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Performance of tropical legumes grown as understory of a eucalypt plantation in a seasonally dry area of the Brazilian Cerrado

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Abstract

Nine tropical legumes were grown outside the canopy and in the understory of an 8-year-old *Eucalyptus grandis* stand in order to assess their seasonal production and forage quality for 4 evaluation periods. Incident photosynthetically active radiation in the understory was 18% of that outside the canopy. In the understory, production of *Lablab purpureus*, *Centrosema schiedeanum*, *Clitoria ternatea*, *Pueraria phaseoloides*, *Alysicarpus vaginalis*, *Aeschynomene villosa*, Estilosantes Campo Grande (*Stylosanthes capitata* + *S. macrocephala*), *Calopogonium mucunoides* and *Arachis pintoi* was <1 kg/ha/d for most samples. Even considering this low production, the large area available for animal production in forest plantations might justify the interest in legumes because of their high nutritive value. *Lablab purpureus* produced the greatest amount of dry matter in the understory in the establishment phase (12.1 kg/ha/d), but did not persist. It could be a suitable candidate for a cover legume species mixture to provide early growth. *Centrosema schiedeanum* developed rapidly and showed a high capacity for ground cover (>70%) and persistence, and had high nitrogen concentration, thus demonstrating good potential for protecting soils and promoting nutrient cycling in forest plantations. Another species with potential is *A. pintoi*, which established slowly but towards the end of the experiment showed moderate to high understory ground cover.

Resumen

Con el fin de determinar la producción estacional y la calidad de forraje durante 4 períodos de evaluación, en condiciones de sequía estacional del Cerrado brasileño se cultivaron 9 leguminosas tropicales bajo y fuera del dosel de una plantación de *Eucalyptus grandis* de 8 años de edad. Bajo el dosel, la radiación fotosintéticamente activa incidente estaba reducida al 18% de la radiación fuera del dosel. La producción de materia seca (MS) de *Lablab purpureus, Centrosema schiedeanum, Clitoria ternatea, Pueraria phaseoloides, Alysicarpus vaginalis, Aeschynomene villosa*, Estilosantes Campo Grande (*Stylosanthes capitata* + *S. macrocephala*), *Calopogonium mucunoides* y *Arachis pintoi* fue <1 kg/ha por día para la mayoría de las muestras bajo el dosel. Incluso teniendo en cuenta esta baja producción, la gran superficie de plantaciones forestales disponible para la producción animal podría justificar el interés en leguminosas forrajeras debido a su alto valor nutritivo. En la fase de establecimiento, *L. purpureus* produjo la mayor cantidad de MS bajo el dosel (12.1 kg/ha por día), pero no fue persistente. Esta especie podría ser un candidato para una mezcla de especies de leguminosas de cobertura, para proporcionar una cobertura y producción tempranas. *Centrosema schiedeanum* presentó un desarrollo rápido y mostró una alta cobertura del suelo (>70%) y de persistencia con alta concentración de nitrógeno, indicando un buen potencial para proteger el suelo y promover el reciclaje de nutrientes en plantaciones forestales. *Arachis pintoi* es otra especie con alto potencial de cultivo bajo dosel; aunque su establecimiento fue lento, al final del experimento mostró moderada a alta cobertura del suelo.

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Introduction

Plantation forests are estimated to cover 264 million ha worldwide, an area that increased at a rate of 5 million ha/yr between 2000 and 2010 (FAO 2010). Raising animals in the understory of forest plantations can help control weeds, reduce the risk of forest fires, and increase land use efficiency and economic returns. It is also a potential strategy for producing animal protein in a more sustainable way. Grasses frequently dominate the understory of tropical forest plantations, but support only low stocking rates (Baggio and Schreiner 1988; Schreiner 1988). Leguminous plants can also occur in the understory (Tajuddin 1986; Sophanodora and Tudsri 1991), where they supply forage of high nutritional value and improve nitrogen cycling.

