Effects of compost level in soil and season on the production and composition of cactus varieties

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ABSTRACT

The objective of this research was to determine the effect of adding compost on nutritive value of cactus cladodes during the four seasons of the year. The production, chemical composition, and *in vitro* digestibility of a cactus variety with spines (WS) and a cactus variety without spines (WOS), were subjected to a complete block design with three quantities of compost (0, 61 and 122 t ha^{-1}) and four seasons (summer, fall, and winter 2013 and spring 2014). The WS variety produced more dry matter (DM) ($p=0.035$) and crude protein (CP) ($p=0.037$) than the WOS variety. Although CP, fiber constituents, and mineral composition of cactus varied ($p<0.001$) with respect to season of the year, *in vitro* DM digestibility did not differ ($p=0.29$) across seasons. Both cactus varieties had high ash (29.0 to 29.2%) and moisture (89.5 to 91.7%) contents. Adding compost to the soil improved ($p<0.001$) the average DM production of both cactus varieties. Compost addition also increased the lignin ($p=0.008$), phosphorus ($p<0.001$) and zinc ($p=0.025$) concentrations and reduced ($p=0.04$) the *in vitro* DM digestibility. The high ash and moisture contents of cactus could reduce the densities of energy and other nutrients that are consumed by livestock.

Keywords**:** Cactus, compost, fiber, protein, minerals, *in vitro* digestibility.

INTRODUCTION

In Mexico, cacti (*Opuntia* spp.) have been used as a vegetable, fruit, and fodder since pre-Hispanic times. Combined with corn and agave, cacti were important in the growth of the Aztec civilization (Kueneman, 2001). Surface area with wild cacti exceeded three million hectares

(Flores-Valdez, 1992). In 2013, approximately 16,000 hectares of cactus cladodes were planted which produced 140,723 metric tons of forage (SAGARPA-SIAP, 2015).

Cacti are well-suited for areas characterized by drought, erratic rainfall, and poor soil conditions subjected to erosion due to their phenological, physiological, and structural adaptations that provide greater efficiency in the usage of available water and resistance to prolonged periods of drought (Kueneman, 2001; Ben Salem and Smith, 2008; Perez-Sanchez *et al*. 2015). This suitability may be important, when the availability of fodder for cattle feed is low, for the expansion of sustainable production systems in countries with arid regions like Brazil, Chile, Mexico, Morocco, South Africa and Tunisia. Cacti are frequently utilized as an emergency supplement for cattle (Ben Salem and Smith, 2008; Kawas *et al*. 2010; Ortiz *et al*. 2012) in arid areas of the world, and cultivated cacti can reduce the grazing pressure on wild populations (Mondragon *et al*. 2003).

The purpose of this research was to determine the dry matter (DM) and crude protein (CP) production, chemical composition, and *in vitro* digestibility of two cactus varieties, without spines and with spines, on the course of four seasons and at three compost levels.

MATERIALS AND METHODS

Treatments

This study took place from February 2013 until June 2015. A cactus variety with spines (WS) and a cactus variety without spines (WOS), were planted on soil with three levels of compost (0, 1.5 and 3.0 % compost; equivalent to 0, 61 and 122 t ha^{-1}). The variety with WS used was Forrajero Mina and the variety WOS used was COPENA-F1.

Soil preparation and planting

Cactus cladodes were planted in double rows with a 1.2 m and 0.5 m between plants in beds 1.2 m wide. The length of the beds was 17.5 m, incorporating the three levels of compost. The design included five repetitions with 300 plants for each variety and 600 for the whole study.

The soil was plowed and the compost was added to the planting beds according to the respective treatments in a randomized complete block design. The cladodes harvested from stock plants were treated with a Bordeaux mixture (0.5 kg of copper sulfate and 1.5 kg of lime in 10 liters of water) to prevent loss by the infection of bacteria and fungi and were allowed to stand under shade for one week prior to planting so that the cuts that were made had sufficient time to heal (Mondragon *et al*. 2003). The soil and compost samples were analyzed for chemical and physical properties.

