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Value of endemic legumes for livestock production on Caatinga rangelands

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ABSTRACT: Rangelands and other native pastures occupy a large area of the planet, with greater temporal and spatial botanical composition and productivity variability. Despite the continuous and historical use of these areas, including overgrazing and fire exclusion, endemic legume species persist in some semiarid rangelands. The objective this work was to review current knowledge of legume use, especially those of the Brazilian Caatinga rangeland. Studies that measure the qualitative and quantitative variations of native legumes are essential for ruminant feed supplementation, to the sustainability of animal production, as well as for economic and environmental improvements in rangelands. Caatinga vegetation of northeastern Brazil consists of deciduous shrubs and small trees which mostly lose their leaves at the beginning of the dry season. The legume family contributes to the greatest number of endemic species but little is known about their productivity or nutritive values. Livestock select Orelha de onça [*Macroptilium martii* (Benth.) Marechal & Baudet] and Mororó (*Bauhinia cheilantha* (Bong.) Steud.) and these should, during rangeland clearing, be preserved. In addition, although Caatinga legumes have great crude protein content, their biological fixation of atmospheric N has yet to be thoroughly studied. On the negative side, some native Caatinga legumes have great levels of neutral detergent fiber-bound N (NDFN) and condensed tannin. As a result, animal performance in Caatinga is often poor, notably in the dry period. Forage legumes also provide several environmental services such as N input via BNF and rehabilitation of degraded land.

Key words: environmental services; forage; native pastures; semi-arid

Valor de leguminosas endêmicas para produção pecuária em áreas de Caatinga

RESUMO: Pastagens nativas ocupam uma grande área do planeta, com composição botânica e produtividade altamente variável, no tempo e no espaço. Apesar do uso contínuo e histórico dessas áreas, com uso do superpastejo e limpa com fogo, as espécies de leguminosas endêmicas persistem em algumas áreas de pastagens semiáridas. Considerando a importância das plantas nativas para a pecuária, se objetivou revisar o conhecimento atual sobre o uso de leguminosas, especialmente aquelas de áreas de Caatinga. Estudos que medem as variações qualitativas e quantitativas das leguminosas nativas são essenciais para o planejamento da suplementação alimentar, para a sustentabilidade da produção animal, bem como para melhorias econômicas e ambientais em pastagens nativas. A vegetação da Caatinga do Nordeste do Brasil é composta por arbustos decíduos e pequenas árvores que na maioria das vezes perdem suas folhas no início da estação seca. A família das leguminosas contribui com o maior número de espécies endêmicas, mas pouco se sabe sobre sua produtividade ou valor nutritivo. Por exemplo, os animais selecionam a Orelha de onça [Macroptilium martii (Benth.) Marechal & Baudet] e o Mororó (Bauhinia cheilantha (Bong.) Steud.) e estes devem, durante a limpeza da pastagem, serem preservados. Além disso, embora as leguminosas da Caatinga tenham alto teor de proteína bruta, sua fixação biológica do N atmosférico ainda não foi completamente estudada. Por outro lado, algumas leguminosas nativas da Caatinga apresentam altos teores de N ligado à fibra em detergente neutro (NFDN), além do tanino condensado. Como resultado, o desempenho animal na Caatinga é frequentemente baixo, principalmente no período seco. As leguminosas forrageiras também fornecem vários serviços ambientais, tais como entrada de N via FBN e recuperação de áreas degradadas.

Palavras-chave: serviços ambientais; forragem; pastagens nativas; semiárido

Introduction

Rangelands occupy approximately 50% of the world's land area. Leguminosae make up an important part of these grasslands in tropical and subtropical climates, especially in arid and semi-arid ecosystems. In Brazil, their total area has decreased over the last years, while cultivated pastures have increased. One of the reasons for this change can be traced to the decline in rangeland legumes.

Numerous legumes were originally endemic to native pasture in semiarid ecosystems around the world (Mitchell et al., 2015; Ydoyaga-Santana et al., 2011). Forage and seeds of these plants can contribute as feed to native fauna, forage to domesticated ruminants, as well as N and organic matter to native soils and plants unable to fix atmospheric N (Muir et al., 2005; Noah et al., 2012). Unfortunately, these legumes have often been extirpated as a result of mismanagement such as overgrazing, broadleaf herbicides and soil cultivation.

Reintroducing legumes back into grass monocultures should contribute to resolving the global problem of limited nitrogen availability, mitigating pasture degradation and increasing soil and vegetation carbon sequestration (Guan et al., 2016). Loiola et al. (2010) pointed out that legumes are economical, socially and ecologically relevant, often important for the local human populations and an essential component to developing sustainable natural resource use based on adequate vegetation management.

