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Influence of cladode orientation and planting season on development and chemical composition of forage cactus

Influência da orientação do cladódio e época de plantio no desenvolvimento e composição química da palma forrageira

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ABSTRACT: Solar radiation influences the growth and development of plants. This work aimed to evaluate the effect of solar radiation under different seasons and cladode orientation during development and chemical composition of forage cactus varieties of the genus *Opuntia* and *Nopalea*. The experiment was conducted at the experimental station of the Agronomic Institute of Pernambuco (IPA), located in Arcoverde-PE. We used a randomized complete block design in factorial scheme (2x3x3), represented by two planting seasons (dry and rainy season), three cladode orientations (North-South, East-West and 45º angle between these), and three forage cactus varieties ("miúda", "IPA clone 20", and "IPA Sertânia"), totaling 18 treatments, with four replications. Response variables included fresh matter productivity (FMP), dry matter productivity (DMP), crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), water content (WC), and absolute growth rate per dry biomass (AGRDB), every two years. There was no difference in DMP, CP, NDF, and ADF for planting seasons and cladode orientation. We observed differences in CP and ADF among cactus varieties, probably related to WC at harvest time. Solar radiation in the different seasons and cladode orientations did not influence dry biomass production and chemical composition of forage cactus. IPA Sertânia and miúda varieties showed the greatest DMP compared to IPA clone 20.

KEYWORDS: Brazilian semiarid, cactaceae, solar radiation, planting season.

RESUMO: *A radiação solar influencia o crescimento e desenvolvimento das plantas. O objetivo deste trabalho foi avaliar o efeito da radiação solar sob diferentes épocas e posições de plantio do cladódio no desenvolvimento e composição química de variedades de palma forrageira dos gêneros Opuntia e Nopalea. O experimento foi conduzido na estação experimental do Instituto Agronômico de Pernambuco (IPA), localizado em Arcoverde-PE. O delineamento utilizado foi blocos ao acaso em esquema fatorial (2x3x3), representados por duas épocas de plantio (período seco e chuvoso), três direcionamentos de plantio do cladódio (Norte-Sul, Leste-Oeste e ângulo de 45º entre esses) e três variedades de palma forrageira (miúda, IPA clone 20 e IPA Sertânia), totalizando 18 tratamentos, com quatro repetições. Foram determinados a produtividade de massa fresca (PMF) e seca (PMS), teor de proteína bruta (PB), fibra em detergente neutro (FDN), fibra em detergente ácido (FDA), teor de água (TA) e taxa de crescimento absoluto por fitomassa seca (TCAFS) a cada dois anos. Não houve diferença significativa para PMS e teores de PB, FDN e FDA entre a época de plantio e entre as posições de plantio do cladódio. Houve diferença na PB e FDA entre as variedades, provavelmente relacionado ao TA na hora da colheita. A radiação solar em diferentes épocas e posições de plantio dos cladódios não influenciam a produção de fitomassa seca e composição química da palma. As variedades IPA Sertânia e miúda apresentaram maiores PMS em comparação ao IPA clone 20.*

Palavras-chave: *Semiárido brasileiro, cactácea, influência da radiação solar, época de plantio.*

Introduction

Cactus (*Opuntia* spp. and *Nopalea* spp.) is native from tropical and subtropical America, but currently is dispersed globally, cultivated or in rangelands, in a variety of environmental conditions in different continents, including America, Africa, Asia, Europe, and Oceania. Cacti have diverse uses including vegetable and fruit production for human consumption, fodder for livestock, erosion control, soil conservation, landscaping, live fences, biofuel, dying from carmine cochineal, and several other products such as cosmetics, beverages, oil, and medicines (DUBEUX-JÚNIOR et al., 2013).

In Brazil, there are approximately 600,000 ha cultivated with cactus, and most of the area is planted with *Opuntia ficus-indica* (cvs. gigante, redonda, and IPA clone 20), *Nopalea cochenillifera* (cvs. Miúda and IPA Sertânia), and *Opuntia* sp. (cv. "orelha de elefante"). Recent efforts were dedicated to diversify the uses of cactus in Brazil, however, the majority of the planted cactus is used as fodder for livestock. Cactus is well adapted to semiarid regions because of its physiological, anatomical, and morphological characteristics. Therefore, it is a staple fodder for goats, sheep, and cattle in the Brazilian semiarid (ALVES et al., 2017a).