Dense shading has been associated with low dry matter (DM) production in tropical legumes (Andrade et al. 2004; Gobbi et al. 2009). Legumes show a variety of responses to shading. For example, species such as *Lablab purpureus* (Bazill 1987), *Arachis pintoi* (Ferreira et al. 2008), *Clitoria ternatea* and *Calopogonium mucunoides* (Congdon and Addison 2003), *Centrosema pubescens* (now: *C. molle*) (Stür 1991) and *Pueraria phaseoloides* (Wong et al. 1985; Congdon and Addison 2003) are considered shade-tolerant, in contrast to *Aeschynomene villosa* (Congdon and Addison 2003) and *Stylosanthes* spp. (Bazill 1987) that are shade-intolerant. *Alysicarpus vaginalis* has been reported to grow well in moderate shade (Wong et al. 1985).

In general, plant performance is affected by climate (precipitation, temperature, day-length), soils (pH, fertility, texture, drainage) and management regime (grazing, cutting, fertilization) as well as by the degree of shading (Stür 1991). Therefore, species recommended for shaded conditions in the wet tropics may differ from those in the dry tropics (Congdon and Addison 2003).

In the tropics, plant stresses caused by shading in forest understory may be worsened by seasonal drought (Valladares and Niinemets 2008). The interaction of these two factors may be significant, as shown in an experiment with *A. pintoi* cv. Belmonte (Andrade et al. 2004). There, in the rainy season the species produced 59.2 kg DM/ha/d in full sun but only 22.4 kg/ha/d under 70% artificial shade. In the dry season, it produced just 3.2 kg/ha/d under 70% shade (14% of that in rainy season), whereas in full sun its production was 23.0 kg/ha/d. Tolerance of one type of stress may be reduced by another simultaneous source of stress (Valladares and Niinemets 2008). In this case, plant strategies for capturing light more efficiently (i.e. investment in above-ground biomass) and controlling water balance (i.e. investment in root biomass, or senescence) are in conflict. Trees affect soil fertility, microclimate, resource (water, nutrients and light) availability and utilization, and pest and disease incidence (Rao et al. 1998), all factors that may interfere with plant growth.

Although the growth and production potential of leguminous forage plants in shade has been examined in various studies (e.g. Congdon and Addison 2003; Andrade et al. 2004), some of these studies were conducted in pots, with irrigation and artificial shading (Ferreira et al. 2008; Azevedo et al. 2009), and others in irrigated plots (Stür 1991). The objective of our study was to assess the growth, persistence and quality of tropical legumes in the understory of an adult stand of eucalyptus subjected to seasonal drought, with the aim of identifying their potential for forage production under such conditions.

Material and Methods

The experiment was carried out at the Forest Experimental Station of the University of São Paulo in Anhembi, São Paulo state, Brazil (22°40' S, 48°10' W; 455 masl). Climate at the site is Cwa (Köppen), with hot rainy summers and cold dry winters. The dry season extends from April to September. Mean annual rainfall is 1,100 mm, annual water deficit is 25 mm, and mean annual temperature is 20.9 °C. Mean temperatures range from 17.1 °C in the coldest month to 23.7 °C in the hottest month. The soil is a nutrient-poor Typic Hapludox (LVAd – dystrophic Red-Yellow Latosol), composed of 18% clay, 9% silt and 73% sand. Nine herbaceous legume species were selected for the study, based on known shade tolerance and on seed availability, and were distributed in 4 blocks outside the canopy and 4 blocks in the understory of an 8-year-old eucalyptus stand, for a total of 72 plots. The stand of *Eucalyptus grandis* was planted at a spacing of 3 x 2 m and was later thinned to 40% for a final density of 1,000 trees/ha in its 7th year of growth. An area nearby, felled, was used for outside-canopy evaluations, replicating the understory design.

The species were *Aeschynomene villosa* (Australian commercial seed mix “Villomix”), *Alysicarpus vaginalis* ‘common’, *Arachis pintoi* cv. Mandovi, *Calopogonium mucunoides* ‘common’, *Centrosema schiedeanum* (now: *C. pubescens*) cv. Belalto, *Clitoria ternatea* ‘common’, *Lablab purpureus* cv. Rongai, Estilosantes Campo Grande (*Stylosanthes capitata* + *S. macrocephala*) and *Pueraria phaseoloides* ‘common’. *Aeschynomene villosa* and Estilosantes Campo Grande are considered to be fairly shade-intolerant and were included for comparison with species expected to be better adapted to understory conditions. Seeds were inoculated with Rhizobium strains of known effectiveness and sown in December 2008 at a density intended to produce 40 seedlings/m^2. Each plot was 2.5 x 5 m and consisted of 5-m rows at 0.5-m distance. In the understory evaluation, the plots were located between tree lines. The area designed for outside-canopy evaluation was distanced at least 10 m from the trees. Root competition might have occurred to some extent (Sudmeyer et al. 2004).