For example, due to seasonal plant characteristics, climate and soil conditions, and non-forage vegetation predominance typical of the Northeast of Brazil, Caatinga rangeland, livestock carrying capacity is low (Santos et al., 2010), which repeats itself in other native pastures around the world (Euckert et al., 2001). The Caatinga is characterized by lower average livestock carrying capacity and land ownership, where approximately 30% of properties have less than 100 ha and 66% less than 10 ha (Hoffmann & Ney, 2010). An alternative for semiarid livestock systems would be to manage for greater productivity gains per area (Moreira et al., 2007). To achieve this, Caatinga should be used by the animals in the rainy season, when it offers the maximum supply of forage; animals should then be supplemented with cultivated or conserved (e.g. hay) forages in dry season (Santos et al., 2010). We suggest that landowners could also use animal stocking rates that foster rangeland plant species diversity, especially legumes. Our objective in this review was to present information about rangeland legumes, focusing primarily on those native to Caatinga.

Semi-Arid Environment

Semi-arid regions occupy approximately 15% of the world's land surface and shelter around 15 million people (Millennium Ecosystem Assessment, 2005). Native rangelands are common in these regions. Northeastern Brazil occupies approximately 18% of the area of the country and is home to 28% of its people (IBGE, 2017). This region presents great climatic and ecosystem variation. However, approximately 70% of its area is classified as semi-arid in which rangelands predominate.

Rainfall in Brazil's northeastern semi-arid region varies in time and space. It has a dry, hot climate, with potential evapotranspiration up to 2,000 mm / year, as well as shallow stony soils with low moisture retention capacity (Lira et al., 2004). About half of the semiarid soils are of sedimentary origin, with high groundwater potential. The other part is of crystalline origin and has a much lower groundwater potential with generally high salt content (Silva & Guimarães Filho, 2006).

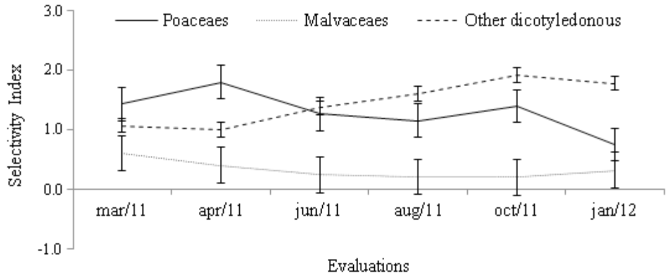
Caatinga is a primary vegetation type of the Brazilian semiarid northeast and is traditionally used as rangeland for large and small domesticated ruminants. Historically it was diverse and rich in woody and herbaceous species (Souza et al., 2017). Most woody species are deciduous perennials while annual herbaceous plants complete their phenological cycle in the first 45 days after rains. Giulietti et al. (2002) listed 18 genera and 318 endemic species belonging to 42 families. Legumes are the most abundant botanical family in the Caatinga, with 264 species. Due to irregular rainfall distribution, cattle, sheep and goat husbandry is the most widely grown for Caatinga vegetation production system as the most important forage resource. Acoording to Oliveira et al (2018) about 40% of this vegetation is in secondary succession and in the process of degradation range from low to severe intensity, and total more than 20 million hectares, reflecting the intense use of the land, such as the overgrazing.

Rangeland Management

The Caatinga plays an important role as ecosystem for sustainability of Brazil's semiarid livestock systems. Vegetation seasonality, adverse climatic and soil conditions, and arboreal-shrub plant predominance result in low livestock carrying capacity. Because of short rainy season, each AU requires 4 to 5 ha (Lira et al., 2004).

Caatinga manipulation for pastoral purposes involves thinning, lowering canopy height to within animal reach and enrichment with native and exotic forage species (Oliveira et al., 2016; Pellizaro et al., 2017). Cultivated pastures increase forage production and intensify grazing, which allows greater stocking rates in Caatinga semi-arid; they also contribute to rangeland conservation by alleviating grazing pressure, transferring it to cultivated pasture with greater herbage production. Oliveira et al. (2016), based on selectivity of sheep grazing thinned Caatinga, recommended thinning Malvaceae plants (not preferred forage) and including more grasses and legumes in the herbaceous canopy to increase carrying capacity, since these plants are more selected by those animals (Figure 1).

Legumes are very common in unadulterated Caatinga and their atmospheric N_2 fixation (Menezes et al., 2016) could play an important role in minimizing environmental impact from industrial N fertilizers (Xu et al., 2017) for animal production



Source: Oliveira et al. (2016).

Figure 1. Selectivity index of sheep in Caatinga thinned, Serra Talhada, Pernambuco.

of this and similar ecosystems, including steppe-savannas types. The addition of manufactured N to pasture ecosystems, economically and sustainably, is still a challenge for livestock production systems. Thus, livestock intensification actions for Caatinga should include more forage legumes.

Grazing management, when done correctly, can bring benefits that help conserve ecosystems. Okasaki (2012) submitted mororó (*Bauhinia cheilantha* (Bong.) Steud.) to three manual defoliation intensities in Caatinga and verified that the light and moderate defoliation promoted greater forage mass than the severe defoliation, which consisted of removing all leaves every 28 days (Table 1). In most cases, however, Caatinga rangeland is often inadequately managed through continuous grazing under great stocking rates, which eliminate desirable legumes such as mororó.

