NUTRITIONAL VALUE OF *OPUNTIA FICUS-INDICA* AS A RUMINANT FEED IN ETHIOPIA

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INTRODUCTION

Most tropical livestock production systems have low productivity due to low feed availability and quality, especially in drought-prone areas where the livestock sector regularly suffers large losses.

The problem is not limited to arid and semi-arid regions of Ethiopia. Declining crop yields accompanied by increasing requirements for food are forcing farmers of the central and northern highland regions to cultivate more land at the expense of grazing pasture and browses. These problems are exacerbated by poor management and financial limitations.

Research efforts to match seasonal fluctuations in feed supplies to needs include: treating crop residues; modifying agronomic practices; varietal selection; pasture improvement; supplementing with non-protein nitrogen (NPN); planting multi-purpose forages; conservation; and rumen manipulation.

However, there are financial limitations and inadequately qualified staff to carry out analytical work. If treated feeds were to be used, animal products would be at unaffordable prices (Nkhonjera, 1989). Availability of crop residues is limited to areas suitable for crop production. In some arid and semi-arid areas, improvement of pasture is restricted to sowing improved grasses on more fertile soils (Evans, 1982). The nitrogen (N) from NPN or legumes degrades very rapidly and there is a mismatch between the degradation of organic matter and N. Manipulation of the rumen ecosystem does not seem economically effective in extensive forms of farming (Leng, 1982). Silage making from low-nutritive-value tropical forages involves the risk of bad fermentation and needs more facilities (Jarrige *et al*., 1982). Consequently, there is a need to get N-source feeds that can immediately supply rumen degradable organic matter to serve as a link between NPN, forage legumes and crop residues.

Most experts recommend planting of trees and shrubs to provide standing feed resources so that herds and flocks can survive critical periods of shortage and prolonged drought. In screening plants for animal nutrition for drought-prone regions, the two most important criteria are drought tolerance and palatability for animals. However, adaptability of forage to marginal land, ease of propagation, persistency, dry matter (DM) yield, high digestibility (D), and N contents are also important. Opuntia meets all of these requirements. Most important, opuntia is suitable as a human food and has other miscellaneous uses. However, more information is needed concerning its nutritive value, its utilization for animal feed, management, establishment and its integration into pastoral and agropastoral systems.

The study of the potential and nutritive value of opuntia could contribute to the development of the livestock sector in dry regions of Ethiopia. This chapter reviews the feasibility and nutritional value of *O. ficus-indica* as a feed resource for farm animals in such areas.

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ECOLOGICAL DISTRIBUTION AND UTILIZATION OF OPUNTIA IN ETHIOPIA

Opuntia ficus-indica (L.) Miller was taken to North Africa from Mexico in the sixteenth century (Pimienta, 1993) and introduced into Ethiopia at the end of the 19th century (CFDP, 1994). It is widely distributed in the northern arid and semi-arid regions of Ethiopia. A survey indicated that about 30 520 ha (1.88% of the total area of the Tigray region) were covered with *O. ficus-indica*, 48.62% growing wild and 51.34% cultivated. It was also found in the hills of the Welo region, where the vegetation is severely degraded.

Since the 1960s, the fruit has been consumed by almost all domestic animals, and livestock totally depends on opuntia during the dry season. Planting of *O. ficus-indica* is common and extensive. Two Ethiopian organizations that play an important role in the expansion of cactus acreage are the Relief Society of Tigray (REST) and the Regional Natural Resource Conservation and Development Bureau. The Cactus Fruit Development Project (CFDP) has promoted the selection, production and distribution of cactus varieties, identification of diseases and design of erosion control measures as part of its strategies (CFDP, 1994).

NUTRITIONAL VALUE OF *OPUNTIA FICUS-INDICA*

The fruits of *O. ficus-indica* contain water (92%), carbohydrates (4-6%), protein (1-2%), minerals (1%) and a moderate amount of vitamins, mainly A and C (Cantwell, 1991, and Neri, 1991, cited by Pimienta, 1993). According to these figures, its fruits are high in carbohydrates (50-75% of DM) and moderate in protein content (12.5-25% of DM), minerals and vitamins.

South African measurements of nutritional quality of *Opuntia* of 4% CP, 64% TDN, 1.4% Ca, 0.2% P and 0.1% Na were similar to Texas data (De Kock, 1980). He indicated that in contrast to fertilized opuntia plantations, the protein content of the ‘wild prickly pear’ was so low that mineral and protein supplements were necessary.

The effect of cultivar is illustrated by a comparative study conducted in Brazil of fodder cultivars for milk production: the CP contents of *O. ficus-indica* cvs Gigante and Redonda, and *Nopalea cochenillifera* cv. Miúda were: 4.83, 4.21 and 2.55%, and their CF contents 9.53, 8.63 and 5.14%, respectively. *In vitro* dry matter digestibility (IVDMD) was 77.37% for Miúda compared with 74.11 and 75.12 for Redonda and Gigante, respectively; mean milk production and milk fat were not significantly different among treatments (Ferreira-dos-Santos *et al*., 1990).