Sample collection and chemical analysis

One hundred twenty samples were collected (two varieties; three compost levels; four seasons; five repetitions). Sample periods were in 2013 during summer, fall and winter, and the spring of 2014. The samples were dried at 60°C in an oven to obtain a constant weight and ground using a Wiley mill (Wiley, USA) with 1 mm mesh.

To obtain residual dry matter (DM), the samples were dried using an oven with forced air at 105°C. The crude protein (CP) and ash contents were also determined (AOAC, 1997) and calculated as Kjeldahl N × 6.25 (Goering and Van Soest, 1970). The neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), cellulose (CEL), neutral detergent insoluble ash (NDIA), and acid detergent insoluble ash (ADIA) were determined using the procedures reported by Goering and Van Soest (1970), using an ANKOM fiber analyzer (Model A200, USA). The fiber component values were presented in an ash-free basis as FDNmo and FDAmo (Uden *et al*. 2005). The hemicellulose content (HEM) of the samples was calculated as FDAmo minus FDNmo. The nitrogen associated with NDF (NNDF) and FDA (NFDA) was determined using the Kjeldahl method. Macro minerals (Ca, P, Na, K, Mg, and S) and trace minerals (Fe, Mn, Zn, Cu, I, Co, Cr, and Se) content were analyzed using an Inductive Coupled Plasma Optical Emission Spectrometer (Perkin Elmer, Mod. Optima 2000, USA).

Rumen in vitro digestibility

The ruminal fluid was obtained to find the *in vitro* degradation of dry matter from rumen-fistulated heifers consuming 4 kg daily of a 15% CP concentrate based on sorghum, soybean meal, dried distiller grains, molasses, and a vitamin-mineral premix, 20 kg of green chopped cactus, and Klein grass hay offered *ad libitum*. The method for *in vitro* degradation used was that by Mehrez and Ørskov (1977), adapted for *in vitro* environments using an Ankom Daisy II® device (Ankom Technologies, USA, 2015). Three samples of each cactus variety were introduced in Ankom® F57 bags, for a total of 360 samples, pre-weighed, and identified.

Statistical analysis

The data for forage production, chemical composition, and *in vitro* degradability were analyzed using a randomized complete block design (SPSS, ver. 10, 2005) with a 2 × 4 × 3 factorial arrangement of treatments (two varieties, 4 seasons, and 3 compost levels). Statistical differences between treatments were obtained using the Tukey method.

RESULTS

Dry matter and protein production

The soil contained very low contents of organic matter (OM), nitrogen, phosphorus, a low electrical conductivity (EC), and high calcium content, whereas the compost contained high contents of OM, nitrogen, phosphorus and high EC (Table 1).

The WS variety produced more DM (p=0.035) and CP (p=0.037) than the WOS variety. For the WS and WOS cactus varieties, the average DM production was 4.2 and 3.2 t ha^{-1}, whereas the CP production was 434 and 329 kg ha^{-1}, respectively (Table 2). The inclusion of compost increased the DM production (p=0.018) from 2.8 to 4.5 t ha^{-1} and the CP production (p< 0.001) from 196 to 556 kg ha^{-1} over all seasons. The cacti presented no significant deterioration during drought conditions, maintaining their forage quality by remaining green.

Table 1. Chemical and physical analysis of soil and compost used at the experiment site.

Component	Soil	Compost
pH	7.20	7.58
Organic matter (%)	1.99	24.40
Nitrogen (%)	0.07	2.02
Calcium (ppm)	13.73	4.53
Phosphorous (ppm)	N/D	457
Magnesium (ppm)	217	4.045
Sodium (ppm)	146	5.34
Potassium (ppm)	361	6,925
Iron (ppm)	3.52	1.75
Manganese (ppm)	1.57	2.95
Zinc (ppm)	1.17	4.40
Copper (ppm)	0.52	1.52
Carbon/Nitrogen ratio	15.79	15.79
Electrical conductivity (mS/cm)	1.33	2.40

Protein and cell wall constituent concentration

Protein and fiber constituents of cacti varied ($p < 0.001$) with the season of the year. Across all seasons, the WS variety contained higher levels of NDF ($p < 0.001$), hemicellulose ($p < 0.001$) and NFDA ($p=0.005$), while the WOS variety contained higher levels of ADIA ($p=0.031$) and lignin ($p < 0.001$, Table 3).