One of the limitations when using Caatinga legumes is the presence of thorns or spines. These structures protect plants against herbivory. Whenever possible, the use of legumes without thorns or spines will facilitate collection and consumption by animals. On the other hand, often the presence of these structures is related to the vigor and plant adaptation.

Table 1. Forage mass at 28 days after defoliation of Mororó submitted to different defoliation intensities, Serra Talhada-PE*.

Defoliation	Forage mass (g DM plant^{-1})**
Light	40.44 a
Moderate	46.44 a
Severe	25.94 b
Average	37.83
Standard error	1.21

*Severe defoliation: removal of all leaves from plants; moderate defoliation: removal of all apical shoots and 50% of leaves from apex to branches; and light defoliation: removal of apical shoots only.
** Average of two defoliation cycles. Means followed by the same lowercase letter in the column do not differ from each other ($p > 0.05$) by the Tukey test.
Source: Okasaki (2012).

Botanical Composition and Forage Mass

Human interference has had negative effects on botanical composition and legumes biomass of rangelands. Legume decline in pasture is usually a result of several activities, including agricultural practices (Hejcman et al., 2007), overgrazing (Van Auken, 2009, Orr & Phelps, 2013), continuous grazing (Jacobo et al., 2006), fire exclusion (Van Auken, 2009; Li et al., 2013), grazing versus browsing (Fernandez-Lugo et al., 2013; Li et al., 2013), animal accessibility, or indiscriminate herbicide use (Lulow, 2008), among others. The tendency for tropical climate is for perennial legume contribution to decline vis-à-vis annuals under inadequate management (Tessema et al., 2012). On the other hand, global climate change, with resultant increase in atmospheric CO_2, may increase the presence of herbaceous legumes in native pastures (Campbell & Smith, 2000), although this will depend on other factors of human origin, as well as the increase of air temperature which dissipates O_2, increasing C_3 plant photorespiration rates.

Botanical composition and forage mass in rangelands vary according to season, precipitation patterns, ambient temperature, grazing pressure, animal species, evaluation method, anthropic actions, among other factors. Botanical composition is the characteristic that most changes with grazing, with greater legume selection, due to the greater palatability of many of these plants, when compared to grasses. In Texas, USA, rangeland, for example, there are 69 genera of herbaceous and shrub legumes (Correll & Johston, 1970), while in the Cross Timbers Region, covering 3,600 km^2 of that state and Oklahoma, Diggs Jr. et. al. (1999) identified 50 herbaceous legume species. Even after 160 years of overgrazing and fire use, Texas contains over 100 legume species endemic to its native pastures (Turner, 1959), although these have been extirpated in many overgrazed rangelands.

In northeastern Brazil, legumes are abundant in rangeland, with variation according to location, time of year, animal species and evaluation methodology (Table 2). In various ecoregions of Pernambuco State, Oliveira et al. (2016) observed varying numbers of shrub-tree and herbaceous legume species.

Only a small proportion of plants present in Caatinga has great forage value and, of that, a minor part of the forage produced is accessible to animals due to plant height (Santos et al., 2010). Ydoyaga-Santana et al. (2011) evaluated Caatinga for 120 days in rainy season with stocking rate of 6 ha /AU and observed reduction in forage mass and a change in the botanical composition of Caatinga grazed by cattle. They found variation in herbaceous forage mass and shrub legumes (Table 3) likely due to precipitation reduction, animal selective consumption, the most of the shrub species are deciduous and some are annuals.

Orelha de onça (*Macroptilium martii* (Benth.) Maréchal & Baudet) is a native herbaceous species occurring in areas of Caatinga, covering pastures of Agreste and Sertão of Pernambuco. It is an important source of livestock feed (Santos et al., 2010) and its proportion and production in pasture are influenced by season and grazing. Its potential for domestication and use in Caatinga rangeland rehabilitation merits greater research.

There is large variability regarding production and presence of legumes in rangeland. Introduction of exotic legumes for rangeland enrichment has been extensively studied in many parts of the world. In Kenya, for example, *Stylosanthes*

Table 2. Legumes found in Caatinga.