Cladode age is an important factor for nutritional value. Young cladodes of *O. ficus-indica* grown for commercial fruit production in Spain had 10.6-15.0% protein, while mature cladodes varied from 4.4 to 11.3% protein (Retamal *et al*., 1987b). Similarly, Gregory (1988, cited by CFDP, 1994) reported that as the age of *O. ficus-indica* increased from one to four years, the CP content decreased: 11.53, 5.74, 5.5 and 5.65%, respectively in the four years, with an average of 7.10%. Compared to mature 12-year-old cladodes, 2-year-old cladodes had substantially higher N, K and Mn, but lower Na, Ca and Fe. This was attributed to age and to higher metabolic activity of young cladodes (Nobel, 1983). Concentrations of 15.3% protein and 0.3% P were reported in commercial *O. ficus-indica* fruit plantations in California (Nobel, 1983). In contrast, the chlorenchyma contained 9.6% protein and 0.12% P for 5-year-old plantations and 7.8% protein and 0.09% P for 12-year-old Chilean opuntia plantations. Young cladodes had significantly higher N, K and Mn, but lower Na, Ca and Fe. Epstein (1972) suggested that Ca and Fe are not very mobile so that both would be expected to accumulate in older tissues (Retamal *et al*., 1987b).

In contrast, Gregory and Felker (1992) reported that *O. ficus-indica* had similar protein contents in all age classes. Their results are unusual, as young cladodes are generally of better nutritional quality than older cladodes, which is attributed to the thickening of the cuticle of older cladodes and the increase in thickness due to the expansion of the water-storage parenchyma (which is very slowly degradable) at the expense of cell contents (Rodríguez-Felix and Cantwell, 1988). The latter authors reported the following composition values per 100 g for cladodes harvested when about 20 cm long: 91.7 g water, 1.1 g protein, 0.2 g lipids, 1.3 g ash and 1.1 g CF (13.3, 2.4, 15.7 and 13.3% on a DM basis, respectively). It was observed that total carbohydrates increased considerably during cladode growth, while protein and CF contents decreased.

Season has a profound impact on the chemical composition of *O. ficus-indica*. According to Retamal *et al.* (1987b), the highest values of moisture content, free reducing sugars, starch and CP were detected in spring (92.5%; 103 mg/g DW; 226 mg/g DW; 14.8% respectively) in young cladodes, while at the end of the season, ash content, ether extractive, crude fibre and calorific content presented the highest values (29.8%; 36 mg/g DW, 144 888 KJ/kg, respectively). Highest concentrations of N, P and K occurred in winter, with Ca showing the opposite pattern (Esteban-Velasco and Gallardo-Lare, 1994).

Compared to most agronomic plants, chlorenchyma levels of Ca and Mg (5.3% and 2.5% of DM, respectively) in cacti tended to be higher and Na level (0.11% of DM) lower (Retamal *et al.*, 1987b). They found that among the 11 elements tested, N was strongly correlated with the nutrient level and metabolic activity, where nocturnal acid accumulation (NAA) tended to be greater when the N level in the chlorenchyma was higher ($r^2 = 0.39$). In contrast, NAA was negatively correlated with chlorenchyma Na content ($r^2 = 0.32$).

The distinctive features of cacti: shallow root systems, leaves modified into spines, and shading of photosynthetic organs; could affect mineral relations. The shallow root enables them to accumulate elements from the upper part of the soil and shading results in accumulation of certain elements (Nobel, 1977). An important feature common to most cacti is the relatively high levels of Ca which may represent accumulation of calcium oxalate (Nobel, 1983).

Flachowsky and Yami (1985) studied composition, D and feed intake of *O. ficus-indica* by Ogaden sheep, where 70-75% (DM basis) was total carbohydrate and about 20% was crude ash. They indicated an apparent D of OM of 70.9%, corresponding to 35 and 467 energy feed units (cattle)/kg (72 MJ ME) in fresh material and DM, respectively. CP was 4.5-5.5% of DM, less than maintenance requirement.

Given free choice, rams preferred chopped fresh cactus to chopped dried cactus or whole fresh cactus (Flachowsky and Yami, 1985). In conditions where water is not a limiting factor for animal production, it could be difficult for animals to take enough fresh cactus to meet their requirements, as a level of water exceeding 780 g/kg fresh forage is claimed to have a detrimental effect on voluntary intake (John and Ulyatt, 1987, cited by Minson, 1990a). Fortunately, this effect may be small and of no disadvantage in arid and semi-arid areas where water is limiting for animal production.

In an experiment replacing alfalfa hay with *O. ficus-indica* cladodes as supplementary summer forage for milk goats, 50 goats were grazed on indigenous pasture alone (control); with lucerne hay (LH) *ad libitum*; and with three LH + cladodes (C) combinations (85% LH+15% C; 79% LH+21% C; 66% LH+34% C). Milk production increased by 55.4, 93.8, 103.6 and 12%, respectively, compared to the control ($p<0.05$) (Azócar and Rojo, 1991).

Gregory and Felker (1992) reported *Opuntia* to be high in moisture content (94.26%) and high in *in vitro* D (about 75%). Most workers have suggested that *Opuntia* is low in its CP (4%) content and P (0.2%) contents, and have recommended that supplements should be given to meet the requirements of animals (De Kock, 1980; Hanselka and Paschal, 1990). It is moderate in energy content measured as digestible nutrients, and high in water, vitamin A, fibre and ash (Hanselka and Paschal, 1990). Fortunately, there are ways of improving it. The application of low rates of N increases the percentage of CP significantly. It was proposed that high N treatment (224 kg/ha every two years) is needed to meet the requirements for lactating cows. Application of P (112 kg/ha) also doubles P content, which is normally low in *O. ficus-indica* (González and Everitt, 1990 cited by Pimienta, 1993).

Anti-nutritional characteristics, such as spines, may affect nutritional value by limiting palatability and digestibility and so utilization efficiency. The common method for removing the spines is burning. A device has been designed to mechanically remove the spines (Carmorlinga-Sales *et al.*, 1993). Another method is use of a chaff cutter (De Kock, 1980).