The addition of compost to the soil increased the CP production from 8.1 to 11.2% ($p=0.040$). It also increased the lignin concentration from 0.83 to 1.22% ($p=0.008$), and increased the phosphorus ($p < 0.001$) and zinc ($p=0.025$) concentrations.

Over all seasons, the WS variety contained higher concentrations of NDF, hemicellulose, and ash in NDF, whereas the WOS variety contained higher concentrations of CP, ADF, lignin, ash in ADF, and nitrogen in ADF.

In vitro dry matter digestibility

The *in vitro* DM digestibility had no difference ($p=0.290$) across seasons. The *in vitro* DM digestibility was higher ($p<0.001$) in the WOS variety. The *in vitro* digestibility values ranged from 61% to 74% for the WS variety and 72% to 88% for the WOS variety (Table 3). With the addition of compost to the soil, the *in vitro* digestibility decreased ($p=0.04$) from 75 to 70%.

Table 2. Production of two cactus varieties, with spines (WS) and without spines (WOS), with three levels of compost in four seasons.

Variable[1]	Season				SE	P	Variety		SE	P	Compost level (t ha^{-1})			SE	P
	Summer 2013	Fall 2013	Winter 2013	Spring 2014			WS	WOS			0	61	122		
DM (%)	6.5^{b}	6.5^{b}	6.9^{b}	8.2^{a}	0.34	0.001	7.3	6.7	0.24	0.055	7.3	6.5	7.1	0.29	0.128
DMP															
Per plant (kg)	0.06^{b}	0.21^{b}	1.17^{a}	0.58^{b}	0.06	0.001	0.6^{a}	0.4^{b}	0.06	0.006	0.4^{b}	0.6^{a}	0.6^{a}	0.09	0.007
Per ha (ton)	0.48^{b}	1.64^{b}	8.27^{a}	4.49^{ab}	0.48	0.001	4.2^{a}	3.2^{b}	0.34	0.035	2.8^{b}	3.9^{ab}	4.5^{a}	0.42	0.018
CPP (kg ha^{-1})	61^{b}	180^{b}	886^{a}	399^{b}	49.24	0.001	434^{a}	329^{b}	34.8	0.037	196^{c}	393^{b}	556^{a}	69.6	0.001

[1] DM: dry matter; DMP: dry matter production; CPP: crude protein production.
Values with different letters denote significant differences ($p<0.05$).

Table 3. Protein, ash, cell wall constituents and *in vitro* digestibility of two cactus varieties, with spines (WS) and without spines (WOS), with three levels of compost in four seasons.