Common name	Scientific name	Site	Source
	Herbaceous		
Anil de bode	*Tephrosia cinerea* (L.) Pers.	Serra Talhada – PE	Ydoyaga-Santana et al. (2011)
Feijão de rolinha	*Rhincosia minima* (L) D. C.		
Feijãozinho	*Centrosema* sp.		
Jureminha	*Desmanthus virgatus* L.		
Malícia	*Mimosa* sp.		
Orelha de onça	*Macroptilium martii* Benth.		
Marmelada de cavalo	*Desmodium asperum* Desv.	Sertânia - PE	Maciel (2016)
Mata pasto	*Senna uniflora* (Mill.) H.S.Irwin & Barneby		
Anil	*Indigofera microcarpa* Desv		
Mucunã	*Dioclea grandiflora* Mart. ex Benth	Aiuaba-CE	Lemos & Meguro (2015)
	Shrub-Tree		
Angico manso	*Anadenanthera macrocarpa* Benth.	Serra Talhada-PE	Ydoyaga Santana et al. (2011)
Canafístula	*Cassia excelsa* Scharad.		
Jurema preta	*Mimosa* sp.		
Mororó	*Bauhinia Cheillantha* Steud.		
Unha de gato	*Mimosa sensitiva* L.		
Umburana de cheiro	*Amburana cearensis* A. C. Smith.	Sertânia-PE	Maciel (2016)
Jucá	*Caesalpinea férrea* Mart. Ex Tul		
Catingueira	*Caesalpinia pyramidalis* Tul		
Pau ferro	*Libidibia iminu* (Mart.) L.P. Queiroz		
Jurema de imbira	*Piptadenia i.*		
Jurema Branca	*Piptadenia stipulacea* (Benth.) Ducke	Santa Terezinha-PB	Guedes et al. (2012)
São João	*Senna macranthera* (DC. ex Collad.) H.S. Irwin & Barneby		
Pitombeira	*Platymiscium floribundum* Vogel	Caruaru-PE	Almeida et al. (2006)
Jatobá	*Hymenaea courbaril* L.	São José dos Cordeiros-PB	Lacerda et al. (2010)
Jurema açu	*Chloroleucon foliolosum* (Benth.) G. P. Lewis		
Gameleira brava	*Acacia paniculata* Willd.		
Mulungu	*Erythrina velutina* Willd.		

Table 3. Forage mass and botanical composition of legumes, before grazing animals entered the rangeland, Serra Talhada-PE.

Component	Forage mass (kg DM ha^{-1})		Botanical composition (%)	
	February	July	February	July
Herbaceous				
Orelha de onça	225	30	3.5	3,9
Other legumes	386	42	6.0	5,3
Other non-legumes	5843	710	90.5	90,8
Total	6454	782	100	100
Shrub-Tree				
Mororó	551	56	15.8	15.0
Jurema preta	415	41	11.9	10.7
Angico manso	143	19	4.1	5.1
Other legumes	1154	119	33.0	31.3
Other non-legumes	1231	143	35.2	37.9
Total	3494	378	100	100

Source: Adapted from Ydoyaga-Santana et al. (2011).

scabra cv. Seca, Glycine (*Neonotonia wightii*) and Siratro (*Macroptilium atropurpureum*) can contribute between 3.5 and 10.3 Mg forage DM to ruminants, as well as to soil organic matter, depending on the cut interval and height (Macharia et al., 2010). In northeastern Brazil, native legumes as Sabiá (*Mimosa caesalpiniifolia* Benth.), Jurema preta (*Mimosa tenuiflora* (Willd.) Poir.), Camaratuba (*Cratylia mollis* Mart. Ex Benth), Mororó, *Desmanthus* spp. and *Stylosanthes* spp., as well as the exotic Leucena [*Leucaena leucocephala* (Lam.) de Wit] and Cunhã (*Clitoria ternatea* L.) may be alternatives for enriching the Caatinga.

On the other hand, introduction of exotic legumes in native pasture can have negative consequences on the conservation of local biodiversity due to competition among plants, as well as the modification of soils and micro-environment (Jaurena et al., 2016). Some exotic legumes adapt so well that they end up becoming invasive. In Brazilian forest, Marques et al. (2014) observed that *Leucaena leucocephala* poduces large numbers of seeds and approximately 15% is persistent for up to five years. Other invasive legume examples include *Lespedeza cuneata* (Dum. Cours.) G. Don due to low palatability in central North America (Peterson et al., 2003) and *Pueraria lobata* (Lour.) Merr. var. *lobata* (Willd.) Maesen & S.M. Almeida ex Sanjappa & Predeep due to the habit of climbing trees in the southeastern United States of America and other parts of the world (Follak, 2011).

Nutritive Value and Selectivity

Some Brazilian native legumes have thorns and spines, which affect the preference of these plants by animals. In general, the proportion of legume in ruminant diet is different from percentage of legumes species that appear in the botanical composition of rangeland. Selected diet is markedly influenced by seasonality of forage mass and botanical composition in rangeland. Table 4 shows some some legumes species that appear in the diet of animals in the Caatinga area.

In Pernambuco, Moreira et al. (2006) observed the contribution of Orelha de onça and Mororó in cattle diets. Grasses in the diet decreased as the rainy season progresses, while the opposite occurred with Mororó, which indicates the importance of this legume in feeding Caatinga ruminants. Moreira et al. (2006) and Ydoyaga-Santana et al. (2011) observed greater legume contribution to animal diets in the rainy season whereas, in the dry period, their importance comes from leaf litter of deciduous shrub and tree plants (*Desmanthus* sp., *Mimosa caesalpiniifolia* Benth., *Bauhinia cheilantha* Bong., etc.), which contributes significantly to ruminant feed, although the proportion coming from legumes has not be determined.