Soil samples collected at 0−20 cm depth were analyzed according to Raij et al. (2001) and showed the following results: P (extracted by ion-exchange resin), 9 mg/dm^3; organic matter, 20 g/dm^3; pH ($CaCl_2$), 3.7; exchangeable cations in mmol$_c$/dm^3: K, 1.2; Ca, 2; Mg, 1; H+Al, 64; Al, 62; sum of bases, 4; cation exchange capacity, 68; base saturation 6%; Al^{3+} saturation, 94%; and sulfur and microelements, in mg/dm^3: S-SO_4^{2-}, 10; B, 0.49; Cu, 1.0; Fe, 88; Mn, 8.8; and Zn, 0.5. In October 2008 the soil was amended with agricultural lime (3 t/ha) and the following per-plot doses, applied to the planted rows: 80 g KCl, 400 g simple superphosphate (SSP) and 40 g FTE (Fritted Trace Elements) BR15. Based on a subsequent soil analysis in August 2009, 2.4 g boric acid, 40.2 g KCl, 119.6 g SSP and 3,200 g dolomitic limestone (90% effective calcium carbonate) were added to each plot.

Data were collected in the following assessment periods: establishment (December 2008−March 2009, 89 days); 2009 dry season (March−October 2009, 226 days); 2009/10 rainy season (November 2009−May 2010, 182 days); and 2010 dry season (June−October 2010, 150 days). Forage production was assessed on the basis of two 1-m^2 samples per plot for the establishment phase and dry-season periods, and 0.25-m^2 samples in the rainy season. Cutting height was 10 cm above soil surface for *A. villosa*, *A. vaginalis*, *C. ternatea*, *L. purpureus* and Estilosantes Campo Grande, and 5 cm for *A. pintoi*, *C. mucunoides*, *C. schiedeanum* and *P. phaseoloides*. Sampling was done at the end of each of the aforementioned periods and subsequently remaining forage was cut and removed. After oven-drying at 60 ºC until constant weight, samples were analyzed for crude protein (CP) concentration (AOAC 1990) and in vitro dry matter digestibility (IVDMD) (Tilley and Terry 1963). To express forage production, the forage dry matter (DM) accumulation rate (kg/ha/d) was calculated by dividing DM production by the number of days of the respective regrowth period. Ground cover was assessed by 3 independent observers via a subjective scale (0% - no cover; 100% - ground totally covered) at the end of the establishment and the dry-season periods.

Photosynthetically active radiation (PAR) was measured monthly at 8 random points in the outside-canopy plots and at 8 points in the understory plots between 11:00 and 12:00 h with a ceptometer (AccuPAR LP-80, Decagon) read at each point in 4 cardinal directions. Weather data (mean temperature and rainfall) from the Anhembi Forest Experimental Station were used to calculate the 10-day sequential climatological water balance (Thornthwaite and Mather 1955) during the experimental period, considering a soil water holding capacity of 100 mm (Figure 1).