Variable[1]	Season						Variety				Compost level ($t\ ha^{-1}$)				
	Summer 2013	Fall 2013	Winter 2013	Spring 2014	SE	P	WS	WOS	SE	P	0	61	122	SE	P
Protein (%)	12.6^{a}	10.3^{ab}	7.5^{b}	8.5^{b}	0.35	0.001	9.6	9.8	0.25	0.490	8.1^{b}	9.9^{ab}	11.2^{a}	0.30	0.040
Ash (%)	25.5^{c}	33.4^{a}	28.8^{b}	28.9^{b}	0.94	0.001	29.2	29.0	0.67	0.352	30.1	29.1	28.1	0.82	0.252
NDF (%)	22.9^{b}	20.9^{b}	27.6^{ab}	34.2^{a}	1.17	0.001	30.5^{a}	22.3^{b}	0.83	0.001	26.8	26.2	26.1	1.01	0.491
ADF (%)	14.8^{a}	14.0^{a}	12.0^{b}	13.9^{a}	0.42	0.001	13.0	14.4	0.29	0.906	12.3	13.9	14.9	0.36	0.844
Hem (%)	8.1^{b}	6.9^{b}	15.5^{ab}	20.3^{a}	1.26	0.001	17.5^{a}	7.9^{b}	0.89	0.001	14.5	12.4	11.3	1.09	0.085
Lignin (%)	1.18^{ab}	0.93^{bc}	0.69^{c}	1.33^{a}	0.10	0.001	0.70^{b}	1.40^{a}	0.07	0.001	0.83^{b}	1.05^{ab}	1.22^{a}	0.09	0.008
NDIA (%)	2.10^{b}	2.08^{b}	5.26^{a}	5.01^{a}	0.24	0.001	4.09^{a}	3.14^{b}	0.17	0.005	4.53	3.28	3.02	0.21	0.849
ADIA (%)	0.07^{b}	0.49^{b}	1.36^{a}	0.83^{ab}	0.09	0.001	0.45^{b}	0.92^{a}	0.07	0.031	0.93^{a}	0.63^{b}	0.51^{b}	0.08	0.025
NNDF (%)	0.91^{a}	0.62^{b}	0.83^{a}	0.90^{a}	0.05	0.001	0.83	0.80	0.03	0.365	0.75	0.86	0.84	0.04	0.418
NADF (%)	0.57^{b}	0.34^{b}	0.53^{b}	1.13^{a}	0.04	0.001	0.58	0.71	0.03	0.140	0.64	0.64	0.65	0.04	0.444
IVDMD (%)	73	74	74	70	1.63	0.290	67^{b}	79^{a}	1.17	0.001	75^{a}	73^{ab}	70^{b}	1.41	0.040

[1]NDF: neutral detergent fiber; ADF: acid detergent fiber; ADIA, ash in ADF; NDIA, ash in NADF; NNDF: nitrogen in NDF; NADF: nitrogen in ADF; IVDMD: *in vitro* dry matter digestibility.

Values with different letters denote significant differences ($p < 0.05$). Hem=Hemicellulose.

Table 4. Macro minerals and trace minerals of two cactus varieties, with spines (WS) and without spines (WOS), with three levels of compost in four seasons.

	Season						Variety				Compost level (t ha^{-1})				
Variable	Summer 2013	Fall 2013	Winter 2013	Spring 2014	SE	P	WS	WOS	SE	P	0	61	122	SE	P
Calcium (%)	2.97^{bc}	2.82^{c}	2.94^{bc}	3.13^{a}	0.05	0.001	2.9^{b}	3.1^{a}	0.04	0.001	3.1^{a}	3.0^{ab}	2.9^{b}	0.05	0.040
Phosphorous (%)	0.20^{a}	0.14^{b}	0.18^{ab}	0.19^{a}	0.01	0.011	0.17	0.19	0.01	0.352	0.10^{b}	0.20^{ab}	0.23^{a}	0.01	0.001
Magnesium (%)	1.35^{b}	1.40^{b}	2.02^{ab}	3.47^{a}	0.16	0.001	2.08	2.05	0.11	0.866	1.93	2.14	2.12	0.14	0.491
Sodium (%)	0.05^{a}	0.04^{b}	0.05^{a}	0.05^{a}	0.01	0.001	0.05	0.05	0.01	0.906	0.05	0.05	0.05	0.01	0.844
Potasium (%)	1.43^{ab}	1.11^{b}	1.96^{a}	1.69^{ab}	0.09	0.001	1.57	1.52	0.06	0.634	1.43	1.68	1.53	0.08	0.085
Iron (ppm)	73.9^{a}	47.1^{ab}	21.8^{b}	76.3^{a}	4.19	0.001	59.8^{a}	49.8^{b}	2.96	0.020	51.5	56.1	56.8	5.93	0.541
Manganese (ppm)	61.9^{a}	28.4^{b}	22.9^{b}	37.6^{b}	2.36	0.001	41.1^{a}	34.3^{b}	1.67	0.005	37.1	37.4	38.6	2.04	0.849
Zinc (ppm)	39.0^{b}	46.9^{a}	35.9^{b}	45.3^{a}	2.58	0.010	39.0^{b}	44.6^{a}	1.83	0.031	36.7^{b}	44.5^{a}	44.1^{a}	2.24	0.025
Copper (ppm)	5.7^{b}	22.8^{a}	5.7^{b}	5.5^{b}	1.33	0.001	9.3	10.5	0.94	0.365	8.7	10.9	10.1	1.15	0.418
Molybdenum (ppm)	1.14^{a}	0.93^{ab}	1.14^{a}	0.54^{b}	0.05	0.001	0.98	0.90	0.04	0.140	0.94	0.98	0.89	0.05	0.444

Values with different letters denote significant differences ($p<0.05$).

