Compatibility, persistence and productivity of grass–legume mixtures in the humid tropics of Costa Rica. 1. Dry matter yield, nitrogen yield and botanical composition

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Abstract

Dry matter (DM) yields and botanical composition of mixtures of *Centrosema macrocarpum*, *Stylosanthes guianensis* and *Arachis pintoi* with *Brachiaria humidicola* and *B. brizantha* were measured over 2.5 years of rotational grazing at 1.75 (LSR) and 3.0 (HSR) AU/ha in the humid Atlantic Zone of Costa Rica.

The legumes *C. macrocarpum* and *S. guianensis* virtually disappeared from the mixtures before the end of the experiment, whereas *A. pintoi* persisted well, especially at the high stocking rate in association with *B. humidicola.*

Mean monthly DM yields of mixtures exceeded 4 t/ha, but yields decreased significantly during the months of lower rainfall. At the low stocking rate, *B. brizantha* yielded more than 5 t/ha. *A. pintoi* formed a stable mixture with *B. brizantha*. The percentage of *A. pintoi* was higher with *B. humidicola* and this grass was practically eliminated in the mixture and replaced by weeds.

At the end of the experiment, *A. pintoi* represented 26% of total DM with *B. brizantha* at the high stocking rate. N yields of mixtures of *A. pintoi* were higher than those of stylo and centro. It was concluded that *A. pintoi* is the most grazing-tolerant legume of those tested for the humid tropics.

Introduction

Legume-based pastures offer a good option for sustainable forage production in the humid tropics of Costa Rica. Grazing studies conducted in Costa Rica showed that a mixture of *Brachiaria brizantha* and *Arachis pintoi* produced 937 kg LW/ha/yr (Hernandez *et al.* 1995) which is 3–4-fold that reported on native pastures (Toledo 1994; Jansen *et al.* 1997). However, some of the major difficulties in promoting grass–legume mixtures in the humid tropics have been identifying legumes which are adapted to the prevailing environmental conditions, compatible with aggressive grass species and able to withstand heavy grazing. *Brachiaria* species are used commonly in the humid tropics, but are vigorous and strongly tillering and tend to suppress associated legumes (McIvor 1978; Schultze-Kraft and Teitzel 1992a, 1992b).

Twining (*e.g. Centrosema* spp., *Neonotonia wightii, Pueraria phaseoloides*) (Davison and Brown 1985; Jones and Clements 1987; Hurtado 1988) and erect (*e.g. Stylosanthes guianensis*) tropical pasture legumes rarely persist under year-round stocking rates exceeding 2.5 beasts/ha (Humphreys 1980). Farmers are unlikely to accept such low stocking rates, because of the investments incurred for establishing grass–legume mixtures and the potential dry matter (DM) yields that can be obtained in humid regions. Therefore, superior performance of legumes in humid regions is necessary for farmers to use them.

Sustainable production of grass–legume mixtures also depends on the amount of N fixed by the legume. Some authors noted that there was a good relationship between the amount of N fixed and DM production of legumes (Othman and Asher 1987). However, cyclic variations in grass–legume balance have been linked to N accretion by the legume (Humphreys 1991).

The CIAT (Colombia) Pasture Program in the Atlantic Zone of Costa Rica has identified various legumes (Roig 1989) and grasses (Vallejos 1988) with good potential for pasture improvement on moderately to well drained soils. However, the performance of these species in legume–grass associations under grazing has not been evaluated

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extensively. Hence, the main objective of this study was to identify compatible grass–legume mixtures that can withstand heavy grazing for the humid tropics of Costa Rica.

This study investigated the effects of legume and grass species and of stocking rate on DM and N yields, botanical composition, legume persistence, nutritive value and animal production of grass–legume mixtures under grazing. An earlier paper (Hernandez *et al.* 1995) reported on animal production in a different grazing experiment with *Brachiaria brizantha* and *Arachis pintoi* conducted under similar conditions. This paper deals with DM and N yields and botanical composition, and subsequent papers in the series will report on legume persistence mechanisms and nutritive value of the grass–legume mixtures.