The Brazilian semiarid region has annual evaporation greater than 2,000 mm and average annual rainfall lesser than 750 mm. Rainfall in this region typically is unimodal with a rainfall season ranging from three to five months. In addition, salinization is becoming a problem, with large areas affected; reducing the potential growth of cultivated plants (DUBEUX-JÚNIOR et al., 2013). Livestock production is one of the major land uses, and cactus has a key role to sustainable promote the social and economic development of this region.

Plant-environment interactions affect potential biomass production, which is directly related to the efficient use of solar energy by converting solar radiation in chemical energy via photosynthesis. Factors such as time and intensity of solar radiation might affect plant growth and development, since photosynthesis depends upon solar radiation (PINHEIRO et al., 2014; TAIZ et al., 2017). Average solar radiation in the Brazilian semiarid is 5.9 kWh m^{-2} (MARTINS et al., 2008), however, only 5% of this energy is used during photosynthesis. One of the reasons for this low efficiency are the different wavelengths reaching the plants in a spectrum not used during the photosynthesis. In addition, the photosynthetic active radiation (400-700 nm) reaching the plant surface is partially transmitted or reflected (TAIZ et al., 2017). Thus, biomass production depends not only on physical and biological aspects of the plant, but also on canopy structure. Leaf area index, or cladode area index for cactus, is a key factor affecting light extinction coefficient, thereby affecting light interception and attenuation of light incidence (BERNARDES et al., 2011; PINHEIRO et al., 2015). These factors are also directly related to plant growth and development (PINHEIRO et al., 2014).

Cactus typically has low cladode area index, when compared to legumes and grasses, resulting many times in reduced biomass productivity. This characteristic, however, varies with genotype, that might present different cladode morphology. Phenotypical cladode variability might affect photosynthetic characteristics and the crop yield. Furthermore, the production system might also affect cladode light interception and use of solar radiation (PINHEIRO et al., 2014).

This study assessed how cladode orientation (i.e. geographical orientation) and seasons of the year affected development and chemical composition of cactus varieties from the genus *Opuntia* and *Nopalea*.

Material and Methods

The research was performed at the Experimental Research Station of Arcoverde (IPA), Pernambuco, Brazil. The experimental site is located 681 m a.s.l. and average annual rainfall is 650 mm. Average maximum temperature is 29.5 ± 2.6 °C and average minimum temperature is 18.5 ± 1.3 °C, with average wind speed of 3.7 ± 0.5 m s^{-1}, cumulative annual evaporation of 1,787.2 mm, and average relative air humidity of 74.3 ± 8.6% (INSTITUTO NACIONAL DE METEOROLOGIA, 2017). Annual rainfall during the experimental period is described in Table 1.