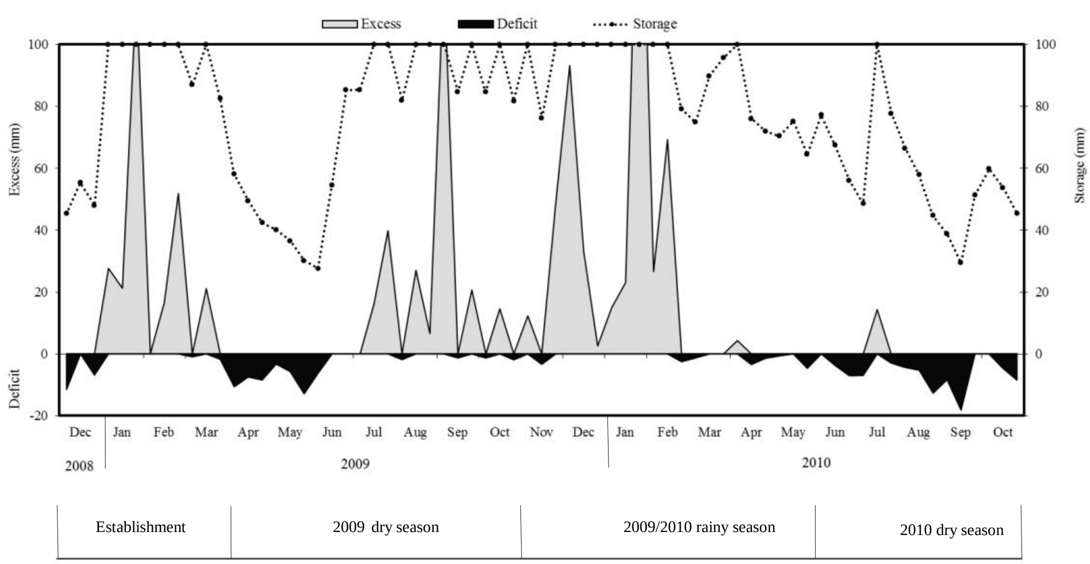

Figure 1. Water balance diagram for the period December 2008−October 2010 at Anhembi, São Paulo, Brazil.

Data analysis for the variables ground cover, DM accumulation rate, CP and IVDMD was performed independently for outside canopy and understory. A complete randomized block design was used with 4 replications, in a split-plot design with the species as plots and the evaluation period as subplot, based on Sampaio (1998), considering the effects of block (b), species (e) and period (p) according to the model:

$Y_{ijk} = \mu + b_i + e_j + (b*e)_{ij} + p_k + (p*e)_{kj} + error_{ijk}$
where: i=1,…,4 ; j=1,…,9 ; and k=1,…,4.

The interaction (b*e) compounds the error to test the effects of block and species.

Ground cover, DM accumulation rate, CP and IVDMD data were subjected to analysis of variance using the GLM procedure (SAS 9.1, SAS Institute, Cary, NC, USA). For multiple comparisons of means and interactions, LSMEANS was adopted, with significance of 5%.

Results

PAR incidence in understory plots was, on average, 18% of radiation in full sun (231 vs. 1,279 $\mu mol/m^2/s$). DM accumulation rate was low in the understory (Table 1) and in 20 of 36 observations, forage accumulation rates of <1 kg/ha/d were recorded. Only *L. purpureus* in the establishment period and Estilosantes Campo Grande in the rainy season yielded >5 kg/ha/d. Relative DM production (= production in understory relative to production outside canopy; calculations not presented) of DM was low and did not reach 40%.

Ground cover was <50% in 17 of the 27 observations made in understory (Table 2), including all assessments of *A. vaginalis*, *A. villosa* and Estilosantes Campo Grande. *Centrosema schiedeanum* cover exceeded 70% in all outside-canopy and in-understory observations. Although *A. pintoi* was slow to establish, it remained at 53% cover in understory at the end of the 2010 dry season, exceeding all except *C. schiedeanum* (P<0.05).

Table 1. Dry matter accumulation rate (kg/ha/d) in understory and outside canopy at the end of 4 assessment periods: establishment (89 days), 2009 dry season (226 days), 2009/10 rainy season (182 days) and 2010 dry season (150 days).

Species	Understory				Outside canopy			
	Establishment	2009 Dry	2009/10 Rainy	2010 Dry	Establishment	2009 Dry	2009/10 Rainy	2010 Dry
Lablab purpureus	12.1a[1]	2.2ab	0.9def	0.0b	35.5a	5.3d	11.2cd	0.0b
Centrosema schiedeanum	3.2b	3.3a	1.3cde	1.2a	9.1d	11.9bc	11.7cd	8.9a
Clitoria ternatea	2.1c	0.3de	2.3c	0.0b	11.2d	2.8d	21.4b	0.4b
Pueraria phaseoloides	0.0d	1.7bc	3.1b	0.2ab	2.6ef	12.6b	17.1bc	6.7a
Alysicarpus vaginalis	0.0d	0.0e	0.0f	0.0b	19.0c	0.0d	15.1bc	0.0b
Aeschynomene villosa	0.7d	0.3de	0.3ef	0.0b	6.8de	5.3d	19.5b	0.0b
Estilosantes Campo Grande	0.0d	1.6bc	5.3a	0.2ab	0.0f	21.5a	46.0a	5.3ab
Calopogonium mucunoides	2.5bc	0.7cde	1.5cd	0.0b	25.0b	3.4d	8.1d	0.2b
Arachis pintoi	0.9d	1.1cd	2.2c	0.4ab	0.3ef	5.8cd	9.3d	3.3ab

[1]Means within sites and columns followed by the same letter are not significantly different (P>0.05).