Native legumes have great crude protein content; however, part is often bound to fibrous fractions, resulting in low digestibility (Silva et al., 2017). In addition, the presence of condensed tannins (Table 5), as well as anti-nutritional compounds may inhibit palatability and digestibility to ruminants.

Animal Performance

Animal performance in rangelands varies and is directly related to the proportion of the greatest quality forage species present and accessible to animals. Thus, legume contribution to ruminant diet quality improvement becomes more noticeable in the dry season. During these months, forage grasses provide livestock low crude protein and high fiber content which results in low digestibility (Silva et al., 2017). Ruminants can reduce this nutritional deficiency by ingesting greater proportions of legumes in dry season.

Average daily gain of heifers browsing Caatinga in the rainy season, according to Ydoyaga-Santana et al. (2010), was 412 g, with approximately 34.6% legume contribution to the diet (Table 6). The authors reported that the performance

Table 4. Caatinga legumes observed in ruminant diets.

Common name	Scientific name	Local	Species animal	Source
		Herbaceous		
Anil de bode	*T. cinerea* (L.) Pers.	Serra Talhada -PE	Cattle	Ydoyaga -Santana et al. (2011)
Orelha de onça	*M. martii* (Benth.) Maréchal & Baudet			
Feijãozinho	*Centrosema sp.*	Sertânia - PE	Sheep	Santos et al. (2008)
Erva de ovelha	*S. humilis* Kunth	Tauá – CE	Goats and Sheep	Araújo Filho et al. (1996)
		Shrub-Tree		
Jurema preta	*Mimosa* sp.	Serra Talhada -PE	Cattle	Ydoyaga -Santana et al. (2011)
Mororo	*B. cheillantha* (Bong.) D. Dietr.			
Catingueira	*C. pyramidalis* Tul.	Serra Talhada -PE	Cattle	Moreira et al. (2006)
Pau ferro	*C.* Mart. Ex Tul.	Sertânia - PE	Sheep	Santos et al. (2008)
Jureminha	*D. virgatus* L.			
Algaroba	*P. juliflora (S.W.)* D. C.			
Amendoim-bravo	*Arachis pusilla* Benth.	Tauá – CE	Goats and Sheep	Araújo Filho et al. (1996)

Table 5. Chemical-bromatological composition of native legumes according to location and source.

Native legumes	DM	CP	NDF	ADF	MM	LIG	ADIN	NDIN	EE	Tannin	IVDMD	IVOMD	Site	Source
	(g kg^{-1} of DM)										(%)			
Anadenathera macrocarpa Benth.	684.1	148.8	353.5	281.6	65.1	-	-	-	17.3	-	24.35	26.05	Serra Talhada (PE)	Moreira et al. (2006)
Caesalpinia pyramidalis	582.1	133.0	386.1	278.0	81.7	-	-	-	28.9	-	35.63	38.8	Serra Talhada (PE)	Moreira et al. (2006)
Mimosa sp.	476.8	168.8	406.4	369.2	45.5	-	-	-	29.6	-	11.19	11.72	Serra Talhada (PE)	Moreira et al. (2006)
Bauhinia cheillantha Steud.	307.0	189.0	469.0	266.0	75.0	92.0	11.2	28.9	28.0	9.0	-	-	Seridó Potiguar (RN)	Silva et al. (2015)
Macroptilium martii Benth.	447.0	117.4	622.5	475.7	108.4	-	-	-	7.4	-	36.75	41.22	Serra Talhada (PE)	Moreira et al. (2006)
Stylosanthes humilis	905.0	169.0	508.0	354.0	99.4	38.3	4.4	22.2	23.0	185.0	-	-	Seridó Potiguar (RN)	Silva et al. (2015)
Macroptilium heterophyllum	608.0	149.0	416.0	306.0	180.0	61.0	4.0	11.6	30.0	27.0	-	-	Litoral Norte do Cará (CE)	Silva et al. (2015)
Rhynchosia minima	603.0	214.0	444.0	286.0	98.0	103.0	14.7	30.4	46.0	11.0	-	-	Mossoró (RN)	Silva et al. (2015)
Desmodium tortuosum (Sw) Dc	877.0	200.0	319.0	208.0	75.0	38.6	11.6	38.6	34.0	85.0	-	-	Seridó Potiguar (RN)	Silva et al. (2015)

DM = dry matter; CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; MM = mineral matter; LIG = lignin; acid-detergent insoluble N; NDIN = neutral detergent insoluble nitrogen; EE = ether extract; IVDMD = in vitro organic matter digestibility; IVOMD = in vitro organic matter digestibility.

Table 6. Chemical composition, consumption, selectivity and performance of Guzerá and Girolando heifers in Caatinga, rainy season, Serra Talhada-PE.