The soil was classified as eutrophic regolithic neosol solodic with fragipan, having the following physical attributes in first 10 cm depth: 450 g kg^{-1} coarse sand, 280 g kg^{-1} fine sand, 190 g kg^{-1} silt and 80 g kg^{-1} clay, 1.43 g cm^{-3} soil density, 2.64 g cm^{-3} particle density, 38% flocculation degree; and chemical: 0.84 g kg^{-1} C, 33.00 mg kg^{-1} P, 0.53 $cmol_c$ kg^{-1} K^+, 3.15 $cmol_c$ kg^{-1} Ca^{2+}, 1.10 $cmol_c$ kg^{-1} Mg^{2+}, 0.05 $cmol_c$ kg^{-1} Na^+, 0.00 $cmol_c$ kg^{-1} Al^{3+}, 2.39 $cmol_c$ kg^{-1} H^+, 4.83 $cmol_c$ kg^{-1} sum of bases, 7.22 $cmol_c$ kg^{-1} cation exchange capacity, 67.00% base saturation, and pH 6.12. Moreover, from 10 to 30 cm deep the physical and chemical attributes were: 440 g kg^{-1} coarse sand, 260 g kg^{-1} fine sand, 220 g kg^{-1} silt and 80 g kg^{-1} clay, 1.53 g cm^{-3} soil density, 2.60 g cm^{-3} particle density, 38% flocculation degree, 0.39 g kg^{-1} C, 12.00 mg kg^{-1} P, 0.49 $cmol_c$ kg^{-1} K^+, 2.15 $cmol_c$ kg^{-1} Ca^{2+}, 1.20 $cmol_c$ kg^{-1} Mg^{2+}, 0.06 $cmol_c$ kg^{-1} Na^+, 0.00 $cmol_c$ kg^{-1} Al^{3+}, 1.23 $cmol_c$ kg^{-1} H^+, 3.90 $cmol_c$ kg^{-1} sum of bases, 5.13 $cmol_c$ kg^{-1} cation exchange capacity, 76.00% base saturation, and pH 6.44 (SOUSA et al., 2011).

The experiment was established in 2008, in two seasons. The first planting season occurred in the last summer week, in March (beginning of the rainy season); the second planting season occurred in the last winter week, in June (end of the rainy season). Three cactus varieties were tested, being two *Nopalea cochenillifera* varieties (IPA-100004 "miúda" and IPA-200205 "IPA Sertânia" or "mão de moça") and one *Opuntia ficus-indica* variety (IPA-100003 "IPA clone 20"). Cactus was planted manually, using one cladode per pit. Planting spacing was 1 m between rows and 0.5 m within row. Right after planting, 20 Mg ha^{-1} of cattle manure was applied. The plants were harvested at two-year intervals, in 2010 and 2012 (March and June, according to planting). The experimental unit (plot) had three 4-m rows with 8 plants per row. Cladodes were positioned facing three orientations: 1 – North-South; 2 – East-West; 3 - 45º angle between North-South/East-West. Orientation of cardinal points was performed between 9 am and 3 pm, using a 2-m height post.

Treatments were allocated in a factorial arrangement (2 x 3 x 3) in a randomized complete block design. Factors included planting season (dry and rainy season), three cladode orientations (North-South, East-West, and 45º between these two), and three cactus varieties (miúda, IPA clone 20 and IPA Sertânia), resulting in 18 treatments, with four replications per treatment.

Weed management consisted of three hand mowing and two pre-emergent herbicide applications 3-(3,4-dichlorophenyl)-1,1-dimethylurea 1500 g ha^{-1} (Diuron) using the rate recommended by the manufacturer. Harvest was performed every two years, sampling the plants in the inner row, excluding the two border plants. During the harvest, the primary cladodes were not harvested. Cladodes were analyzed for fresh matter productivity (FMP), dry matter productivity (DMP), crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF), according to Cavalcante et al. (2014). Water content (WC) was determined using the following calculation: WC = [(FMP-DMP)/FMP] x 100 and expressed as % FM (PIMIENTA-BARRIOS et al., 2012). Absolute growth rate per dry biomass (AGRDB) was calculated according to Carvalho et al. (2011), using the following formula: AGRDB = DMP/T, where T = time; results were expressed in Mg ha^{-1} $year^{-1}$. Data were analyzed using the statistical package Assistat® 7.7 (SILVA; AZEVEDO, 2006). Means were compared using Tukey test and 5% probability level.

Results and Discussion

In the first harvest, treatments affected ($p \leq 0.05$) fresh matter productivity, CP and ADF. Treatments did not affect dry matter productivity and NDF (Table 2). In the second harvest, treatments also affected fresh and dry matter productivity (Table 3).

In the first harvest, planting season and cladode orientation affected fresh matter productivity, cactus varieties affected CP and ADF (Table 2), and there were different interactions. Planting season × cladode orientation affected CP (Table 4) and planting season × cactus variety affected dry matter productivity (Table 5). The triple interaction planting season × cladode orientation × cactus variety on CP (Table 6).