Given that *O. ficus-indica* is a Crassulacean Acid Metabolism (CAM) plant, the organic acid content varies during the day. Teles *et al.* (1984) found that levels of malonic, malic and citric acids in materials collected at 18:00 were: traces, 0.95 and 0.31 mg/g, respectively. In similar material collected at 06:00, concentrations were 0.36, 9.85 and 1.78 mg/g, respectively. The pH ranged from 5.2 in the evening to 4.4 in early morning, and the percentage of malic acid varied from >0.5% at 08:00 to <0.1% at 16:00 (Cantwell, 1991, and Neri, 1991, cited by Pimienta, 1993). However, the effect of organic acid variation during the day has not been studied with opuntia.

Nutritional changes after harvest have been noted, though not explained. Neri (1991, cited by Pimienta, 1993) observed reduction in the content of both total and reducing sugars, and an increase in pH and protein content. In production systems where water is not limiting, storing opuntia increases DM so that animals can consume more of it to meet their requirements. The increase in its protein content is more important and needs investigation.

ANALYSIS OF ETHIOPIAN OPUNTIA

Samples were taken from opuntia plants grown in a greenhouse on sandy soil, with no fertilization, representative of tropical poor soils in which *Opuntia ficus-indica* usually grows.

Four branches (A, B, C and D), as groups, each with three cladodes, as age groups, and their fruits (f) were separated. The cladodes on each branch were labelled as young (y), middle-aged (m) or old (o). They were six months, one year and two years old, respectively.

Dry matter, ash and mineral content determinations

Dry matter content was determined by drying chopped samples for four days in an oven set at 80°C. Ash content was determined by incinerating dried samples at 500°C until a greyish-white colour was attained. The solution for mineral determination was prepared as stated by Retamal *et al.* (1987b) except that the solution for Ca, Mg and K analysis was further diluted with distilled water (1:100) making the final dilution factor 1:1000. The concentration of Ca, Mg, K and Na in the solution was determined by atomic absorption spectrometry and the concentration of P was determined spectrophotometrically. The result for each element was calculated from the respective standard graphs (MAFF, 1986). Crude protein (CP), crude fibre (CF) and ether extract (EE) were determined by the proximate analysis method (MAFF, 1986). Nitrogen-free extract (NFE) was calculated as the DM not accounted for by the sum of CP, CF, EE and ash (NFE = DM -CP -CF -EE -ash) (Van Soest, 1982). A bioassay was performed using the faeces liquor technique (El Shaer *et al*., 1987) and used for *in vitro* dry matter digestibility (IVDMD) assay. IVDMD was calculated as: IVDMD = (A - (B - C))/A, where: A = dry weight of sample; B = dry weight of residue after digestion; and C = dry weight of reagent blank.

The mean proportional weight loss of the triplicates or duplicates for each sample was recorded as the IVDMD (Omed *et al*., 1989). Data were analysed by ANOVA (General Linear Model, GLM) test and the significance of difference between means detected using Fisher's least significance difference (LSD) test.

The relationship of chemical composition data with IVDMD was performed by simple linear regressions, and significance of correlation by ANOVA. For comparison, appropriate multiple regression equations using combinations of CP, CF, NFE, EE and ash as an independent variable and IVDMD as a dependent variable were used.

Mineral composition

The mineral composition of samples is summarized in Table 44. There was significant age effect on Ca, Mg and Na contents and a highly significant effect on P content. Age did not affect K content. It is well established that tropical legumes, tropical grasses and other roughages are low in minerals, particularly P (Fleming, 1973; Minson, 1988). The P content (Table 44) of the present samples was low in comparison to temperate pasture grasses (McDonald *et al*., 1995). Older cladodes had lower P contents than younger cladodes and fruits, which was in accordance with most previous results (De Kock, 1980; Nobel, 1983; Hanselka and Paschal, 1990; Gregory and Felker, 1992). All the results were within the range of 0.02 to 0.58% reported for 586 tropical grasses, whose mean was 0.22% (Minson, 1990b). In addition, all the P values were above the recommended level (0.17%) for cattle weighing 450 kg and gaining 0.5 kg/day (NRC, 1968).

O. ficus-indica has been reported to be high in Ca content (Nobel, 1977; De Kock, 1980; Retamal *et al.*, 1987b). The values obtained disagree with this (Table 44). This may be due to the young age of the samples having allowed less accumulation of calcium oxalate (Nobel, 1977). Fruits had significantly lower Ca content than other parts and Ca content of young cladodes was higher (but not significant; $p>0.05$) than either middle-aged or old cladodes. The significantly higher Ca content found in young cladodes also disagreed with other reports (Epstein, 1972; Nobel, 1983; Retamal *et al.*, 1987b), but the difference was small. Fruits had lower Ca content than cladodes, explained in part by the low mobility of Ca (Epstein, 1972).

Ca content of 390 tropical grasses varied from 0.14 to 1.46% (Minson, 1990b), a range containing most of the values obtained. All samples contained sufficient Ca to meet the required 0.17% recommended by NRC (1968). Most samples were within the high range of temperate pasture grasses (>0.6%) (McDonald *et al.*, 1995).

O. ficus-indica has been reported as high in Mg content (Retamal *et al.*, 1987b). Mg content of these samples was high and significantly ($p<0.05$) increased with age. All the values were within the range reported by Minson (1990b). In addition, the results were above the 0.11% Mg level recommended by the ARC (1965). Though there is less likelihood for Mg to be deficient, as most tropical grasses and legumes have enough of it (Norton, 1982), these results showed that *Opuntia* had a sufficiency of Mg.

