and low sprouting. Always cut the cladodes at the junction with sharp and clean knives. The custom of breaking cladodes manually forcing and twisting in joints should be avoided, because it impairs the healing of the cut and favors the installation of fungi. The cladodes should be inspected to ensure the absence of cochineal and rotting. The cladodes must undergo a wilt (the shade) average of 12 days for healing of cuts and loss of part of the water. To avoid contamination by fungi can be used any copper-based fungicide on the cut (20 g/20 L) or Bordeaux [63].

Planting spacing—Generally, it uses 1.4–2.0 m spacing between lines of planting and 10–30 cm, between the plants within line. A denser planting for *Nopalea cochenillifera* is recommended and less dense to plants of genus *Opuntia*. It is important to ensure a spacing of at least 20–25 cm between cladodes in line to allow clean with hoe. Examples of average densities would be spacing as 1.6 m × 0.25 m (25,000 plants/ha) or 1.4 m × 0.25 m (28,600 plants/ha). Higher densities can be found in 2.0 m × 0.10 cm spacing (50,000 plants/ha) or 1.4 m × 0.10 m (71,400 plants/ ha). An indication for systems in double rows irrigated is 1.80 × 0.50 × 0.40 m spacing to spineless cactus of genus *Opuntia* and 1.80 × 0.50 × 0.25 m for *Nopalea cochenillifera* [63].

Planting techniques—Traditionally, the spineless cactus planting in dry soil is performed 30–60 days before the rainy season. However, with the use of irrigation, the spineless cactus can be planted practically any time of year, since the cladodes are subjected to wilt and not be placed in wet soils. The organic and phosphorus fertilization must be deposited in bottom of groove, topped with a bit of land to avoid contact with the cladode. It is recommended that in clay soil the organic fertilizing is not placed at bottom of groove at planting, because it can provide the proliferation of fungi and cause rot of cladode. In this case, the organic fertilizing should be done later, spread among the ranks of planting during the rainy period, or when used in groove the manure should be cured. The position of planting of cladodes in groove or pit can be tilted (45°) or vertically, with the cut facing the soil. The form of planting most often used is burying1/3 of cladode. In the case of irrigated system, it is recommended to direct the wide face of cladode in east-west direction for it to make the most of the Sun's radiation to stimulate photosynthesis, sprouting and rooting [63].

Organic and chemical fertilization—The spineless cactus features a large response to organic fertilizing that must be applied in quantities of 20–40 tons/ha of cattle manure, goats or sheep, or 100 kg of manure for each ton of fresh matter produced. Thus, for a production of 300 tons FM/ha would require 30 tons of manure. With the high productivity achieved by spineless cactus, the extraction of nutrients from soil is quite high and if these are not replenished, it may result in depletion of the soil. The five soil nutrients that appear to exert greater effect on performance of *Opuntias* are N, P, K, B and Na. How fertilizers have high cost, it is necessary to undertake a soil analysis for to know which nutrients that are disabled and apply them in the right quantities for each situation. When forward the soil analysis, one must ask the recommendation of fertilization to cultivation of spineless cactus [63].

Care with crops—Spineless cactus should be treated as crop, and since the producer will make a relatively high investment with the irrigated system deployment, every care should be taken to keep the terrain free of invasive plants. For that, at least three cleanings of terrain a year are required. If three cleanings cannot be held completely, at least one cleaning between lines should be made. Some herbicides have been used to facilitate the work, but so far there is no official indications of products to be used in the control of invasive plants in planting of spineless cactus [63].

Pest and disease control—The two major pests that affect spineless cactus are the scale cochineal and carmine cochineal. In this case can be used the same methods above of control for spineless cactus management in drought conditions [7, 12].

Cutting intensity in harvest—Traditionally, in Brazilian semiarid region, the spineless cactus is handled in drought conditions with the realization first cut to 2 years' age after planting and subsequent cuts every 2 years. With the use of irrigation and fertilization organic and chemistry, as well as low intensity management, can perform the first cut to 12 months and the subsequent cuts according to the need of forage. As most producers does not provide the ideal conditions of management and fertilizing soil, even with irrigation it would be wise to perform the first cut between 18 and 24 months, to consolidate the establishment of spineless cactus and then annual cuts. The results of research with the cultivars *Opuntia* and *Nopalea* proved that higher cuts, preserving even the secondary cladodes, produced 55% more than the cut while preserving the primary cladodes and 144% more when only the mother-cladode was left. This is another important management practice, because many producers practice very intense cuts, leaving only the mother-cladode. In more up cuts, even losing the part of production that is in field in first cut, the subsequent yields are highly compensators and the longevity and sustainability of spineless cactus is much favored [63].

6. Final considerations

The spineless cactus can achieve high productivity if handled correctly, with proper planting system, cultural practices, intensity and frequency which takes into consideration the photosynthetic capacity of culture, ensuring the animal supplementation.

Although be adapted to the edaphoclimatic conditions of the Brazilian Semiarid, the spineless cactus is demanding in cool night temperature and high relative humidity of the air for the good development.

In nonirrigated soil, the spineless cactus can present high productivity when compared to other traditional crops. However, in certain semiarid regions, often are necessary irrigation events in its production system so that it can meet its water needs for achieving high productivity.

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