Materials and methods

Site and climate

The experiment was conducted between September 1989 and November 1992 at the "Los Diamantes" research station at Guápiles (10°13'N, 83°47'W; 250 m elevation) in the Atlantic Zone of Costa Rica. The soil is a well drained loamy Eutric Hapludand or Umbric Andosol, of medium–high fertility (Wielemaker and Oosterom 1990). Soil pH (H_20) range is 5.7–5.9 and available phosphorus (Olsen) between 6–8 ppm. There are no known major or trace mineral nutrient deficiencies for legume and grass growth. Mean annual rainfall is 4332 mm, which is well distributed throughout the year, except for a short drier period between December and April, when average monthly rainfall is 100–200 mm (Figure 1). The mean daily temperature is 24.6°C, with relatively small diurnal and annual variation.

Design

The treatments consisted of a factorial (3x2x2) of 3 legumes of contrasting growth habit [*Centrosema macrocarpum* (centro) CIAT 5713; *Stylosanthes guianensis* (stylo) CIAT 184; and *Arachis pintoi* (pintoi) CIAT 17434], 2 grasses of different morphology [*Brachiaria brizantha* (brizantha) CIAT 6780; and *B. humidicola* (humidicola) CIAT 6339], and 2 stocking rates [1.75 (LSR) and 3.0 (HSR) AU/ha]. In this experiment, one animal unit (AU) is defined as an animal of 400 kg LW. The species have been described in Mannetje and Jones (1992). There were 2 replicates for each treatment.

Pasture establishment and grazing

The grass–legume mixtures were established during September 1989. Intensive cultivation was necessary since the land was previously dominated with a dense stand of the strongly rhizomatous weed, *Paspalum fasciculatum,* locally known as "gamalote". The grasses were established by planting small bunches of tillers on a 1.0 × 0.5 m grid. The legumes stylo and centro were sown between the grasses, at seeding rates of 3 and 5 kg/ha, respectively, and pintoi was planted vegetatively by working 1 t/ha of stolons

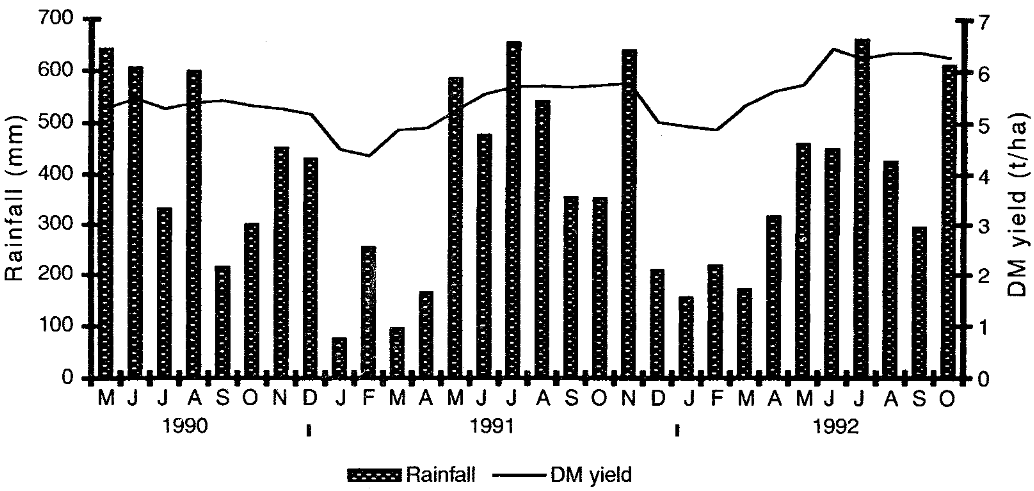

Figure 1. Mean monthly rainfall and available DM yields (t/ha) of the grass-legume mixtures during the study.

into the soil between grass rows. All species established well, except for stylo, which was replanted once in January–February 1990. At planting, 15 kg/ha P was applied as triple superphosphate, but no further fertiliser application was made during the experiment.

Pre-trial grazing with steers (250–320 kg LW) began in January 1990, with a 4 d grazing–24 d rest cycle. Experimental data were collected from May 1990 except for stylo plots, where data collection began in July 1990. Experimental grazing commenced in July 1990 with a 4 d grazing–30 d rest cycle because of slow recovery of *Brachiaria brizantha* under the 24 d rest cycle. Each of the 24 plots was grazed separately and simultaneously.

