*Forum*

# *Opuntia* Forage Production Systems: Status and Prospects for Rangeland Application

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## Abstract

This paper reports recent findings in *Opuntia* genetics, nutrient fertilization, and cultivation with promise to overcome limitations for *Opuntia*-based forage production systems. The essentially spineless, fast-growing *Opuntia ficus-indica* (L.) Mill. has been planted on millions of hectares for forage in tropical areas of Brazil and North Africa. The spiny, cold-hardy *Opuntia* species have been used for forage in Mexico and the southwestern United States, after the cladodes have been chopped or singed to remove the spines. Due to the recent increases in fuel prices, burning of the spines is more costly. Where only spiny varieties exist, some range animals forage on them without manipulation. As a result, spines frequently penetrate and form lesions on mouth and esophageal tissues, leading to serious health issues. Slow growth and low protein (ca. 5%) of the native *Opuntia* spiny species on nonfertilized rangeland is an impediment to greater use of *Opuntia* for forage. The only spineless species adaptable to US Department of Agriculture cold hardiness zones $< 8$ (i.e., *Opuntia ellisiana* Griffiths) is relatively slow growing. Full sibling crosses indicate spine heritability is probably single-gene controlled. Interspecific hybrids between the frost-sensitive, fast-growing, and spineless *O. ficus-indica* with cold-hardy, spiny, slower-growing *O. lindheimerii* Engelm. have produced spineless progeny, with greater cold hardiness than *O. ficus-indica*, and greater productivity than cold-hardy, spineless *O. ellisiana*. Nitrogen limitations on water-use efficiency of *Opuntia* have been overcome for the 120 million ha of semiarid northeastern Brazil with added nitrogen and phosphorus fertilization. With control of competing vegetation and fertilization, this system has 40 t dry matter $\cdot ha^{-1}$ of 9.2% crude protein forage with 600 mm rainfall in 16 mo. *Opuntia ficus-indica* plantations were profitable even though a duplication of fertilizer current prices was considered.

## Resumen

Este trabajo reporta los hallazgos recientes en genética, fertilización, y cultivo de *Opuntia* que aseguran superar las limitaciones para los sistemas de producción de forraje que se basan en esta especie. La especie de crecimiento rápido *O. ficus-indica* (L.) Mill. que es una especie sin espinas que se ha plantado en millones de hectáreas para forraje en áreas tropicales de Brasil y norte de África. Las especies de *Opuntia* con espinas, más tolerantes al frío, se han utilizado para forraje en México y el sudoeste de Estados Unidos, después que se han picado o levemente quemado las plantas para remover las espinas. Debido al alza reciente de los precios del combustible, la quema de las espinas ha pasado a ser mucho más costosa. Donde sólo existen variedades espinosas, algunos animales las ingieren sin ningún manejo. Como resultado de ello, las espinas penetran y forman lesiones en la boca y en los tejidos del esófago, que conducen a serios problemas de salud. El crecimiento lento y el contenido bajo en proteína (alrededor del 5%) de las especies espinosas de *Opuntia* nativas en pastizales nativos no fertilizados es un obstáculo para un uso mayor de *Opuntia* para forraje. La única especie sin espinas adaptable a las zonas de tolerancia al frío del Departamento de Agricultura de los Estados Unidos de Norteamérica $< 8$ (*O. ellisiana* Griffiths) es de crecimiento relativamente lento. Cruzas totales entre hermanos indican que la heredabilidad de las espinas está probablemente controlada por un gen simple. Híbridos interespecíficos entre *O. ficus-indica*, de crecimiento rápido, sensible al frío y sin espinas con *O. lindheimerii* Engelm., resistente al frío, con espinas y de crecimiento más lento, han identificado progenie sin espinas, con mayor resistencia al frío que *O. ficus-indica* y mayor productividad que *O. ellisiana*, especie sin espinas y tolerante al frío. Se han superado las limitaciones de N sobre la eficiencia del uso del agua por parte de *Opuntia* para las 120 millones de hectáreas de la zona semiárida del noreste de Brasil mediante la fertilización con nitrógeno y fósforo. Este sistema ha producido 40 toneladas de materia seca por hectárea con 9,2% de proteína bruta con 600 mm de lluvia anual mediante el control de la vegetación competitiva y la fertilización después de 16 meses. Las plantaciones de *O. ficus-indica* resultaron rentables aún si se considera una duplicación del precio actual de los fertilizantes.