Macro minerals and trace minerals

Mineral composition of cacti varied ($p<0.001$) with the season of the year (Table 3). The ash concentrations were 29.2% for the WS variety and 29.0% for the WOS variety. The WS variety contained the highest concentration of iron ($p=0.02$) and manganese ($p=0.005$), while the WOS variety contained higher levels of calcium ($p<0.001$) and zinc ($p=0.031$) (Table 4). Other minerals (P, Mg, Na, K, Cu and Mo) occurred at similar concentrations ($p>0.05$) within the two cactus varieties. The addition of compost increased the phosphorus ($p<0.001$) and zinc ($p=0.025$) concentrations.

DISCUSSION

Dry matter and protein production

In arid regions of Mexico, the soils are high in calcium and low in organic matter and phosphorus (Nikolskii-Gavrilov *et al*. 2014), similar conditions were observed in the soil where the cladodes were planted. The average DM production was higher for the WS variety (4.2 t ha^{-1}) than for the WOS variety (3.2 t ha^{-1}). These values are higher than those reported by Santos-Haliscak (2009) of 2.1 t ha^{-1} for the WS cactus and 1.2 t ha^{-1} for the WOS cactus. Considering that cactus fodder plantations reach their potential production in 5 to 7 years (Lopez-García *et al*. 2003), a yearly production of 17 tons of DM ha^{-1} may be obtained (Felker, 2003). The increased DM and CP productions were obtained by harvesting 60-day old cladodes (Pinos-Rodriguez *et al*. 2010) and the cactus nutritional quality depends on the species with a general decrease occurring with cladode maturity (Tegegne, 2002).

The inclusion of compost increased the DM and CP production over all seasons. The higher CP concentration obtained from compost inclusion in soil may be the result of the high nitrogen content of the compost. The incorporation of livestock or poultry manure as a way to fertilize fodder will increase its crude protein content, the majority of which is non-protein nitrogen (Valdez *et al*. 2010).

Protein and cell wall constituent concentrations

The high fiber and ash contents of cactus (up to 58% NDF and 25% ash) can decrease the consumption of protein and energy, with the latter partially present as NADF, the cell wall fiber fraction less degradable (Davila-Gutierrez, 1996).

The CP values were higher (8.5 to 12.6%) than those reported by other scientists (Gonzalez, 1989; Ben Salem and Nefzaoui, 2003; Santos-Haliscak, 2009). Ben Salem and Nefzaoui (2003) reported CP content of less than 5% in spineless cactus and Cordoba-Torres *et al*. (2015) reported CP content that varied from 4.5 to 6.9% in five *Opuntia* varieties.

This level of CP in the diet provides less than 7% to 8% of CP, which is the amount required by ruminal bacteria for a normally functioning rumen (NRC, 1987). Fertilizing with compost increases the nitrogen content of forage, and consequently, the CP content (Gonzalez, 1989).

Due to current crop management practices, CP values ranging from 7.5 to 10% were obtained by Gonzalez (1989), whereas the values of 7.5 to 9.7% were reported by Santos-Haliscak (2009).

The cactus NDF (22.3 to 30.5%) and ADF (13.0 to 14.4%) were comparable to findings reported by other scientists (Mondragon *et al*. 2003; Santos-Haliscak, 2009), although they were lower than those reported by Andrade (2011a). Santos-Haliscak (2009) reported values ranging from 25.5 to 29.5% NDF and 12.7 to 16.5% ADF for the three varieties with spines and the three varieties without spines. The inclusion of compost increased the CP, ADF, NDFN, and lignin concentrations over the four seasons and decreased the ash and AIA values. Guevara *et al*. (2011) and Valdez *et al*. (2010) also reported an increment in the CP concentration of cacti with chemical and organic fertilizers.