Table 2. Ground cover (%) in understory and outside canopy at the end of 3 assessment periods: establishment (89 days), 2009 dry season (226 days) and 2010 dry season (150 days).

Species	Understory			Outside canopy		
	Establishment	2009 Dry	2010 Dry	Establishment	2009 Dry	2010 Dry
Lablab purpureus	97.5a[1]	75.8b	0.0c	100.0a	72.5b	0.7c
Centrosema schiedeanum	73.3b	97.8a	85.7a	72.5b	100.0a	99.9a
Clitoria ternatea	59.6c	15.6d	1.9c	73.8b	72.9b	14.8c
Pueraria phaseoloides	29.3ef	73.2b	6.5c	33.3d	100.0a	95.2a
Alysicarpus vaginalis	17.5fg	0.3e	0.0c	75.0b	18.0c	8.5c
Aeschynomene villosa	42.1d	18.2d	0.0c	54.4c	71.5b	4.6c
Estilosantes Campo Grande	0.9g	36.7c	7.4c	7.9e	88.2ab	76.0b
Calopogonium mucunoides	59.2c	31.1c	0.0c	94.2a	75.8b	11.2c
Arachis pintoi	33.3de	91.1a	53.3b	15.4de	79.6b	98.9a

[1]Means within sites and columns followed by the same letter are not significantly different (P>0.05).

CP concentrations varied from 12.8 to 30.5% in legumes grown in the understory and from 8.2 to 27.5% in those grown outside the canopy (Table 3). The difference, in favor of in-understory plants, ranged between 5 and 20% between sites.

IVDMD varied from 42.3 to 69.4% in legumes grown in the understory and from 26.3 to 70.1% in those grown outside canopy (Table 4). There were no consistent differences between the 2 sites. *Alysicarpus vaginalis*, which exhibited the lowest digestibility, did not persist in the understory. *Lablab purpureus* (47.2−62.5%) and *A. pintoi* (58.2−70.1%) had the highest digestibility values (P<0.05) overall.

Discussion

Eucalyptus grandis intercepted 82% of incident radiation, even without a fully closed canopy. This degree of shading is similar to that found in adult rubber plantations in Southeast Asia (Chong et al. 1997).

Forage production and cover

In the establishment phase, *L. purpureus* produced 12.1 kg/ha/d and achieved 97.5% cover, producing the best results in understory. Relative DM production of this species (34%) was similar to that reported for the most productive tropical legumes (25.7−38.5% for the seasonally dry tropics) under 84% artificial shade (Congdon and Addison 2003). The species' quick establishment may be related to the large size of its seeds (Kolawolea and Kangab 1997). While it helps control weeds and protect the soil, *L. purpureus* did not regenerate to maintain its impressive early performance. As 2009 was an exceptionally wet year (Figure 1), with 666 mm of rainfall between April and October, the low production observed in *L. purpureus* was not due to drought stress but was probably related to the low cutting height adopted, and mainly to the species' life cycle as a short-lived herb (Aganga and Tshwenyane 2003).

Table 3. Crude protein (% dry matter) concentration in understory and outside canopy at the end of 4 assessment periods: establishment (89 days), 2009 dry season (226 days), 2009/10 rainy season (182 days) and 2010 dry season (150 days).