In the second harvest, there was an effect of cactus variety on fresh and dry matter productivity (Table 3), and an interaction planting season × cactus variety for fresh and dry matter productivity (Table 7). There was also effect of planting season (Table 3) and interaction cladode orientation × cactus variety for fresh matter productivity (Table 8).

Planting cactus during the rainy season and cladodes East-West oriented, in the first harvest, resulted in greater fresh matter productivity. However, there was no effect of planting season, cladode orientation, and cactus variety for dry matter

Table 1. Rainfall at the experimental site from 2008 to 2012.

Rainfall (mm)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
2008	0.0	88.4	179.6	85.3	154.3	54.5	107.2	45.6	12.4	5.7	0.0	21.2	754.2
2009	-	89.3	-	-	256.9	78.7	80.5	97.7	2.3	6.1	4.8	36.1	652.4
2010	143.3	90.1	67.6	0.0	34.7	210.6	73.5	31.9	37.3	62.1	0.0	31.2	782.3
2011	36.2	58.0	36.1	89.0	229.8	0.0	78.0	39.2	22.4	18.2	21.8	0.0	628.7
2012	91.2	7.7	10.0	38.7	43.7	27.3	59.3	37.9	5.9	7.7	10.9	0.9	341.2
Rainfall Period													
February 2008/2010 1,549.9 mm							February 2010/2012 1,390.8						

Data obtained at the experimentalsite from Instituto Nacional de Meteorologia (2017).

Table 2. Effect of cladode orientation, planting season, and cactus genotypes on fresh and dry matter productivity, crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) of forage cactus varieties grown at Arcoverde Experimental Station (IPA), Arcoverde-PE, harvested in 2010.

Factor	Fresh Matter	Dry Matter	CP	NDF	ADF
	Mg ha^{-1}		% in DM		
Planting season					
Dry season	228.6 b	19.4 a	8.2 a	47.9 a	17.8 a
Rainy season	278.7 a	20.0 a	7.6 a	50.5 a	19.4 a
Cladode orientation					
East/West	284.4a	21.8 a	7.5 a	47.6 a	17.8 a
North/South	233.6 b	18.3 a	8.7 a	50.6 a	18.9 a
45°	242.9 ab	19.0 a	7.5 a	49.4 a	19.1 a
Variety					
IPA-Sertânia	252.2 a	18.9 a	7.8 b	48.2 a	16.6 b
Miúda	253.5 a	21.1 a	5.7 c	50.5 a	14.8 b
Clone-20	255.2 a	19.1 a	10.2 a	48.9 a	24.4 a
C.V (%)	23.7	25.8	23.5	18.4	22.9

CP crude protein (% in DM), *NDF* neutral detergent fiber (% in DM) and *ADF* acid detergent fiber (% in DM). Means followed by the same letter, within each factor and response variable, do not differ using the Tukey test (P >0.05).

Table 3. Effect of cladode orientation, planting season, and cactus genotypes on fresh and dry matter productivity of forage cactus varieties grown at Arcoverde Experimental Station (IPA), Arcoverde-PE, harvested in 2012.

Factor	Fresh matter	Dry matter
	Mg ha^{-1}	
Planting season		
Dry season	187.6 b	21.4 a
Rainy season	234.5 a	25.3 a
Cladode orientation		
East/West	237.0 a	25.0 a
North/South	195.3 a	22.4 a
45°	200.8 a	22.6 a
Variety		
IPA-Sertânia	263.0 a	27.7 a
Miúda	243.7 a	30.6 a
Clone-20	126.4 b	11.7 b
C.V (%)	35.9	38.3

Means followed by the same letter, within each factor and response variable, do not differ using the Tukey test (P >0.05).

Table 4. Effect of planting season × cladode orientation on cactus crude protein (CP) grown at Arcoverde Experimental Station (IPA), Arcoverde-PE, harvested in 2010.

	Planting season	Cladode orientation		
		East/West	North/South	45°
Crude Protein (%)	Summer/dry season	7.29 bA	10.02 aA	7.30 bA
	Winter/rainy season	7.64 aA	7.38 aB	7.8 aA

Means followed by the same letter, small letters compare means within and between cladode orientation, and capital letters compare cladode orientation in distinct seasons, do not differ by the Tukey test (P >0.05).