Table 44. Mean mineral composition (% of DM) of fruits and cladodes of *Opuntia ficus-indica*

	Element				
	Ca	Mg	K	Na	P
Fruits	0.45^{c}	0.14^{c}	0.40	0.07	0.37^{a}
Young cladodes	1.03^{a}	0.20^{a}	0.37	0.06	0.33^{a}
Middle-aged cladodes	0.94^{b}	0.19^{a}	0.38	0.05	0.25^{b}
Old cladodes	0.73^{b}	0.22^{ab}	0.17	0.05	0.23^{b}
Probability	p<0.05	p<0.05	ns	ns	p<0.001
Grand mean	0.79	0.19	0.33	0.06	0.30
Standard deviation	1.177	0.147	0.927	0.004	0.014

Notes: (1) Different superscripts indicate significantly ($p<0.05$) different means. (2) ns = Non-significant.

The low K content of the older cladodes (Table 44) may reflect the high metabolic rate of fruits and younger cladodes (Nobel, 1983). Retamal *et al.* (1987b) observed that younger cladodes had substantially higher K content, which was not found in this study.

The Na content of both fruits and cladodes was very low (Table 44) as reported by De Kock (1980) and Retamal *et al.* (1987b). Retamal *et al.* (1987b) reported that younger cladodes had lower Na contents, which was not observed in the results reported here (Table 44). The values indicate that the low Na content of cacti was probably due to the low genetic capacity for accumulation, low requirements for growth or low availability in the soil (Norton, 1982; Retamal *et al.*, 1987b). The latter authors reported that Na content was negatively correlated with nocturnal acid accumulation (NAA), confirming the above claim.

It is firmly established that tropical plants have low Na contents (Fleming, 1973), though its deficiency is related to particular species (Minson, 1990a). The results were within the range of Na contents typically found in tropical grasses, i.e. 0.01 to 1.8%. All the samples contained less than 0.08%, which is the recommended level (ARC, 1965). However, in the arid and semi-arid areas, salinity of drinking water may be high (McDowell, 1985), which could compensate for any deficiency.

Chemical composition

Both fruits and cladodes had low DM contents (9.17%), with the lowest values observed in young cladodes (Table 45). Average ash percentage of the DM was 8.67%. CP declined with age ($r = -0.79$) in the cladodes, though the pattern was inconsistent. Fruits and young cladodes had significantly ($p<0.05$) higher CP content than middle-aged and old cladodes (Table 45) while there was no significant differences between fruits and young, middle-aged and old cladodes. Young cladodes had the lowest mean CF content (Table 45). CF content was negatively correlated with CP contents ($r = -0.33$), and NFE contents ($r = -0.53$). However, the differences between CF contents were not significant at the 0.05 level. NFE was positively correlated with age ($r = 0.64$), and negatively correlated with EE ($r = -0.42$) and ash ($r = -0.77$).

In vitro dry matter digestibility

Average IVDMD (Table 45) was highest for fruits ($p<0.01$), followed by young cladodes, and significantly declined with age in the older cladodes. IVDMD was negatively correlated with age ($r = -0.95$), and NFE ($r = -0.80$), and positively correlated with CP ($r = 0.76$) and ash contents ($r = 0.73$). A relationship between IVDMD and chemical composition, including age was calculated:

$$\text{IVDMD} = 74.1 - (4.12 \times \text{Age}) - (0.009 \times \text{CP}) + (0.482 \times \text{CF}) - (0.91 \times \text{EE}) + (0.989 \times \text{ash})$$

$$(r^2 = 0.93;\ p<0.001).$$

Table 45. Mean *in vitro* dry matter digestibility (IVDMD), estimated digestible energy (DE) and total digestible nutrient (TDN) contents and chemical composition of fruits and cladodes of *Opuntia ficus-indica*

	DM %	**IVDMD** % DM	**DE** MJ/kg DM	**TDN** % DM	**CP** % DM	**CF** % DM	**NFE** % DM
Fruits		82.92[a]	15.57[a]	77.78[a]	13.10[a]	10.39	65.78
Young cladodes		77.88[b]	13.98[b]	73.48[b]	13.42[a]	7.96	66.78
Middle-aged cladodes		71.14[c]	13.14[c]	67.63[c]	10.76[b]	8.03	72.15
Old cladodes		69.64[c]	12.99[c]	66.32[c]	9.15[b]	10.72	70.85
Probability		p<0.01	p<0.001	p<0.001	p<0.01	ns	ns
Grand mean	9.17	75.40	13.92	71.33	11.61	9.28	68.89
Standard deviation		1.651	0.226	0.312	0.366	1.238	1.281

Key: DM = dry matter. IVDMD = *in vitro* DM digestibility. DE = digestible energy. TDN = total digestible nutrient. CP = crude protein. CF = crude fibre. NFE = nitrogen-free extract

Notes: (1) Different superscripts indicate significantly ($p<0.05$) different means. (2) ns = Non-significant.

Table 46. Mean DM and chemical composition of *Opuntia ficus-indica* fruits and cladodes from 16 locations in Ethiopia (% on DM basis)

Sample	DM	CP	CF	EE	Ash	NFE
Af	7.5	12.07	9.05	1.94	9.10	67.84
Ay	6.8	12.42	8.68	1.53	10.40	66.97
Am	8.7	9.18	8.40	1.49	7.25	73.68
Ao	10.6	7.95	13.32	2.18	6.90	69.65
Bf	7.7	11.63	7.73	1.12	10.25	69.18
By	6.8	9.78	21.54	2.18	10.95	55.63
Bm	8.7	8.62	8.12	1.77	6.90	74.59
Bo	8.6	10.46	9.37	1.40	9.45	74.59
Cf	7.9	13.11	14.12	1.78	9.35	61.64
Cy	6.9	13.83	7.62	1.91	9.50	67.14
Cm	10.3	12.35	8.16	1.47	8.75	69.27
Co	11.3	9.83	12.30	1.03	9.05	67.79
Df	8.6	14.13	8.00	1.20	8.80	67.87
Dy	6.9	14.00	7.58	1.34	10.85	66.23
Dm	11.6	10.75	7.53	0.92	7.30	73.50
Do	12.9	10.47	6.54	1.09	6.80	75.10