Species	Understory				Outside canopy			
	Establishment	2009 Dry	2009/10 Rainy	2010 Dry	Establishment	2009 Dry	2009/10 Rainy	2010 Dry
Lablab purpureus	20.8c[1]	20.1bc	22.0ab	-	15.4c	19.3d	14.4c	-
Centrosema schiedeanum	26.4ab	22.9ab	24.7a	28.4a	22.0a	26.1a	23.2a	25.6ab
Clitoria ternatea	27.8a	24.4a	16.2c	-	24.4a	25.2ab	14.1c	27.5a
Pueraria phaseoloides	-	21.3ab	18.8bc	22.5b	18.3bc	18.9d	20.3ab	21.8c
Alysicarpus vaginalis	-	-	-	-	17.3bc	-	8.2d	-
Aeschynomene villosa	30.5a	22.1ab	15.8cd	-	22.9a	15.5e	13.6c	-
Estilosantes Campo Grande	-	17.8c	12.8d	18.2b	-	14.8f	11.7c	17.6d
Calopogonium mucunoides	22.7c	21.4ab	20.9b	-	18.4b	22.4bc	19.5b	17.4d
Arachis pintoi	23.2bc	20.9bc	16.5c	27.2a	-	20.1cd	14.6c	25.6ab

[1]Means within sites and columns followed by the same letter are not significantly different (P>0.05).

Table 4. In vitro dry matter digestibility (% dry matter) in understory and outside canopy at the end of 4 assessment periods: establishment (89 days), 2009 dry season (226 days), 2009/2010 rainy season (182 days) and 2010 dry season (150 days).

Species	Understory				Outside canopy			
	Establishment	2009 Dry	2009/2010 Rainy	2010 Dry	Establishment	2009 Dry	2009/2010 Rainy	2010 Dry
Lablab purpureus	62.0b[1]	60.8ab	59.7a	-	62.5a	55.0ab	47.2bc	-
Centrosema schiedeanum	54.2c	48.4c	48.3b	56.0b	56.1a	38.9c	45.3bc	48.3cd
Clitoria ternatea	62.1ab	59.5ab	48.4b	-	60.9a	54.4ab	39.8c	58.1b
Pueraria phaseoloides	-	50.1c	52.6b	56.5b	53.9a	50.9b	53.1ab	55.7bc
Alysicarpus vaginalis	-	-	-	-	59.5a	-	26.3d	-
Aeschynomene villosa	69.4a	60.7ab	47.5bc	-	59.5a	36.4c	42.5c	-
Estilosantes Campo Grande	-	58.1b	51.3b	56.0b	-	48.1b	41.7c	53.9bc
Calopogonium mucunoides	50.5c	44.4c	42.3c	-	49.0b	37.7c	40.0c	38.8d
Arachis pintoi	65.1ab	64.1a	59.6a	69.0a	-	61.5a	58.2a	70.1a

[1]Means within sites and columns followed by the same letter are not significantly different (P>0.05).

The second highest production observed throughout the evaluation in understory was 5.3 kg/ha/d by Estilosantes Campo Grande. This rate of herbage accumulation, however, could support just 0.29 animal units (AU)/ha/yr, assuming that 1 AU = 450 kg live weight (LW), DM consumption = 2% of LW, and grazing efficiency = 50%. A low carrying capacity in understory has also been reported for mature rubber plantations in Southeast Asia planted with *Calopogonium caeruleum* and *Pueraria phaseoloides* (Chong et al. 1997). The highest carrying capacity in that study was 2 sheep/ha, with a LW gain of 100 g/hd/d; forage availability ranged from 200 to 800 kg/ha, which compares well with the yields observed in our study. Even considering the low productivity of the legumes, it might be expected that the large potential for animal production under the vast areas of forest plantations would increase the interest in high quality forages. However, under Brazilian conditions, plantation owners are mainly interested in tree production and prefer a maximum number of trees to achieve high timber yields rather than improve light conditions for understory forage production.

Tropical C4 plants need more light for photosynthesis than C3 plants, owing to the greater energetic cost of their CO_2-concentrating apparatus (Sage and McKown 2006). Some C4 plant species, however, can adapt to shaded environments given their phenotypic plasticity. Studies conducted in Brazil have shown that some tropical grasses (mostly C4) maintained vigorous growth rates and moderate production even in heavy shade: in the Cerrado biome between January and May (under 442 mm of total rainfall), *Panicum maximum* (now: *Megathyrsus maximus*) cv. Tanzânia, produced between 7 and 25 kg/ha/d in the understory of a 5.4-year-old *Eucalyptus urophylla* stand, which intercepted 68% of incident light (Andrade et al. 2001). In the wet tropics *Urochloa brizantha* cv. Marandu produced 37 kg/ha/d in the rainy season under a mature rubber plantation (Costa et al. 1999) and *U. decumbens* cv. Basilisk grown in 70% artificial shade produced between 24 and 64 kg/ha/d over 3 harvests, while the legume *Arachis pintoi* cv. Amarillo produced 16 and 21 kg/ha/d over 2 harvests (Gobbi et al. 2009). These results reflect the greater yield potential of grasses for grazing under heavy shade, compared with leguminous forages. The latter, however, could play a significant role for livestock production in forest plantations owing to their superior nutritive value.