***In vitro* dry matter digestibility**

Values of *in vitro* DM digestibility varied from 61 to 74% for the WS variety and 72 to 88% for the WOS variety. Andrade *et al*. (2011a) reported that DM digestibility ranged from 59 to 75%, whereas Tegegne (2002) reported values of 70 to 78%. These high values have been associated to lignin concentrations lower than 5% (Cerrillo and Juarez, 2004; Salem *et al*. 2006; Salem *et al*. 2012). Apparently, the reduction of *in vitro* DM digestibility in the WS variety could have been due to its higher NDF concentration.

The organic matter and CP digestibility were higher for the large cladodes compared to the small cladodes (Andrade *et al*. 2011b), and the greatest weight gain in lambs was obtained with diets containing 20% cactus (Tegegne, 2007; Andrade *et al*. 2011b). The inclusion of cactus in goat and sheep diets improved both DM and OM consumption, increased the CP digestibility, and reduced water consumption (Costa *et al.* 2009; Andrade *et al*. 2011a; Andrade *et al*. 2011b).

With the addition of compost to the soil, the *in vitro* digestibility decreased from 75% to 70%. Castañeda-Colorado *et al*. (2008) reported values ranging from 52 to 56% in unfertilized forage and 43 to 45% in fertilized forage. The reduction of *in vitro* DM digestibility appeared to be due to an increased ADF. Because samples were oven dried at 60°C, and lignin did not significantly increase, polymeric reactions that might have increased the fibrous residues may be discarded.

Macro minerals and trace minerals

The ash concentrations of 29.2% for the WS variety and 29.0% for the WOS variety were lower than those reported by Ben Salem and Nefzaoui (2003), although they are similar to those reported by Santos-Haliscak (2009), which ranged from 24.9 to 33.0% for the three WS and three WOS varieties. Ben Salem and Nefzaoui (2003) reported ash concentrations of 23.8%, 5.2% of which was calcium, and only 0.1% was phosphorus. Calcium was 10% of the ash value, while phosphorus was less than 0.7%. The high ash content in cactus varieties is due to high concentrations of calcium and oxalates. Cacti are one type of plant that contains a higher ash content, and its main components are calcium, magnesium, and sodium. The mechanism by which the calcium is present depends on the age of the cladodes. In the young cladodes, calcium is present primarily as calcium oxalate, which decreases with advancing maturity (McCoon and Nakata, 2004).

The WS variety had the highest Fe and Mn concentrations, whereas the WOS variety had the highest concentrations of Ca and Zn. Other minerals (P, Mg, Na, K, Cu and Mo) occurred at similar concentrations in the two varieties. While Ca and Zn concentration was lower, Fe and Mn were higher, and Mg, K, Fe, and Cu were comparable to findings reported by other scientists (Nobel, 1988; Santos-Haliscak, 2009).

The inclusion of compost increased the phosphorus and zinc concentrations over all seasons. This effect is consistent with the results reported by Zuñiga-Tarango (2009) for phosphorus but not for zinc, which generally decreased with the inclusion of organic fertilizer.

CONCLUSIONS

The cactus variety with spines produced more dry matter and protein than the variety without spines. Because both cactus varieties contained high ash and moisture contents, we can assume that concentrations of energy and other nutrients were also low. The addition of compost to the soil increased the dry matter and crude protein production of both cactus varieties. This addition also increased the lignin concentration and reduced the *in vitro* dry matter digestibility. It appears that the additional crude protein content of cactus fertilized with compost could be non-protein nitrogen. Although the crude protein associated with the fiber fractions was high, this nitrogen fraction may be less degradable in the rumen. The results in this study demonstrate that production and forage quality of cactus can be improved with an organic fertilizer such as cattle compost, and then native cacti without spines can compete favorably with improved varieties with spines as a feed supplement for cattle.

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