Chemical composition of pasture, g kg^{-1} DM	DM	CP	NDF	ADF	EE	MM	IVDMD	TDN
	55.7	12.6	57.0	45.0	1.7	8.8	31.8	56.0

Botanical composition of the diet (%)	Evaluation period		
	May	June	July
T. cinerea (L.) Pers.	-	-	1.0
M. martii (Benth.) Maréchal & Baudet	16.0	16.0	5.4
B. cheilantha (Bong.) D. Dietr.)	14.2	18.0	19.7
Mimosa sp.	2.3	-	6.5
Non legumes	66.8	64.0	65.3
Consumption DM (kg animal^{-1} day^{-1})		4.83	
Consumption CP (g cow^{-1} day^{-1})		609	
Consumption TDN (g cow^{-1} day^{-1})		2705	
Daily gain (g cow^{-1} day^{-1})		412	

Source: adapted from Ydoyaga-Santana et al. (2010) and Ydoyaga-Santana et al. (2011).

observed in the grazing animals was probably due to the 6 ha /AU stocking rate, allowing the animals greater selectivity.

Milk production of cows exclusively fed Caatinga vegetation in the rainy season at 5 ha/ head stocking rate, according to Moreira et al. (2007), was 5.3 kg cow^{-1} day^{-1} (Table 6). These cows selected legumes at 39.5% of the diet.

In general, under Caatinga rangeland conditions, animal performance is low (Table 7), especially during dry season. Additional studies that measure qualitative and quantitative variations of native rangeland legumes presence and proportion in ruminant diets under varying physical and temporal factors are essential prior to determining feed supplement. In sustainable rangeland animal production systems, quantity and quality of exisiting forage should be supplemented and the semi-arid region of Brazil is no exception.

Use of Legumes in the Ruminant Food

The use of annual native legumes with precocious and vigorous seedlings during pasture establishment or over-seeding of degraded rangeland may facilitate the eventual establishment of perennial legumes and other forages in stable communities (Roscher et al., 2015). In those situations, including useful annual legumes in early successional stages, have been rarely studied until now in subtropical and tropical rangelands. In natural systems, the role of atmospheric N fixation by legumes depends on the degree of degradation and especially soil fertility (Carino & Daehler, 2002), as well as the succession phase (Bauters et al., 2016) with legumes playing an important role in increasing biodiversity (Goergen & Chambers, 2009; Hu et al., 2016). Little information is available for warmer climates, but the lack of success with perennial legumes (Muir & Pitman, 2004) indicates that the alternative may be more aggressive, short-lived annual legumes. It may be worthwhile to evaluate legume mixtures that contribute fast-growing annual and long-lived perennials in tropical and degraded subtropical rangelands and pastures, as recommended for milder climates (Harris, 2001).

Legume introduction to pastures and rangelands can be hampered by several factors. Grass species are usually more competitive, and therefore more productive and persistent than legumes (Davies, 2001; Mischkolz et al., 2013). The difficulties are lack of commercial seed sources (Smith et al.,

Table 7. Chemical composition, consumption, selectivity, and performance of cows in native pasture, rainy season, Serra Talhada-PE.

Chemical composition of pasture, g kg^{-1} DM	DM	MM	CP	EE	NDF	ADF
	49.8	8.7	11.5	1.8	53	40

Botanical composition of the diet (%)	Evaluation period			
	March	April	May	June
T. cinerea (L.) Pers.	0.6	-	-	0,7
C. pyramidalis Tul.	0.7	-	-	-
M. martii (Benth.) Maréchal & Baudet	17.9	19.6	7.2	4.3
B. cheilantha (Bong.) D. Dietr.	4.9	11.6	25.6	36.0
Mimosa sp.	3.4	4.5	4.6	8.5
Non legumes	70.7	62.0	61.8	47.3
Consumption DM (kg animal^{-1} day^{-1})		8.18		
Consumption CP (g head^{-1}day^{-1})		914		
Consumption TDN (g head^{-1} day^{-1})		3061		
Estimated milk production (kg cow^{-1} day^{-1})		5.29		
Estimated milk production corrected (kg cow^{-1} day^{-1})		5.58		
Milk fat content (%)		4.33		

Source: adapted from Moreira et al. (2006) and Moreira et al. (2007).

2010), impermeable seeds (Dittus & Muir, 2010; Bushman et al., 2015), low vigor seedlings resulting in slow establishment (Chandra, 2009), low seed productivity (Fischer et al., 2015), pod dehiscence and low persistence under continuous stocking, especially of very palatable legumes in relation to grasses less sought after by grazing animals (Muir et al., 2011). The domestication of unpalatable legumes (Nisi et al., 2015), for example, containing condensed tannins (Cooper et al., 2014) or less accessible, may contribute to the persistence of rangeland legume biodiversity (Nisi et al., 2015).