Key: DM = dry matter. CP = crude protein. CF = crude fibre. EE = ether extract. NFE = nitrogen-free extract

CHEMICAL COMPOSITION

CP content

Opuntia ficus-indica was reported to be low in CP content (De Kock, 1980; Glanze and Wernger, 1981; Flacowsky and Yami, 1985; Ferreira-dos-Santos *et al*., 1990). In contrast, some authors reported *Opuntia ficus-indica* as a moderate CP source (Nobel, 1983; Retamal *et al*., 1987b; Rodríguez-Felix and Cantwell, 1988; Cantwell, 1991, and Neri, 1991, cited in Pimienta, 1993). The results obtained (Table 45) agreed with the last-named authors. However, most of their samples were from cultivated plantations, while the opuntia used for this study was treated as a wild plant. Age and conditions of cultivation may explain the difference (De Kock, 1980; Retamal *et al.,* 1987a; Hanselka and Paschal, 1990).

As is the case in most plants, age significantly affected CP content. The mean CP contents of all the fruits and cladodes of all ages (grand mean = 11.61%) were greater than the average CP content of all fibrous crop residues (6.1%) (Kossila, 1984) and tropical grass samples (7.7%) reported by Butterworth (1967) or the 10.6% of Minson (1990b). However, it was less than the average CP content of 340 tropical legumes: 17.2% reported by Minson (1988) or 16.7% reported by Minson (1990b), while most were comparable to the average CP content (13.3%) of 470 temperate grasses (Minson, 1990b). All values were above the level (6-7%) reported as the limit to microbial activity, and thus productivity and feed utilisation efficiency (Minson, 1990b).

Crude fibre content

CF content is usually taken as a negative index of feed quality (Van Soest, 1982). In this study, *Opuntia ficus-indica* was extremely low in CF. Similar results were previously reported by Rodríguez-Felix and Cantwell (1988) and Ferreira-dos-Santos *et al.* (1990).

As plants mature there is a significant increase in CF content (Van Soest, 1982). In cacti, however, there were no significant differences in CF among age groups ($p>0.05$). Rodríguez-Felix and Cantwell (1988) even reported a decrease in CF in older cladodes, suggesting that the significant decrease in IVDMD values of older cladodes (Table 45) was not due to the increase CF content.

All the samples reported here were below the range of CF contents determined for either tropical legumes (12.4 to 43.4%, with a mean of 30.6%) and tropical grasses, with a mean of 33.4% (Butterworth, 1967). They were lower than the mean CF content of temperate grasses (20.0%) and temperate legumes (25.3%) reported by Norton (1982).

Nitrogen-free extract content

The NFE content, which represents the highly digestible carbohydrates (Van Soest, 1982), of all the samples was relatively high (Table 45). The high NFE values of the older cladodes indicated that they had the highest soluble cell contents. The increase in NFE with age ($r = 0.64$) agrees with the observation that total carbohydrates increased during cladode development (Rodríguez-Felix and Cantwell, 1988), which could, to some extent, buffer the decline in IVDMD as cladodes get older (Radojevics *et al*., 1994). The negative correlation between NFE content and IVDMD ($r = -0.80$) might be due to changes related to other factors.

In vitro dry matter digestibility

Low digestible energy and protein contents are the two most important features of a diet that imposes physical restriction on feed intake (Van Soest, 1982). Consequently, energy and protein are usually given first consideration in any feeding system, and thus there is a real need for a digestible feed resource (Yilala, 1989).

The data in Table 45 showed that *Opuntia ficus-indica* was highly digestible, agreeing with the values reported by Ferreria-dos-Santos *et al.* (1990). Although there were relatively small differences in CP and CF contents between fruits and young cladodes, the IVDMD was significantly higher for fruits. Their high digestibility was attributed, in part, to the translocation of soluble carbohydrates (Norton, 1982). Younger cladodes were more digestible than middle-aged and old cladodes. This seemed to be related to the lower CP contents of older cladodes (r = 0.76). However, none of the CP contents was below 6-7% – the limiting level for microbial growth (Minson, 1990b) – or below the DMD/CP ratio (>10:1) that was noted as limiting for microbial synthesis and fermentation conditions (Hogan, 1982).

It was less likely that CF content of old cladodes had significantly affected their digestibilities. This suggestion was confirmed by the extremely low CF contents (Table 45), which had no correlation with age (r = -0.04). When compared with other grasses and legume forages, it might be argued that *Opuntia ficus-indica* with such low CF content had a lower IVDMD than might be expected. The degree of lignification was also unlikely to cause significant reduction in D because non-legume dicotyledenous plants, to which *Opuntia* belongs, are chiefly unlignified and have a high cell wall recovery (Van Soest, 1982). The extremely low CF content might, however, have caused a high rate of digestion and affected digestibility due to acid accumulation in the bottles, which is difficult to buffer (Van Soest, 1982).

A proportion of the decline in digestibility values for the old cladodes could be associated with the indigestible cutin, which prevents microbial attack (Monson *et al*., 1972) Cutin is present in the cuticle of cacti (Hanna *et al*., 1973; Uden, 1984). Differences exist in the ability of cuticle to crack under stress (Hanna and Akin, 1978), which has not been investigated in *Opuntia ficus-indica*.