Table 5. Effect of planting season × cactus variety on dry matter productivity of forage cactus grown at Arcoverde Experimental Station (IPA), Arcoverde-PE, harvested in 2010.

	Planting season	Cactus variety		
		IPA-Sertânia	Miúda	Clone-20
Dry matter productivity (Mg ha^{-1})	Summer/dry season	21.41 aA	18.07 aB	18.66 aA
	Winter/rainy season	16.42 bB	24.06 aA	19.6 abA

Means followed by the same letter, small letters compare cactus varieties within and between planting season, and capital letters compare cactus varieties in distinct seasons, do not differ by the Tukey test (P >0.05).

Table 6. Effect of planting season × cladode orientation × cactus variety on cactus crude protein (CP) at Arcoverde Experimental Station (IPA), Arcoverde-PE, harvested in 2010.

Planting season	Cladode orientation	Cactus variety	Crude protein (%)
Summer/dry season	East/West	IPA-Sertânia	8.2 bcA
		Miúda	5.4 cA
		Clone-20	8.3 bcA
	North/South	IPA-Sertânia	8.8 bcA
		Miúda	7.8 bcA
		Clone-20	13.5 aA
	45°	IPA-Sertânia	6.1 bcB
		Miúda	5.5 cA
		Clone-20	10.3 abA
Winter/rainy season	East/West	IPA-Sertânia	6.5 abcA
		Miúda	5.7 bcA
		Clone-20	10.7 aA
	North/South	IPA-Sertânia	8.3 abcA
		Miúda	5.3 cA
		Clone-20	8.5 abcB
	45°	IPA-Sertânia	8.8 abcA
		Miúda	4.7 cA
		Clone-20	9.8 abA

Means followed by the same small letter for treatments within season, and capital letters for treatments between seasons, do not differ by Tukey test (P>0.05).

productivity (Table 2). In the second harvest, there was a similar trend of planting season for fresh matter productivity, with greater productivity for plants established during the rainy season. There was no significant differences for cladode orientation for fresh and dry matter productivity, however, IPA Sertânia and Miúda presented greater fresh and dry matter productivity (Table 3). Greater fresh matter productivity for plants established during the rainy season is a result of greater water availability during the rainy season.

The characteristics of fresh matter productivity are not considered important in studies with other forage plants. However, the fresh matter productivity becomes important when used for the design and control of the flow of animals, and due to the amount of water in cladodes, which is high and important for the animals in arid and semiarid regions. In practice, it may also be noted that the supply of forage cactus to the animals occurs during the dry season, where the forage plants is dry and the temperature is high, which affect the intake of water by the animals. Thus, the forage cactus in the diet of animals has importance both as water and nutrients supplier. The absence of a significant response to dry matter productivity may be related to the dynamics of the development of the forage cactus root system, in order to capture water and nutrients from the soil (LEITE et al., 2018). Furthermore, the rainy season can generate short periods of complete growth of the root system. Which disappears during the dry season, as a strategy for saving energy and humidity (LEITE et al., 2018; ZÚÑIGA-TARANGO et al., 2009).

Cladode orientation effect on fresh matter productivity in the first harvest likely occurred because of different cladode water content during harvest (92% in 2010 and 89% in 2012) (Table 9). In previous studies, differences in water retention and accumulation in cactus cladodes after a pulse of water

Table 7. Effect of planting season × cactus variety on fresh and dry matter productivity of forage cactus grown at Arcoverde Experimental Station (IPA), Arcoverde-PE, harvested in 2012.

Planting season	Summer/dry season			Winter/rainy season		
Cactus variety	IPA-Sertânia	Miúda	Clone-20	IPA-Sertânia	Miúda	Clone-20
Fresh matter productivity	212.6 aA	202.7 aB	147.4 aA	313.4 aA	284.7 aA	105.3 bA
Dry matter productivity	23.8 aB	26.4 aB	14.1 aA	31.6 aA	34.9 aA	9.4 bA

Means followed by the same small letter within and between period, and capital letters for cactus variety in distinct periods, do not differ by Tukey test (P>0.05).