Leguminosae in silvopastoral systems

There are cultivated and natural (such as Caatinga) silvopastoral systems (SPS). In some natural SPS, legumes contribute significantly to biological atmospheric N_2 fixation. For example, shrub legumes present in the Caatinga, including *M. tenuiflora* and *M. arenosa* are considered efficient biological N fixers (BFN) as pioneer species in the initial stages of plant succession (Freitas et al., 2010). Benefits from the presence of legumes in SPS include not only BFN but also high primary productivity and provision of protein to grazing and browsing ruminants. In many cases, however, secondary compounds, such as condensed tannins, reduce the benefit of protein, since they precipitate in the rumen as well as inhibiting animal consumption due to palatability issues (Muir et al., 2015).

In addition to natural SPS, there are systems deployed by man. The use of tree legumes in semiarid cultivated SPS is still low. Recent research efforts with Sabiá (*M. caesalpiniifolia*) and Gliricidia (*Gliricidia sepium* (Jacq.) Steud.) show BFN to pastures besides the production of wood and fuel, increasing the profitability of that system (Apolinário et al., 2015). In the initial 3 years of establishment, animal productivity is similar among SPS containing sabiá or gliricidia compared to *Brachiaria decumbens* monoculture (Costa et al., 2016). However, with the maturation of Sabiá trees, competition with herbaceous stratum vegetation may reduce the system's carrying capacity (Dubeux Jr. et al., 2017). Despite the reduction, sale of firewood and wood stakes compensates for the animal product loss and, in fact, can double the system's gross income.

Other experiences with tree legume use in Brazilian SPS include exotic legumes such as acacia (*Acacia mangium* Willd.) and jurema branca (*Mimosa artemisiana*) with *Brachiaria decumbens* understory (Xavier et al., 2014). Leucaena has also been introduced into rangeland by the Caatinga-buffelgrass-leucaena system by EMBRAPA (Guimarães Filho et al., 1995), but severe drought can limit performance, in which *Leucaena* must be replaced by other legumes. Many research opportunities exist to expand native BFN trees in Brazil and around the world in both cultivated and rangeland SPS.

Nutrient Cycling and N Fixation

Several studies have focused on native legume rhizobia-legume symbiosis, (Reis Jr. et al., 2010; Santini et al., 2013), isolation, characterization and evaluation of the diversity of rhizobia of these legumes (Andrade, 2013), and total BFN. Considering the capacity of atmospheric BFN that most native legume species have, the potential contribution of these plants to soil fertility, nutrient cycling, as well as to greater forage crude protein, additional research is merited. It should be noted, however, that not all legumes fix atmospheric N_2 and, among those that do, the proportion of BFN varies widely (Sprent & Gehlot, 2010).

Environment variability found in the Caatinga leads to differences in BFN capacity estimates (Freitas et al., 2010). For example, greenhouse work evaluating *Desmanthus pernambucanus*, *M. martii* and *Macroptillium lathyroides* in the semi-arid soils of Paraíba, Brazil found that the three species fixed nitrogen, but with large differences among species and soils as a function of fertility. For example, in a non-fertilized REGOLYTIC NEOSOL, *D. pernambucanus* fixed 6 mg N per plant, the same species receiving manure fixed 87 mg N per plant, while *M. lathyroides* fixed, respectively, 27 and 244 mg N per plant while in a HOSPAL PLANOSOL the values were 20, 198, 240 and 331 mg N per plant, respectively (Freitas et al., 2011).

Freitas et al. (2010) estimated Caatinga shrub-tree BFN potential based on 15N natural abundance. They identified species with potential to fix large amounts of N, with emphasis on *M. tenuiflora* (Willd.) Poir, *M. sandy* (Willd.) Poir and *Piptadenia stipulacea* (Benth.) Ducke. The contribution of BFN was up to 68% of plant N. However, the amount of N added annually via leaf biomass was low, varying from 2.5 to 11.2 kg N ha^{-1} $year^{-1}$, due to the low proportion of fixing plants in the botanical composition. In regeneration situations of native vegetation, where succession is dominated by N-fixing species, BFN can reach 130 kg N ha^{-1} $year^{-1}$.

Diniz (2016) evaluated two *D. pernambucanus* accessions (from Santa Cruz de Capibaribe-PE, 5G and 6G) and a *Desmanthus* spp. (AS) from Australia under field conditions in the Pernambuco Forest Zone. Cut intensity was at 40 cm height in 75-day intervals and reported great amounts of BFN (Table 8). Their BFN ranged from 61.94 to 93.11 kg ha^{-1} $year^{-1}$.

Legumes can contribute to nutrient cycling in Caatinga ecosystems. Nitrogen transfer to grasses may occur by several processes: direct exudation of soluble N of legume roots (Nyfeler et al., 2011), nodule senescence and decomposition (Fustec et al., 2011), leaf and branch decomposition (Rasmussen et al. al., 2012) and ruminant excreta (Liu et al., 2011). These transfers are usually dominated by indirect processes (Lima et al., 2016). Indirect cycling moves nutrients

Table 8. Biologically fixed nitrogen (BFN), nodule dry mass and C/N ratio in *Desmanthus* spp.