C_4 plants are photosynthetically more efficient than C_3 plants, but they exhibit low nutritive value (Van Soest, 1982). The morphological characteristics (Norton, 1982); temperature of growth (Minson, 1990a); the well-developed, more slowly degradable, parenchyma sheaths of C_4 plants (Akin, 1982); and the few mesophyll cells (Van Soest, 1982) might limit the digestibilities of fruits and cladodes. However, any impact of these must be small, as the samples were highly digestible (Table 45). These high IVDMD values were related to the high cell contents, which are roughly represented by nitrogen-free extract (NFE) contents and low CF contents (Table 45) (Van Soest, 1982).

Regression analyses of IVDMD against separate chemical composition data (CP, CF, NFE, EE and ash) confirmed that CF and EE contents are not related to digestibility (r^2 = 0.0%), although combination had a highly significant ($p<0.001$) effect. IVDMD was best predicted by regression including age (r^2 = 93.6%).

The IVDMD of almost all the fruits and the cladodes were above the mean values reported for tropical grasses (30-75%, with a mean of 54%) (Minson and McLeod (1970) in Minson, 1988), temperate grasses (45-85%, with a mean of 67%), tropical legumes (36.0 to 69.3%, with a mean of 54%) and temperate legumes (mean of 60.7%) (Minson, 1988). None of the IVDMD values was below the digestibility level recommended for different ruminants kept for different production purposes. For example, for higher performance levels of larger animals, forage digestibility over 66% is required (Burns, 1982); a lactating beef cow producing 10 kg milk/day requires forage of 67% D, and a cow producing 5 kg milk/day, high yielders of Ethiopian indigenous breeds, requires 53% D (Burns, 1982). Thus, *Opuntia ficus-indica* can be a feasible forage in the tropics where even applying N to grasses does not appear to improve D (Minson, 1973).

Higher IVDMD is obtained by drying samples at 100°C for one hour followed by a moderate temperature of 70°C (Burns, 1981). However temperatures above 80°C causes thermo-chemical degradation of non-structural parts. Content of water-soluble carbohydrates (WSC), *in vitro* digestibility (IVD) and percentage of nitrogen insoluble in neutral detergent are affected most by drying temperature. Thus, prolonged heating at high temperature promotes loss of sugar through the Mailliard reaction. The reaction is favoured by high temperature, moisture content and soluble carbohydrates in the plant material: all these requirements were met for opuntia. Oven-drying at high temperature can also increase structural constituents. Therefore, Mailliard products were produced and structural constituents increased, limiting digestion as they are totally unavailable or very slowly degradable (Van Soest, 1982).

CONCLUSIONS

O. ficus-indica was moderate in CP, high in Ca, normal in Mg and low in Na, K and P contents in relation to ruminant requirements from a diet, and similar to common temperate or tropical grasses and legumes. It was highly digestible. *Opuntia ficus-indica* may serve as a link between crop residues, legume forages and NPN sources by supplying readily available organic matter.

Extremely high water content may affect total DM intake by animals, especially during wet seasons and where water is not a limiting factor for animal production. Therefore, research must gear to silage production in combination with coarse crop residues.

This study has evaluated some feed quality parameters at one point in time. For any true evaluation and in order to incorporate *Opuntia ficus-indica* into feeding systems, its effect on animal performance must be investigated. Likewise, further work on its combination with other feeds is needed.

THE USE OF OPUNTIA AS A FODDER SOURCE IN ARID AREAS OF SOUTHERN AFRICA

Gerhard C. DE KOCK

INTRODUCTION

Drought is a natural and normal attribute of the arid lands of arid and semiarid climates. Agricultural drought may be defined as a deficiency of rainfall with respect to the median or to the mean, that seriously impairs agricultural production for a period of several months to several years, extending over a large geographical area. Drought should not be confused with aridity, which rather refers to the average long-term relationship between rainfall and potential evapotranspiration, although it may occur in non-arid zones as well.

Southern Africa, with its variable and limited rainfall, is arid, and seasonal and severe droughts normally occur. During droughts, considerable stock and stock-product losses occur due to the lack of fodder.

CLIMATE

Southern Africa is subject to the most complex bio-climatic conditions on the African continent (Le Houérou *et al*., 1993). This complexity results from a combination of various geographic conditions, among which are the following:

* Large variation in latitude between Messina in Northern Transvaal (22°30' S) and Cape Agulhas (34°50' S), a distance of approximately 1350 km north-south.
* Large variation in elevation, from sea level to about 3 500 m, with a direct effect on rainfall and temperature.
* The presence of the oceans to the east and west. These are associated with the influences of warm currents (Mozambique and Agulhas) in the east, and a cold current (Benguela) to the southwest.
* Mean annual precipitation varies from 40 mm at the mouth of the Orange River, to over 2500 mm on the eastern slopes of the Drakensberg and the upper and western slopes of the Cape mountains.

The rainfall regime may be tropical summer mono-modal; Mediterranean winter mono-modal; spring and autumn bimodal; or completely amodal (without a regular dry season). The mean potential evaporation may vary from a little less than 1000 mm along the Cape and Natal, to over 2 500 mm in the Upington-Pofader-Pella area on the southwest border with Namibia.

OPUNTIA CULTIVATION

Cacti perform well on deep, light textured soils, including coarse sands, but clay should be avoided. Shallow soils tend to give low yields. Cacti are tolerant of pH up to 8.5, and maximum electrical conductivity at soil saturation should not exceed 5-6 mS/cm (Le Houérou, 1992).

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Cacti respond to application of nitrogen and phosphorus fertilizer. A production increase of 200 to 300% has often been observed following moderate nitrogen and phosphorus application. Manuring also increases yield even with very low precipitation of 150-200 mm (Monjauze and Le Houérou, 1965; Le Houérou, 1992; De Kock, 1980). Cacti cannot withstand waterlogging.