**Key Words:** cold hardiness, cultural practices, economic feasibility, fertilization, progeny

## INTRODUCTION

As forage for range livestock, Opuntias have both advantages and disadvantages. Spines and smaller glochids of the areoles are a distinctive feature of nearly all cacti that cause mechanical injury to the skin, face, and digestive tract, and are a strong

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deterrent to most herbivores. Feeding these species requires mechanical or flame treatments prior to feeding. Occasionally, sheep, goats, and cattle eat spiny cactus that have not had the spines removed, resulting in infected lesions in their digestive tract and poor health or death of these livestock (Migaki et al. 1969; Merrill et al. 1980).

In the continental United States, another negative attribute of *Opuntia* is that native spiny Opuntias are slow growing whereas the spineless, fast-growing species such as O. *ficus-indica* (L.) Mill. are not cold-hardy and are poorly adapted to most US rangelands. The low protein concentration of unfertilized cactus (5–6% crude protein [CP]; Everitt and González 1981; Meyer and Brown 1985) is another limitation when feeding grazing animals.

On the positive side, these cacti have greater water-use efficiency due to the crassulacean acid metabolism (CAM) photosynthetic pathway that is several times more efficient in converting water and $CO_2$ to dry matter plants than either $C_4$ or $C_3$ plants (Nobel 1991, 1994; Han and Felker 1997). Cacti can produce more dry matter per milimeter of rainfall than any other type of plant. When high population densities are planted, O. *ficus-indica* is very productive. Simulations (García de Cortázar and Nobel 1990) under natural conditions led to a maximum predicted productivity of about 20 t dry matter $\cdot$ ha$^{-1}$ $\cdot$ yr$^{-1}$ worldwide. Measurements with no water limitations gave 40 t dry matter $\cdot$ ha$^{-1}$ $\cdot$ yr$^{-1}$ in Chile (García de Cortázar and Nobel 1991). A very high density planting (24 plants $\cdot$ m$^{-2}$) with unlimited water and ample nutrients led to 50 t $\cdot$ ha$^{-1}$ $\cdot$ yr$^{-1}$ in Chile (García de Cortázar and Nobel 1992) and O. *ficus-indica* fertilized and watered daily had a productivity of 47 t $\cdot$ ha$^{-1}$ $\cdot$ yr$^{-1}$ in Mexico (Nobel et al. 1992). With high nitrogen (N) and phosphorus (P) applications in Texas to O. *lindheimerii* Engelm., González (1989) obtained 62 t dry matter $\cdot$ ha$^{-1}$ $\cdot$ yr$^{-1}$.

Worldwide, the greatest use of cactus for forage occurs in Mexico, South Africa, Tunisia, and Brazil (Mondragón-Jacobo and Pérez-González 2001; Felker et al. 2006). Flores and Aranda (1997) reported that 18 *Opuntia* species were used as forage on more than 3 million ha of rangeland in northern Mexico with 150 000 ha of cactus being planted by ranchers and small producers using government support. López et al. (1996) reported that 25 species and 12 varieties of *Opuntia* are being used for forage in the Mexican state of Coahuila. Flores and Aranda (1997) reported that more than 650 000 cattle died during the 1993 to 1996 drought in northern Mexico yet ranchers with nopales (*Opuntia*) appeared to have fewer livestock losses than ranchers without nopales. Furthermore, reproduction rates and production levels were greater for animals supplemented with nopales.