Measurements

Data collection for DM yield and botanical composition began in May 1990 for pintoi and centro mixtures and in July 1990 for stylo mixtures. Measurements were made before and after each grazing cycle. Botanical composition was determined by the dry weight (DW) rank method (Mannetje and Haydock 1963; Jones and Hargreaves 1979), taking 60 samples per plot. Forage dry matter yield (DM) on offer was estimated by the comparative yield method of Haydock and Shaw (1975) also taking 60 samples per plot. Annual DM yields were estimated assuming linear growth rates during the grazing period.

Samples of legumes and grasses were taken before each grazing cycle and analysed for N concentration (Kjeldahl). N yields of legumes and grasses were calculated as the product of DM yield and N concentration.

Statistical analysis

After having shown homogeneity of variance for each grazing cycle (28–34 d), the data on DM yield and botanical composition were analysed for a split plot design, with treatments being assigned to main plots and cycles to sub-plots. Least significant difference (LSD) and Duncan's multiple range test were used to test differences between treatment means.

DW percentage of centro and stylo was low in mixtures with brizantha. Therefore, the data on N yield were pooled across grasses and SRs, and a regression analysis was carried out to describe the relationship between N yield (y) and DM yield of legumes (x).

Results

Dry matter yield before grazing

Mean total DM yields were above 4 t/ha in all grazing months, although they significantly ($P < 0.01$) decreased in the dry period (November – April) (Figure 1). However, there was not a high correlation between mean DM yield and monthly rainfall ($r = 0.51$).

Mean DM yields were significantly ($P < 0.001$) lower at 3.0 than at 1.75 AU/ha and mixtures with brizantha had significantly ($P < 0.001$) higher DM yields than those with humidicola (Table 1). Legume species had no significant effect on DM yields in the brizantha associations, but with humidicola, mean DM on offer in the centro association was significantly ($P < 0.01$) lower than in the other mixtures. In the last 6 grazing months, there was a dramatic (> 125%) increase in available DM in the humidicola+pintoi mixture at the HSR. This was due to a sudden increase in *P. fasciculatum* (Table 3; Figure 2).

Table 1. Half-yearly mean total dry matter yields (t/ha) per cycle measured in mixtures of *B. brizantha (Bb)* and *B. humidicola (Bh)* with *A. pintoi*, *C. macrocarpum* and *S. guianensis* grazed at two stocking rates (LSR = 1.75 AU/ha; HSR = 3.0 AU/ha).

	LSR		HSR	
	Bb	*Bh*	*Bb*	*Bh*
+ *A. pintoi*				
May 90–Oct 90	6.9ab[1]	6.2ab	4.7a	4.2b
Nov 90–Apr 91	6.3b	5.5b	4.2a	3.6bc
May 91–Oct 91	7.6a	5.6b	5.2a	3.4bc
Nov 91–Apr 92	6.8ab	5.3b	4.7a	3.0c
May 92–Oct 92	7.5a	7.0a	5.3a	6.9a
Mean	7.0	5.9	4.8	4.2
+ *C. macrocarpum*				
May 90–Oct 90	7.0ab	4.3bc	5.1a	3.4a
Nov 90–Apr 91	6.3b	3.8c	4.6a	3.0a
May 91–Oct 91	7.8a	5.5a	5.5a	3.9a
Nov 91–Apr 92	7.1ab	5.0ab	5.3a	3.5a
May 92–Oct 92	7.8a	5.9a	5.6a	4.1a
Mean	7.2	4.9	5.2	3.6
+ *S. guianensis*				
[2]July 90–Oct 90	7.1ab	4.6b	5.2ab	3.9a
Nov 90–Apr 91	6.4b	4.3b	4.5b	3.7a
May 91–Oct 91	7.7a	6.0a	5.7a	4.4a
Nov 91–Apr 92	6.9ab	5.7ab	5.2ab	3.9a
May 92–Oct 92	7.8a	6.7a	5.6a	4.6a
Mean	7.2	5.5	5.2	4.1
Mean of SR ($LSD_{.05}$ = 1.6)	6.3		4.5	

Mean of grasses over SR and legumes:
B. brizantha 6.1 *B. humidcola* 4.7

[1]Means followed by different letters are significantly different ($P < 0.05$).
[2]Observations on stylo mixture did not commence until July 1990.