WATER REQUIREMENT AND USE

Cacti and other drought tolerant fodder crops use water more efficiently than conventional fodder crops. According to De Kock (1980), opuntia uses 267 kg H_2O/kg DM, or 3.7 mg DM/g; *Atriplex* sp. uses 304 kg H_2O/kg DM, or 3.3 mg DM/g; and *Agave* sp. uses 93 kg H_2O/kg DM, or 10.7 mg DM/g.

The productivity of opuntia is also very high if compared to most native vegetation under similar conditions. Opuntia produces up to 10 t of aboveground DM/ha/yr in arid zones, 10-20 t in semi-arid zones and 20-30 t in sub-humid areas under appropriate or close to optimum management (Monjauze and Le Houérou, 1965; De Kock and Aucamp 1970; Steynberg and De Kock 1987; Nobel 1988; Le Houérou 1991b, 1992).

Such high yields, however, demand careful crop management and good deep soils. Under such conditions, productivity is about ten times that of standard rangelands under common management conditions. With neither cultivation nor fertilization, yield is still three to five times that of rangeland (De Kock, 1980; Le Houérou, *et al*., 1988). The rain use efficiency (RUE) and water use efficiency (WUE) under rainfed and irrigated conditions are summarized in Table 47.

Table 47. Rain use efficiency (RUE) and water use efficiency (WUE) under rainfed and irrigated conditions for several crops

Crop	**RUE** (kg DM/mm/yr)	**WUE – Transpiration coefficient** (kg H_2O/kg DM)	**WUE** (mg DM/g H_2O)
Agave	45.0	93	10.7
Opuntia	40.0	267	3.7
Atriplex nummularia	28.0	304	3.3
Pearl millet	25.0	400	2.5
Barley	20.0	500	2.0
Sorghum	15.0	666	1.6
Wheat	13.3	750	1.3
Alfalfa	10.0	1000	1.0
Rangeland	5.0	2000	0.5

Using the WUE characteristic of an opuntia in an area with 200 mm mean annual precipitation, the yields of cactus material presented in Table 48 were produced under various systems of limited irrigation (De Kock and Aucamp, 1970). In arid and semi-arid areas with limited supply of irrigation, irrigating spineless opuntia is more efficient than irrigating a small area of alfalfa.

Table 49 summarizes the fodder yield and the amount of digestible nutrients produced by spineless cactus (*Opuntia robusta*), oldman saltbush (*Atriplex nummularia*) and alfalfa per unit of water received (25 mm).

Table 48. Yield of spineless opuntia (2920 plants/ha) under limited irrigation at the Carnarvon Station (average rainfall: 200 mm/yr) (Two seasons: 1965-66; 1967-68)

Irrigation + rainfall (mm/yr)	**Number of times irrigated**	**Irrigation schedule**	**Fresh weight yield** (t/ha)	**Dry weight yield** (t/ha)
No irrigation + 178 mm rainfall	0	-	24.89	3.27
75 mm irrigation + 178 mm rainfall	1	September	38.61	4.21
152 mm irrigation + 178 mm rainfall	2	September and November	66.49	6.11
229 mm irrigation + 178 mm rainfall	3	September, November and January	97.60	9.09
305 mm irrigation + 178 mm rainfall	4	September, November and January and March	106.68	10.57

Table 49. Comparison between fodder yield and digestible nutrients (kg/ha) produced by three fodder crops per unit of water received

Season	**Spineless cactus**		**Oldman saltbush**		**Alfalfa**	
	Fodder yield	Digestible nutrients	Fodder yield	Digestible nutrients	Fodder yield	Digestible nutrients
1	161.6	100.4	578.3	235.6	247.5	137.0
2	3001.0	1746.3	944.8	397.2	367.4	208.4
3	3551.8	2081.0	1229.4	555.8	394.9	210.5
4	2169.1	1279.5	752.6	303.2	316.4	180.5
5	2220.9	1301.8	876.3	373.0	331.5	182.0

PRODUCTION

In South Africa, there are three species of spineless cacti utilized for fodder production:

(ix) *O. robusta*. This cactus has large, circular, bluish cladodes, almost spineless. It was first introduced into South Africa in 1911 from the selection programme of Luther Burbank in California. This tetraploid is tolerant to *Dactilopius opuntia*. It does not produce marketable fruit and so is mainly used as fodder.

(x) *O. fusicaulis* has narrow, lanceolate, green cladodes with an upright growth habit.

(xi) *O. ficus-indica* f. *inermis* is a green, oblong type, with dense growth habit.

O. fusicaulis and *O. ficus-indica* cannot produce both fodder and fruit in the same stand in fruit orchards (unless pruning waste is considered). Fodder plantations are harvested every two to three years, before they produce fruits.

In South Africa, opuntia cactus is propagated vegetatively by placing pads flat on the ground with a shovelfull of soil or a stone on top, to improve contact with the soil. Alternatively, double joints can be planted in a furrow, burying the lower end with soil drawn from an adjacent furrow. Roots will develop from the areolas within a few weeks.

Rows are laid out following contour lines. Deep furrows or trenches are made with a heavy ripper and partially filled with manure, which in turn will be covered by soil, planting cladodes on top. The method is more expensive than simple planting, but it yields better growth in the first two to four years, implying earlier production and higher productivity. Rows are usually established 2 to 6 m apart with 1 to 2 m between plants. Planting density may vary from 850 to 5000 plants/ha. The best time for planting in South Africa is September and October, when the pads are fully-grown and ready to sprout. The resulting plants will be well established before the first frost of the following winter. It is preferable to use one-year-old cuttings as planting material.