In Brazil (Domingues 1963; Cordeiro Dos Santos and Gonzaga de Albuquerque 2001) and Tunisia (Monjauze and Le Houérou 1965; Nefzaoui and Ben Salem 2001), there are plantations with several hundred thousand hectares of spineless *Opuntia* that are used for livestock feed. Extensive spiny *Opuntia* stands in Tigray, Ethiopia, also have been used for livestock food after the spines have been chopped (Brutsch 1997). In South Africa considerable scientific study has been devoted to utilization of cactus for forage (De Kock 2001). All of the cacti used commercially for livestock in the United States is of the wild spiny type, i.e., O. *lindheimerii* in Texas (Felker 1995) and to a lesser extent O. *polyacantha* Haw. in Colorado (Shoop et al. 1977).

CAM species show an average increase in biomass productivity of 35% in response to a doubled atmospheric $CO_2$ concentration (Drennan and Nobel 2000), predicted to occur before the end of the twenty-first century (Nobel 1996). With increasing temperature and drought duration, the percentage enhancement of daily net $CO_2$ uptake caused by elevated $CO_2$ concentration increases. Thus net $CO_2$ uptake, productivity, and the potential area for cultivation of CAM species will be enhanced by the increasing atmospheric $CO_2$ concentration and the increasing temperatures associated with global climate change (Drennan and Nobel 2000). Similarly, Nobel (1996) indicated a further expanding of CAM plants in the regions where they profitably can be cultivated.

Nutrient content of *Opuntia* spp. depends on the genetic characteristics of the species or clones, the cladode's age, the cladode sampling location, the cladode harvesting season, and the growing conditions, such as soil fertility and climate (Monjauze and Le Houérou 1965; Boza et al. 1995; Nefzaoui and Ben Salem 2001; Gugliuzza et al. 2002; Guevara et al. 2006). *Opuntia ficus-indica* was high in calcium (Ca), normal in magnesium (Mg), and low in sodium (Na), potassium (K), and P contents in relation to ruminant requirements from a diet, and similar to common temperate or tropical grasses and legumes (Tegegne 2001). Iron and aluminium are found in traces (López-García et al. 2001). In *Opuntia* spp., Ca is the main mineral constituent of the plants. It is found in a free form or as calcium oxalate. This salt can reach from 8% to 50% of dry matter (DM) and to 85% in the ashes of old plants (Tovar-Puente et al. 2007). Cactus cladodes have high oxalate content; total oxalate is about 13% of the DM, of which 40% is in a soluble form. These oxalates are probably bound to Ca, making this mineral less available to animals. Cactus feed, i.e., cladodes aged 1–3 yr is rich in provitamin A and vitamin C (Le Houérou 1996). Vitamin A is likely the vitamin of most practical importance in cattle feed. Vitamin A does not occur as such in plant material; however, its precursors, carotenes or carotenoids, are present in plants in various forms (National Research Council [NRC] 2000). The content of carotenoids is 29 μg 100 $\cdot$ g$^{-1}$ and the content of ascorbic acid is 13 mg 100 $\cdot$ g$^{-1}$ (Felker 2001). The nutrient content of seven *Opuntia* forage clones and three age classes (about 1 yr, 2 yr, and 3 yr old) was determined in the Mendoza plain, Argentina (Guevara et al. 2004). The nutrient content for all clones and age classes pooled was the following (% DM): organic matter (OM), 81.6% to 86.8%; in vitro organic matter digestibility, 69.5% to 82.1%; CP, 3.2% to 5.0%; neutral detergent fiber, 22.7% to 27.1%; acid detergent fiber, 12.0% to 16.0%; DM, 7.3% to 11.5%. A significant ($P < 0.05$) or nearly significant ($P = 0.08$) linear negative relationship between each nutritional parameter and age classes was found for all clones, except for OM that showed a significant linear relationship with only two clones.

Below we discuss some factors limiting the use of *Opuntia* for forage and provide methods to overcome these limitations.

## Fertilization to Increase Crude Protein Contents

With N fertilization, typically low protein concentrations of *Opuntia* can be increased to attain 10% CP (N × 6.25), a level meeting the needs of a lactating cow (González 1989). Nobel (1983) measured N concentrations of O. *ficus-indica* cladodes