Annual DM yield and botanical composition

Mean annual DM yield averaged 22.5 t/ha over all treatments (Table 2). Annual DM yield at the LSR was 45% ($P < 0.01$) higher than that at the HSR, and that of brizantha mixtures was 25% ($P < 0.05$) higher than that of humidicola. With brizantha, there was no significant effect of legume species on mean total annual DM yield; however, in the humidicola treatments, mixtures with centro gave significantly ($P < 0.01$) lower yields than those with pintoi and stylo.

DM yields of pintoi were significantly ($P < 0.001$) higher at the HSR and in mixtures with humidicola compared with those with brizantha (Table 2). In general, annual DM yields of centro and stylo were low except for stylo with humidicola at the LSR.

Between May 1990 and October 1992, significant ($P < 0.001$) changes occurred in the botanical composition of DM on offer (Table 3).

Brizantha maintained higher DW percentages than humidicola in all treatments. In 1992, volunteer species, mainly *P. fasciculatum* and *Mimosa pudica*, invaded humidicola mixtures, while brizantha mixtures contained only a minor proportion of volunteer species. The persistence of the legumes was affected by associated grass species as well as by SR. Centro and stylo performed well only in the first year and only in association with humidicola. Centro had virtually disappeared by the second year in all treatments, whereas stylo persisted to some extent only with humidicola at the LSR (Table 3).

Table 2. Mean annual dry matter yield (t/ha) of the sown grass and legume and volunteer spp. estimated from *B. humidicola (Bh)* and *B. brizantha (Bb)* associations with *A. pintoi*, *C. macrocarpum* and *S. guianensis* grazed at 2 stocking rates (LSR = 1.75 AU/ha; HSR = 3.0 AU/ha).

	LSR		HSR	
	Bb	*Bh*	*Bb*	*Bh*
+ Arachis pintoi				
Sown grass	25.7	16.2	15.6	6.0
Sown legume	2.7	5.6	4.9	6.8
Volunteer spp.	0.9	4.6	1.2	5.0
Total	29.3	26.4	21.7	17.8
+ Centrosema macrocarpum				
Sown grass	27.1	2.1	18.5	5.7
Sown legume	0.3	1.8	0.4	1.8
Volunteer spp.	2.6	15.6	1.1	7.9
Total	30.0	19.5	20.0	15.4
+ Stylosanthes guianensis				
Sown grass	28.0	16.5	17.7	12.4
Sown legume	0.4	4.8	0.5	1.6
Volunteer spp.	0.9	3.8	1.4	1.6
Total	29.3	25.1	19.6	15.6

Mean total DM of SR over grasses and legumes (t/ha)		Mean total DM of grasses over legumes and SR (t/ha)	
LSR	26.6	*Bb*	25.0
HSR	18.3	*Bh*	20.0
LSD ($P < 0.05$)	4.3		3.6

Table 3. Half-yearly mean dry weight percentages of associated grass (G) and legume (L) and volunteer species (V) in the mixtures managed at two stocking rates (1.75 and 3.0 AU/ha).