Table 8. Effect of cladode orientation × cactus variety on fresh matter productivity of forage cactus at Arcoverde Experimental Station (IPA), Arcoverde-PE, harvested in 2012.

Cladode orientation	Cactus variety	Fresh matter productivity (Mg ha^{-1})
East/West	IPA-Sertânia	322.2 aA
	Miúda	240.1 aA
	Clone-20	148.6 aA
North/South	IPA-Sertânia	204.5 aA
	Miúda	281.2 aA
	Clone-20	100.2 bA
45°	IPA-Sertânia	262.2 aA
	Miúda	209.8 aA
	Clone-20	130.3 aA

Means followed by the same letter, small letters within and between cladode orientation, and capital letters for varieties in different positions, do not differ by the Tukey test (P>0.05).

Table 9. Effect of cladode orientation, planting season, and cactus variety on water content and absolute growth rate per dry biomass (AGRDB) of forage cactus at Arcoverde Experimental Station (IPA), Arcoverde-PE, harvested in 2010 and 2012.

Factor	Water content %		AGRDB Mg ha^{-1} year^{-1}	
Year	2010	2012	2010	2012
Planting season				
Dry season	92 aA	89 aB	9.7 aA	10.7 aA
Rainy season	93 aA	89 aB	10.0 aA	12.6 aA
Cladode orientation				
East/West	92 aA	89 aB	10.9 aA	12.5 aA
North/South	92 aA	89 aB	9.2 aA	11.2 aA
45°	92 aA	89 aB	9.5 aA	11.3 aA
Cactus variety				
IPA-Sertânia	92 aA	90 aB	9.5 aA	13.9 aA
Miúda	92 aA	87 aB	10.5 aA	15.3 aA
Clone-20	93 aA	91 aB	9.6 aA	5.9 bA

Means followed by the same letter, small letter within each factor and capital letters between years, do not differ by Tukey test (P >0.05).

moisture were observed (ALVES et al., 2013). Assessing the same cactus varieties, did not find differences in water content among the three varieties before the pulse of water, however, after a rainfall of 158.5 mm, there were differences among varieties for water content (92% for IPA clone 20, 89% for miúda and 87% for IPA Sertânia) (personal observation, data not published).

In the first harvest, cactus variety did not affect fresh or dry matter productivity, but there were differences for chemical composition. IPA clone 20 had greater CP (10.2%) and ADF (24.4%) compared to IPA Sertânia (7.8 and 16.6%) and miúda (5.7 and 14.8%), respectively for CP and ADF (Table 2). In the second harvest, there was difference for fresh and dry matter productivity, with IPA Sertânia (263 and 27.7 Mg ha^{-1}) and miúda (243.7 and 30.6 Mg ha^{-1}) showing greater productivities, when compared with IPA clone 20 (126.4 and 11.7 Mg ha^{-1}) (Table 3).

Cactus growth and development varies with biotic and abiotic factors. These factors change with time and affect plant development as well (CAVALCANTE et al., 2014). In previous studies, Santos et al. (2011), no found similar pattern for dry matter productivity of these three cactus varieties (IPA Clone 20, IPA Sertânia and miúda) in a rainfed trial in Serra Talhada, PE. We observed greater productivity of IPA Sertânia (13.4 Mg ha^{-1}) and miúda (29.4 Mg ha^{-1}) compared with IPA clone 20 (4.9 Mg ha^{-1}) (data not published). These results likely reflect the greater susceptibility of IPA Clone 20 to *Dactylopius opuntiae* (VASCONCELOS et al., 2009). Chemical composition might vary with cactus cultivar. Alves et al. (2017b) observed differences in CP and ADF among IPA Sertânia, miúda, and IPA Clone 20. Therefore, the differences observed in the current study for these responses were expected, given the different genotypes.