The ground cover produced by *C. schiedeanum* in this study (Table 2) corroborates the potential of *Centrosema* spp. as cover crops in plantations of perennial tree species (Chee and Wong 1990). This species developed rapidly and showed a high capacity for ground cover as well as persistence under cutting. It maintained >70% ground cover throughout in both understory and outside the canopy. At the end of the 2010 dry season, ground cover was 86% in understory and 100% outside the canopy, higher than that of any of the other legumes tested ($P<0.05$). Stür (1991) ranked *Centrosema pubescens*, a closely related species (now: *C. molle*), among the 13 most productive of 84 legumes studied in irrigated plots under 80% artificial shade. Although *Centrosema* species are climbing vines that could smother small trees (Congdon and Addison 2003), such behavior was not observed in our study.

DM production of *A. pintoi* was low, varying from 0.4 to 2.2 kg/ha/d in understory. Andrade et al. (2004) reported that shade-tolerant species such as *A. pintoi* can maintain similar DM production in sunlight and under low to moderate shade (up to 30−50%), while Stür (1991) found that production was not maintained in heavy shade (i.e. 80%). Andrade and Valentim (1999) reported that *A. pintoi* BRA-031143 persisted when 70% of incident light was intercepted, but DM production decreased markedly as increasing levels of shading were imposed. In the Amazonian state of Acre, Brazil, with mean annual rainfall of 1,900 mm and a marked dry season, *A. pintoi* cv. Belmonte produced 22.4 kg/ha/d in the rainy season and 3.2 kg/ha/d in the dry season under 70% shade (Andrade et al. 2004), which highlights the association of shading and dry season stress. Part of the difference in performance between that study and ours may be attributable to the high temperatures in Acre and the use of artificial shade, which minimizes competition with trees for water and nutrients and reduces evapotranspiration (Andrade et al. 2004). Despite its low yields and slow establishment *A. pintoi* proved capable of providing moderate to high levels of ground cover, remaining at 53% at the end of the experiment (Table 2). This supports the findings of Congdon and Addison (2003) that this species presents high potential as a soil cover crop. In comparison, the other species tested (except *C. schiedeanum*) achieved <10% ground cover at the end of the study.

Although Estilosantes Campo Grande produced up to 46 kg/ha/d outside canopy, it developed slowly, having covered <10% of ground surface (Table 2) at the end of the establishment phase. Mostly, it showed low DM production and ground cover (Tables 1 and 2) in the understory. These results are in contrast with those of Azevedo et al. (2009) who grew Estilosantes Campo Grande in irrigated pots under 75% artificial shade; he made a single harvest and found DM yield was greater under deep shade than in full sun. Differences in moisture availability in the two situations might explain the difference.

All 4 species of *Stylosanthes* tested by Bazill (1987) showed poor adaptation to shade provided by a *Pinus caribaea* forest in Costa Rica. However, adaptation to shade varies with species and accessions (Stür 1991), and Estilosantes Campo Grande produced 5.3 kg/ha/d at the end of the 2009/10 rainy season, more than any other species ($P<0.05$).

Nutritive value

The nutritive value of forages is often expressed in terms of their crude protein (CP) concentration and digestibility; both are closely associated with DM consumption. Low CP concentration (<7%) decreases rumen fermentation and microbial synthesis of protein, slowing rate of passage of digesta and limiting DM intake (Minson 1990). Low digestibility limits the intake potential and energy availability of forage crops for animal production (Jung and Allen 1995). Legumes show higher CP concentration and more stable year-round values than grasses (Barcellos et al. 2008).