	Low stocking rate						High stocking rate					
	B. brizantha			*B. humidicola*			*B. brizantha*			*B. humidicola*		
	G	L	V	G	L	V	G	L	V	G	L	V
+ A. pintoi												
May 90–Apr 91	84.9	12.3	2.8	87.9	10.8	1.3	80.4	16.5	3.1	76.1	20.7	3.2
May 91–Apr 92	88.1	9.1	2.8	59.9	30.4	9.7	74.7	18.4	6.9	28.1	58.4	13.5
May 92–Oct 92	81.8	10.9	7.3	36.3	19.4	44.3	62.3	25.1	12.6	4.7	20.2	75.1
Mean	84.9	10.8	4.3	61.4	20.2	18.4	72.5	20.0	7.5	36.3	33.1	30.6
+ C. macrocarpum												
May 90–Apr 91	94.6	1.5	3.9	26.1	28.8	45.1	92.1	3.6	4.3	37.4	31.7	30.9
May 91–Apr 92	88.9	0.3	10.8	4.8	1.1	94.1	92.7	1.1	6.2	37.3	2.6	60.1
May 92–Oct 92	83.9	0.2	15.9	2.6	0.3	97.1	92.7	0.4	6.9	30.7	1.7	67.6
Mean	89.1	0.7	10.2	11.2	10.1	78.8	92.5	1.7	5.8	35.1	12.0	52.9
+ S. guianensis												
July 90–Apr 91	92.1	5.7	2.2	54.9	38.3	6.8	87.2	8.1	4.7	69.7	25.2	5.1
May 91–Apr 92	96.8	0.1	3.1	69.8	10.4	19.8	91.5	0.3	8.2	73.0	3.5	23.5
May 92–Oct 92	97.8	0.1	2.1	64.6	4.3	31.1	90.8	0.2	9.0	58.7	1.5	39.8
Mean	95.6	2.0	2.5	63.1	17.7	19.2	89.8	2.9	7.3	67.1	10.1	22.8

Mean of SR over grasses and legumes	G	L	V	Mean of grasses over SR and legumes	G	L	V
LSR	67.5	10.2	22.2	*B. brizantha*	87.4	6.3	6.3
HSR	65.5	13.3	21.1	*B. humidicola*	45.7	17.2	37.1
LSD ($P < 0.05$)	ns	ns	ns	LSD ($P < 0.05$)	7.7	6.7	5.3

At the end of grazing, centro and stylo represented less than 5% of total pasture on offer (Figure 2). In contrast, pintoi was persistent at both stocking rates. In the second year of grazing, the amount of pintoi in humidicola swards increased dramatically so that it represented more than 70% of forage on offer at the high SR (Figure 2). However, this dominance of pintoi was not sustained. On the other hand, pintoi was more stable in the brizantha mixture; at the HSR, it increased significantly ($P < 0.01$) over the 2.5 years of grazing (Figure 2). At the end of grazing, pintoi represented 26% of total forage on offer in the mixture with brizantha at the HSR, but only 9% at the LSR. Centro and stylo yields with brizantha were insignificant and are not shown in Figure 2.