Planting season × cladode orientation affected CP because greater CP was observed in cactus planted during the rainy season, regardless of cladode orientation. However, cactus planted during the dry season in the North-South orientation had higher CP compared with cactus planted in the rainy season (Table 4). Differences in chemical composition between cactus varieties during rainy and dry seasons was reported by Alves et al. (2016, 2017a). In the rainy season, plant growth and development leads to nutrient accumulation across plant organs (LOPES et al., 2018). Water deficit negatively affects cell multiplication and elongation, resulting in reduced photosynthesis and respiration, as well as transpiration and evaporation (TAIZ et al., 2017). As a result, in some plants the CP is greater in the rainy season (COSTA et al., 2014).

Planting season × cactus variety affected dry matter productivity in the first harvest, likely because of changes in the DM. IPA Sertânia had lower DMP when planted in the rainy season. However, miúda had greater DMP when planted during the rainy season. There was no difference for IPA clone 20 when planted either in the rainy or dry season (Table 5). Field observations indicated that IPA Sertânia is more sensitive to diseases compared to the other two varieties when planted during the rainy season.

Planting season × cladode orientation × cactus variety affected CP in the first harvest, with greater CP for IPA clone 20 planted during the dry season, North-South orientation, or during the rainy season, East-West orientation. However, this genotype had lower CP when planted during the dry season, East-West orientation (Table 6).

Planting season × cactus variety affected fresh and dry matter productivity in the second harvest. IPA clone 20 had lower fresh and dry matter productivity when planted during the rainy season when compared with other varieties, which did not differ among themselves. Miúda had greater fresh and dry matter production when planted during the rainy season (Table 7).

Cladode orientation × cactus variety affected fresh matter productivity in the second harvest. Cladode orientation and variety did not differ for most of the cases, except for IPA clone 20, which had the lowest production when planted in the North-South orientation (Table 8). Treatments did not affect the absolute growth rate per dry biomass (AGRDB) both in 2010 and 2012 harvests. Reasons for lack of differences for this response include the similar photoperiod and low variation between day and night across seasons due to the proximity with the equator and the fact that these cactus varieties are perennial (or semi-perennial) and harvested annually (or biennially), buffer the potential effect of the earth translation movement because of the long growing period (PEIXOTO, 2009). However, there were differences among varieties in 2012, when IPA clone 20 had lesser growth (5.9 Mg ha^{-1} yr^{-1}), compared with IPA Sertânia (13.9 Mg ha^{-1} yr^{-1}) and miúda (15.3 Mg ha^{-1} yr^{-1}), which did not differ among each other. The water content in the cladodes did not differ among treatments; however, in 2012 the water content was lower because of less rainfall during this growth period (Table 1 and 9).

Cladode orientation did not affect fresh and dry matter productivity nor chemical composition of cactus varieties grown in the semiarid region of Morocco and Brazil (BAKALI et al., 2016; LEITE et al., 2018). This region is located near the equator with minimal variation for daylength; therefore, variability of total amount of solar radiation is low. Furthermore, because cactus new sprouts come in all different directions, the photosynthetic active radiation (incident and reflected) is distributed for the entire plant (ANDRADE et al., 2014).

Cactus has the crassulacean acid metabolism (CAM), therefore, under water stress it opens its stomata during the night and close them during the day, reducing the water losses. During the night, the atmospheric CO_2 is captured and metabolized into oxaloacetate and malate, and stored in vacuoles. During the day, the malate is decarboxilated and used in the Calvin cycle. This temporal compartmentation and the compacted arrangement of mesophyll cells reduce CO_2 and water losses during the day, improving C accumulation and incorporation into organic products during the day (LIGUORI et al., 2013). Greater fresh biomass production during the rainy season is likely due to greater water accumulation during this period.

Conclusions

1. Different planting seasons (dry and rainy seasons), cladode orientation during the establishment (North-South, East-West, and 45º between these two), did not affect cactus (*Opuntia* and *Nopalea*) dry matter productivity and chemical composition;

2. IPA Sertânia and miúda were more productive than IPA clone 20 in regards to their dry matter productivity in the second harvest.

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