The selection of a planting layout depends on the type of use envisaged. For direct browsing, dense stands (3 000 to 5 000 plants/ha) with short plants are used. In contrast, the cut-and-carry system requires a wider space to allow a tractor and a trailer to collect the harvest. In this case, a 1 m × 6 m layout is preferred, giving a mean planting density of about 1 666 plants/ha.

CROP MANAGEMENT

Under rainfed condition, yield may vary from 2 to 10 t DM/ha/yr, if harvested every 2 to 3 years. Yield rates from irrigated opuntia are presented in Table 48. Yield is increased if weed competition is reduced. Contour planting to reduce rainfall runoff can also improve yield. The protein content of fodder opuntia can be raised from 3.5 to 4.5% crude protein to 8 to 10% through application of nitrogenous fertilizer.

UTILIZATION

Fresh spineless cladodes contain approximately 90% moisture. The energy requirement for the survival of a 35-kg sheep is approximately 350 g of TDN per day; therefore, the ingestion of 538 g of dry cactus is enough to obtain sufficient energy. This means that 5 to 6 kg of fresh cactus must be ingested daily. However, a sheep eats an average of 4 kg a day.

For cattle, to provide the daily energy requirements for the survival of a 400 kg beast, 2 850 g of TDN are required per day. Therefore, such an animal will require approximately 4 385 g of dry cactus to meet its requirements. That means a daily ingestion of 44 to 45 kg of fresh cladodes. However, an animal only eats an average of 40 kg of cactus per day.

One of the reasons why animals (especially sheep) do not eat sufficient amount of fresh cactus cladodes is the high moisture content. Although the high water content limits consumption by animals, this moisture can be valuable during droughts, to reduce the need for drinking water. Penned sheep could be kept alive for 500 days without drinking water, provided they had free access to fresh cactus cladodes. The intake of TDN can be increased if the fresh cladodes are wilted or dried before feeding.

Cactus cladodes are very low in crude protein in general, but any ration for non-reproductive sheep and cattle should contain at least 8% of crude protein. Rations or feeds with low protein content are poorly ingested by animals. A sheep with a liveweight of 35 kg requires approximately 50 g of crude protein per day. The average 500 g of dry material from the daily ration of cactus cladodes contains only 20 g of crude protein, so cactus cladodes must be supplemented with some form of crude protein. Cactus cladodes are low in phosphorus and sodium, requiring supplementation of these elements as well. In general, cactus cladodes are not a balanced feed but rather a good, inexpensive source of energy.

Grazing

The easiest way to utilize cactus is by direct grazing, which requires little labour and therefore is cheaper. There is a risk of overbrowsing and destruction of the plantation if strict control of stock and grazing is absent. Grazing or harvesting should take place every two to three years. The pads reduce in feeding value after the third year (Walters, 1951). For efficient grazing, the plantation can be divided into small paddocks, which are then used intensively for a short period each. Large loses can occur during grazing due to wastage.

Chaffing

Increased intake by animals and better utilization can be obtained by chopping the cladodes. To limit waste, it is preferable to feed the chaffed material directly in the trough.

Meal

Chaffed cactus cladodes can be dried on any suitable surface, and then milled. A supply of cactus meal can thus be stored for use during droughts and/or for supplementing fresh cactus pads to increase dry matter intake.

Silage

Good silage can be made from cactus cladodes by chaffing them with oat straw, low grade alfalfa or any other dry roughage on the basis of 84 parts mass of cactus cladodes and 16 parts of roughage, with the addition of molasses meal. When cladodes bearing fruit are used for silage, the addition of molasses is not necessary. The silage is then made and used in a conventional manner.

Opuntia fruit and cladodes – even the spiny types – can be made into silage with low quality hay, cereal straw or veldt hay, and supplemented with protein feed (cotton or sunflower seed meal, and urea) and a mineral supplement of phosphorus and sodium (bone meal, salt and lime) and this can sustain dairy production in arid and semi-arid rural areas during dry seasons and drought periods.

Supplementary feeding

In an emergency, where nothing else is available, cactus cladodes can be fed alone in any form, and sheep and cattle can survive on it for many months. Wool sheep were kept for 500 days on cactus cladodes alone and survived.

For optimal utilization, however, cactus cladodes should be supplemented. As protein is the most important deficiency of cactus, a protein-rich supplement should be supplied. A supplement comprising one-third bone meal, one-third common salt and one-third urea can be used. Another possibility is a ration consisting of cactus meal and 6.5% of fishmeal, which will supply the needs of sheep.

The most suitable supplement for cactus meal is alfalfa, either meal or hay. It is recommended to provide 100 g of alfalfa in summer and 200 g in winter, with cactus *ad libitum*. Any other hay legume with a reasonably high protein content could be used instead of alfalfa. Cactus cladodes are an excellent succulent supplement on dry Karoo range (shrub type veldt, high in protein), or in dry grass range during winter, with a protein-rich supplement.

LAXATIVE ACTION

A problem experienced when cactus cladodes are fed in any form to sheep and cattle is the severe laxative action. This laxative action is not a disease symptom and has no detrimental effect on the animal's health. It is the result of a fast passage through the digestive system. The laxative effect can be curtailed by:

* Feeding fodder lime (approximately 3% of the total intake), to counteract acidosis. The high acid content of cactus cladodes is related to the Crassulacean Acid Metabolism of the plant.
* Limit access of the animals to drinking water.
* Feed hay with cactus cladodes. Hay as a supplement retards the laxative effect. Alfalfa hay is regarded as an exceptional supplement to spineless cactus cladodes in any form.