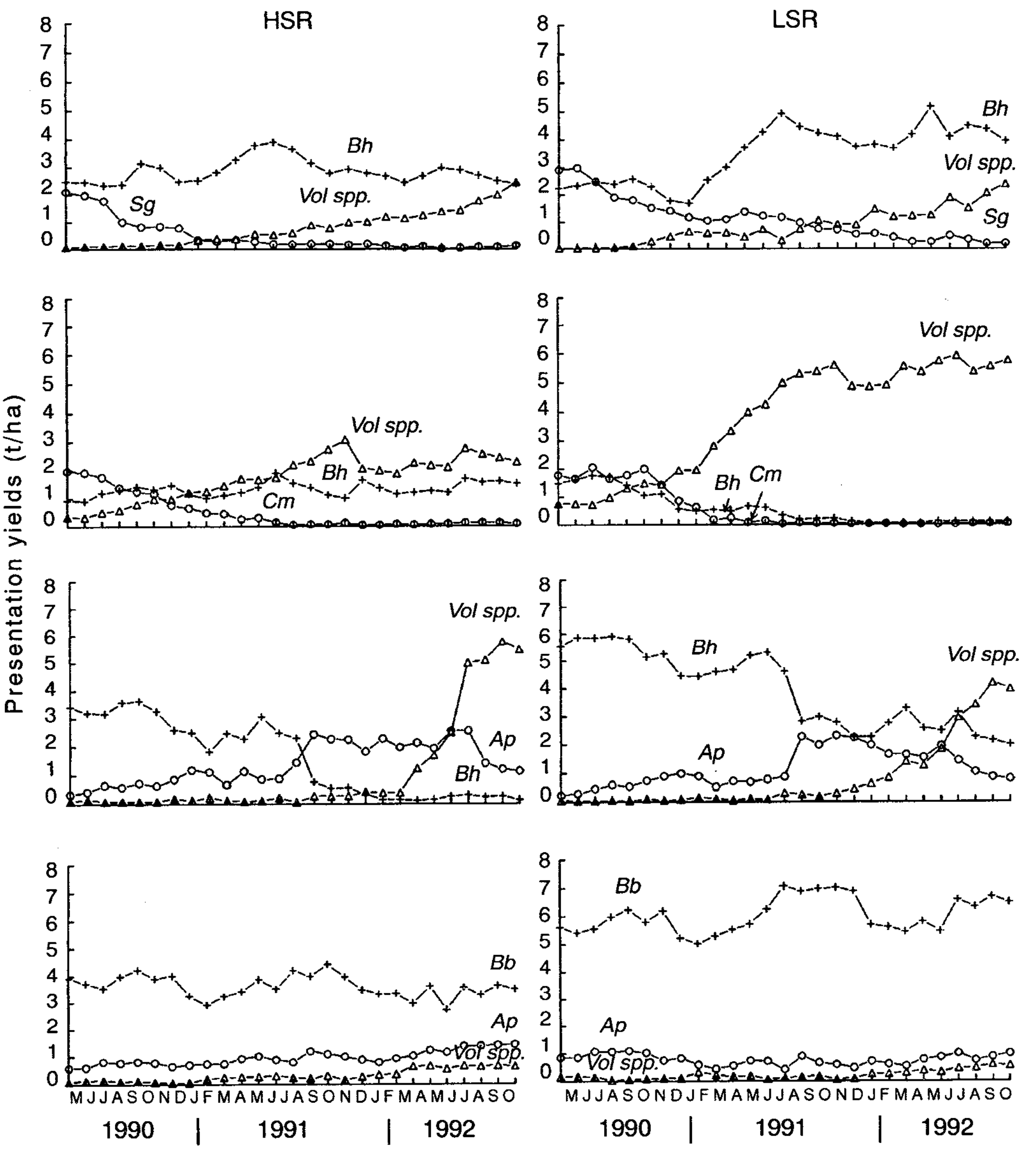

Figure 2. The effect of stocking rate (HSR = 3.0 AU/ha; LSR = 1.75 AU/ha) on the DM presentation yields of species in the mixtures of *A. pintoi* (*Ap*), *S. guianensis* (*Sg*) and *C. macrocarpum* (*Cm*) with *B. humidicola* (*Bh*) and of *A. pintoi* with *B. brizantha* (*Bb*).

Nitrogen yield

Total annual N yields of pintoi mixtures were significantly ($P < 0.05$) higher than those of stylo and centro (Table 4). N yields of stylo and centro were greater in mixtures with humidicola than with brizantha. On the other hand, pintoi accounted for a significant percentage of total N yield in both mixtures, especially at the HSR (Table 4).

Total N uptake of mixtures was linearly related to legume DM yields (Figure 3a). However, there was no significant relationship between N uptake of grasses and DM yields of legumes (Figure 3b).

Table 4. Mean annual N yields (kg N/ha/yr) of grasses and legumes in grass–legume mixtures managed at 2 stocking rates (LSR = 1.75 AU/ha; HSR = 3.0 AU/ha).

Mixture	LSR			HSR			Mean total N yield
	Grass	Legume	Total	Grass	Legume	Total	
brizantha + stylo	238.2bc	8.2c	246.4c	201.7c	10.6d	212.3c	229.3c[1]
humidicola + stylo	264.1ab	106.5a	370.6b	210.8bc	29.4d	240.2bc	305.4b
brizantha + centro	241.8bc	9.5c	251.3c	199.3c	24.3d	223.6bc	237.4c
humidicola + centro	221.4c	52.0b	273.4c	196.8c	48.4c	245.2b	259.3c
brizantha + pintoi	276.9a	66.8b	343.7b	276.3a	116.3b	392.6a	368.1a
humidicola + pintoi	276.2a	134.2a	410.4a	242.1b	159.2a	401.3a	405.8a

[1]Within columns, values followed by different letters are significantly different ($P < 0.05$).