Variables	Genotypes			CV %
	AS	5G	6G	
BFN (kg ha^{-1} $year^{-1}$)	61.94 ^{NS}	93.11 ^{NS}	78.29 ^{NS}	5.48
Nodule dry mass (mg $plant^{-1}$)	665.38 ^{NS}	423.08 ^{NS}	665.61 ^{NS}	24.60
C/N ratio (g g^{-1})	17.601 ^{NS}	16.344 ^{NS}	16.090 ^{NS}	17.37

^{NS} not significant at $p \leq 0.05$. Source: Diniz (2016).

obtained in deeper soil layers by deep legume taproots to eventually return to more shallow soil layers, where there is usually a greater concentration of grass roots (Kulmatiski et al., 2010).

There are also indications that legume root systems may have greater P-extraction efficiency than that of grasses (Adams et al., 2010), which, combined with the triple symbiosis (legume-rhizobium- mycorrhiza) (Reddy & Saravanan, 2013), may increase the total P stock available for other components of these ecosystems. Because of fixation, their greater nitrogen use efficiency, in turn, allows legumes access to a N pool unavailable to most other plant species. As a consequence, species of this family usually denote invasive and pioneering charateristics in disturbed environments with soil-nutriet deficiencies (Pérez-Fernández et al., 2016).

Desmanthus spp. (Table 8) C/N ratios are within mineralization/immobilization equilibrium range for tropical soils (Fanin et al., 2015), demonstrating the important role legumes can play vis-à-vis typically low grass C/N ratios in tropical ecosystems. The presence of soluble allied compounds at low C/N ratios favors soil microorganism decomposition and mineralization and nutrient recycling (Caldeira et al., 2013).

Environmental Service and C Sequestration

Forage legumes provide a variety of environmental services including forage for ruminants, fuel, lumber, shade, BFN, forage for insect pollinators, C sequestration and stock, nutrient cycling and primary productivity in environments with N limitation (Dubeux Jr. et al., 2017). Tree legumes produce substantial biomass (above and below ground) which, depending on the management, are allocated to tissues such as twigs and trunks (in addition to roots), which have a low decomposition rate and a high half-life when compared to leaf tissue and leaf/stem of herbaceous vegetation. Thus, C allocated to tree stems is immobilized, even if temporarily (Apolinário et al., 2016), minimizing greenhouse gas emission by grazing animals.

In semi-arid Itambé-PE, Brazil, Sabiá and Gliricidia accumulated approximately 50 Mg DM ha^{-1} over 5 years. Assuming 40% C plant tissue dry matter, potentially 20 Mg C/ha were accumulated in above-ground biomass during this period, i.e. 4 Mg C ha^{-1} year^{-1}, equivalent to 14 Mg CO_2-eq. year^{-1}, not counting root biomass that possibly represents 15-20% of above-ground biomass for vegetation. This amount of C accumulated by trees is sufficient to compensate the emission of methane by grazing animals. Thus, SPS with tree legumes is one of the few grazing systems with potential to be an atmospheric CO_2 drain. Tree legumes have deep roots, allowing not only water and nutrient absorption from deeper layers of the soil, but also C sequestration. Nutrients absorbed in deeper layers are recycled to the surface via litter deposition, contributing to raise the pool of available nutrients for herbaceous vegetation in shallower soil where these root.

Apolinário et al. (2015) indicated that BFN in Gliricidia and Sabiá leaves varied from 30 to 121 kg N ha^{-1} year^{-1}, indicating the BFN benefit from these legumes. Some of that BFN is transferred to herbaceous vegetation via litter deposition or animal excreta. Other environmental services such as forage for insects, pollinator nectar, natural pharmaceuticals, ornamental and recreational properties are still little studied in tree legumes, an open field for research, especially in tropical regions where the presence of tree legumes is most commonly observed.

Final Considerations

Key legume species should be identified in every semi-arid rangeland rehabilitation effort. In northeastern, semi-arid Brazil, for example, Orelha de Onça and Mororó are of great importance in the ruminant diet selection and should be preserved during thinning and clearing of woody species from rangeland. They and similar legumes such as *Desmanthus* spp. and *Stylosanthes* spp. represent potential candidates for breeding programs.

Native legume rangeland BFN capacity represents potential contribution to the soil fertility, nutrient cycling, as well as to a greater crude protein in forage consumed by domesticated large and small ruminants. A more detailed assessment of native-legume N availability is needed because legume N bound to plant cell walls or condensed tannins may interfere with BFN availability to soil microorganisms, plants and foraging animals.

Forage legumes provide various benefits, including environmental services, forage for domesticated ruminants, fuel, building material, BFN, forage for insect pollinators or herbivores, seeds for wildlife, healthier hyrdological cycles, C sequestration in soils and plants as well as nutrient cycling. Studies that measure the qualitative and quantitative variations of native legumes in rangelands are essential to maximizing these benefits. These in turn will maximize sustainable animal production from rangelands along with indirect economic and environmental improvements.

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