Crude protein. In our study, all species but one (*C. mucunoides*) presented particularly high CP values at the end of the 2010 dry season (Table 3), due to reasons we cannot ascertain. CP concentrations of the legumes we studied are close to those reported in the literature (Minson and Wilson 1980; Araujo Filho et al. 1994; Costa et al. 2009; Heinritz et al. 2012) with the exception of *A. vaginalis*, which showed a very low value after 180 days of rainy season growth (Table 3). This is probably a reflection of the early maturity of *A. vaginalis*, which seeded abundantly during the wet season, and disappeared in the subsequent dry season (Table 1). The decrease in the CP concentration of this species may reflect the development of fibrous structures as the plants matured and reproduction proceeded.

In the present study, CP values at the understory site were 5−20% higher than outside the canopy. This confirms reports in the literature (Lin et al. 2001; Congdon and Addison 2003) that protein concentrations are higher in shade-grown legumes, which can be attributed to increased rates of mineralization, litter degradation, and nitrogen cycling in the wetter, cooler conditions of a forest understory. In this context, fast decomposing legume litter may play an important role, particularly in plantations of *Eucalyptus* trees whose litter is known to decompose slowly for several reasons, among them a high C:N ratio (Balieiro et al. 2004). Microbial decomposition demands N; hence this activity may benefit from higher foliar N content of associated legumes (Forrester et al. 2006). As an example, Balieiro et al. (2004) studied litter decomposition in a mixed stand of the leguminous tree *Pseudosamanea guachapele* and *Eucalyptus grandis*. They reported an 11% increase in soil N deposition by the leguminous tree, associated with a shorter litter residence time (23%) than in eucalyptus, and increased N mineralization.

Digestibility. IVDMD values in understory were 51.2−59.8 % (Table 4), similar to those reported in the literature for *L. purpureus* (Aganga and Tshwenyane 2003), *C. ternatea* (Minson and Wilson 1980) and *P. phaseoloides* (Abaunza et al. 1991). No information on IVDMD values was found for *A. villosa* and Estilosantes Campo Grande. For *C. pubescens* (closely related to *C. schiedeanum*), Abaunza et al. (1991) reported an IVDMD of 52.2%, while Minson and Wilson (1980) reported 60−70% for *A. pintoi*. In our experiment, similar values were found for these species 89 days after planting, while values for *A. vaginalis* and *C. mucunoides* were lower. The low digestibility of *C. mucunoides* has been attributed to its dense epidermal hairs (Minson and Wilson 1980). *Alysicarpus vaginalis* was poorly adapted to the conditions of the experimental site and its quick maturation may have contributed to low IVDMD.

General considerations and research needs

The low DM production obtained by the legumes in this experiment should not be considered the only criterion in assessing their potential usefulness in forest plantations. Even at low animal stocking rates the better-adapted species may provide additional income when applied over large areas. Other potential benefits of legumes include faster decomposition of litter (see discussion above), reduction of forest fire risk, erosion and weed control, and nitrogen fixation for improved growth of the tree component in a silvopastoral system.

Among the research topics that could be suggested as a result of this study, 2 are highlighted:

(1) Studies of genetic variation within a species may permit the identification of genotypes that are adapted to heavy shade, even in species that this study found to be poorly adapted to such conditions.

(2) Similar to the common practice in SE Asian rubber and oil palm plantations (Jalani et al. 1998) of sowing

mixtures of cover legume species primarily for weed control (e.g. *Pueraria phaseoloides* + *Centrosema pubescens* (now: *C. molle*) + *Calopogonium mucunoides* + *Calopogonium caeruleum)*, the potential of species mixtures for understory livestock production should be researched. The benefit of such mixtures is due to increased diversity with potential substitutory and/or complementary effects. In the case of the legumes tested in this study, a mixture of *L. purpureus* and *C. schiedeanum* may provide a useful understory pasture. The inclusion of shade-tolerant tropical grasses could bring further benefits.

Conclusions

Three of the species tested show potential for use as understory forage legumes in forestry plantations: *Lablab purpureus* establishes quickly and has high initial DM production both outside canopy and in understory; however, being an annual, it does not persist and must be replanted. *Centrosema schiedeanum* shows rapid development, a high capacity for ground cover, and good persistence, and can also protect soils in tree plantations. While *Arachis pintoi* was slow to establish, it is capable of providing moderate to high ground cover in the understory subject to seasonal drought. These legumes can all increase the nutritive value of plantation understory vegetation for grazing, even though their DM production was comparatively low.

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