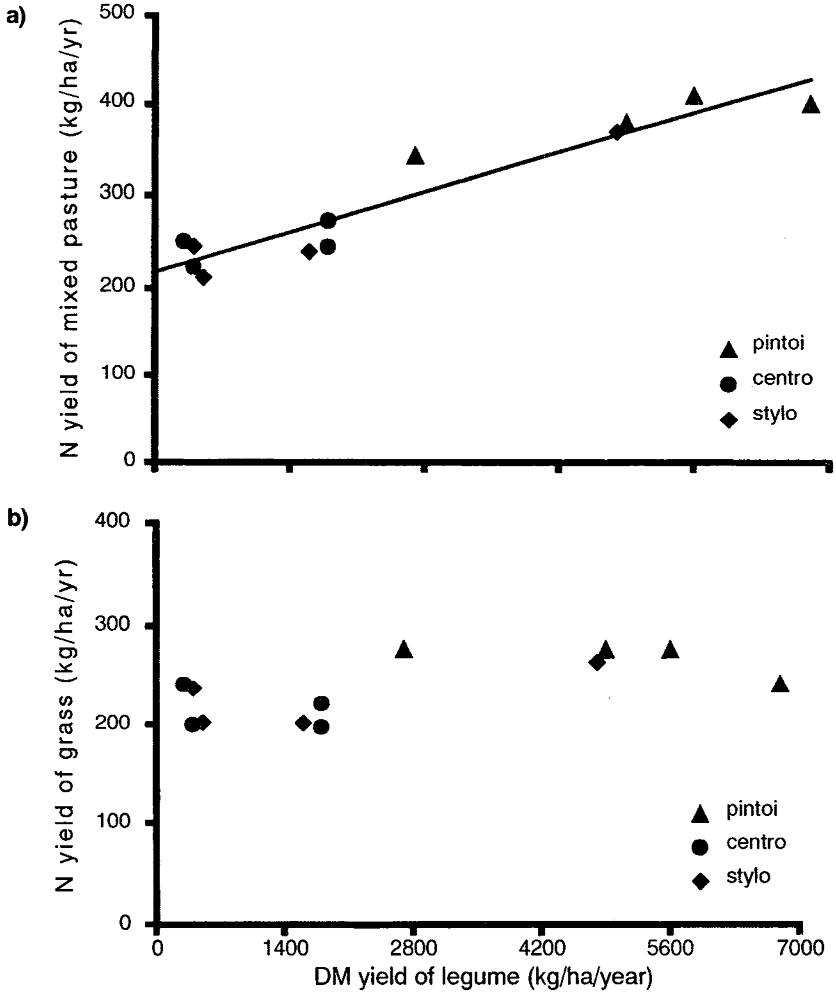

Figure 3. Relationship between (a) annual dry matter yield of legume (x) and N yield of mixed pasture (y) : $y = 216.13 + 0.032x$ ($r^2 = 0.89$); and (b) annual dry matter yield of legume and N yield of grass.

Discussion

In general, the legumes established better with the more stoloniferous humidicola than with the tufted brizantha. In the first 6 months of grazing, legumes contributed 26% of total forage on offer with humidicola, which was 3 times higher than with brizantha. This is contrary to what might be expected from results reported in the literature; generally, legumes are more compatible with tufted grasses (Wong and Mannetje 1981; Toledo and Fisher 1990). However, the humidicola accession (CIAT 6339) used in this experiment is less aggressive than other *Brachiaria* cultivars (Grof 1982; Vallejos 1988). Apparently, lodged tillers of brizantha suppressed growth of centro and stylo in the establishment phase by limiting the amount of light, while pintoi survived, because of its ability to tolerate shading (Ng 1991). In Brazil, Spain *et al.*(1993) showed that *S. capitata* and centro represented 30–60% of total DM on offer in association with *Panicum maximum* cv. Vencedor, compared with only 5% in mixtures with brizantha.

This and other experiments (Hurtado 1988; Argel 1993; Hernandez *et al.*1995) have shown that pintoi can withstand heavy grazing. Its very prostrate growth habit and dense mat of stolons ensure protection of a high percentage of growing points from defoliation (Grof 1985; Argel 1993). A rapid decline in the contribution of stylo and centro suggests that both SRs were too high for these legumes. The failure of these legumes to persist for more than 2 years conforms with general experience in Brazil, Peru and Colombia (Grof 1986; Serrão *et al.* 1990; Lascano and Avila 1991). Centro and stylo are less tolerant of grazing because of the twining growth habit of the former, with buds readily accessible to the grazing animal, and the erect shoots branching from the main stem of stylo, which also makes it vulnerable to heavy grazing (Thomas *et al.* 1985).

The sudden dominance of pintoi over humidicola in the second grazing year corresponded with a period of excessive rainfall, which presumably created optimum conditions for growth of the legume. Experience with pintoi in Costa Rica and elsewhere in central America (Roig 1989; Argel 1993) showed that this legume is very aggressive under wet conditions and can even withstand flooding for short durations (CIAT 1986). Alternatively, wet conditions may have supressed the growth of humidicola.

Pintoi formed a good mixture with brizantha under heavy grazing, as reported by Hernandez *et al.* (1995) in a grazing experiment at Los Diamantes, Guapiles, Costa Rica. In that study, pintoi represented 34% of total DM with brizantha when grazed at 6 animals/ha but only 6% at 3 animals/ha.

The results of our experiment emphasise the need for selection of appropriate companion grass species for pintoi as well as for the development of appropriate grazing management. Pintoi dominated the prostrate humidicola as it has done with the creeping African star grass (*Cynodon nlemfuensis*) in Costa Rica at Turrialba (Heurck 1990) and other *Brachiaria* spp. like *B. dictyoneura* and *B. ruziziensis* in the wet zone of Colombia (Grof 1985).

The last 6 grazing months of the study coincided with the high rainfall season, which partially explains the significant increase in mean DM yields in this period. Low DM yields observed with brizantha in the first year may be attributed to frequent grazings at the beginning of the experiment, suggesting the need for more appropriate grazing management of this species. Agronomic studies conducted under the same experimental conditions showed that brizantha was very susceptible to frequent cutting (CATIE 1990), which may be related to a rapid decline in soluble carbohydrates following cutting or grazing (Jones and Carably 1981). On the other hand, a sharp increase in available DM yields of humidicola mixtures in the second and third years was associated with a shift in species composition in the pasture towards a greater percentage of the unpalatable (Martinez *et al.* 1993b) stoloniferous *P. fasciculatum,* which has a high tolerance for wet conditions (Ibrahim 1990; Martinez *et al.* 1993a).

It is interesting to note that, although pintoi tended to become a monoculture under heavy grazing with humidicola, it was subsequently invaded by *P. fasciculatum.* In monoculture, pintoi is very prostrate and can be invaded easily by weeds (Dwyer *et al.* 1990), but in competition with grasses, pintoi is more vigorous, growing up to 50 cm in height (Ayarza *et al.* 1993). Apart from this, the invasion of pintoi by weeds may be associated with the high buildup of N, stimulating growth of the grass weed.

Pintoi yielded more than 100 kg N/ha/yr, which indicates that this species can fix significant amounts of N for the growth of associated grasses. In the humid tropics, soil N tends to deplete rapidly after deforestation, and the incorporation of legumes in these ecosystems can play an important role in maintaining high soil N levels (Toledo 1994). This is supported by results of Miller and van der List (1977), which showed that each 1000 kg legume DM resulted in an additional 33–34 kg N in the pasture system. Thomas *et al.* (1992) showed that *Arachis pintoi* fixed sufficient amounts of N (144 kg/ha/yr) in mixtures with *Brachiaria dictyoneura* to balance N losses from the pasture system.

There was no relationship between N yields of grasses and DM yields of legumes, which was probably due to low yields of centro and stylo. Other factors such as defoliation and the rate of decomposition of legume litter may affect N transfer to the associated grass (Miller and van der List 1977; Humphreys 1991). Annual N yields of grasses were 30–78 kg/ha higher in mixtures with pintoi than with stylo and centro except for mixtures of humidicola and stylo at the LSR, indicating that considerable amounts of N fixed by the legume were being transferred to the associated grass.

We conclude that *Arachis pintoi* was the most grazing-tolerant legume tested but good grazing management and selection of appropriate grass species are required to sustain stable mixtures with this legume.

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