Multilocational agronomic evaluation of selected *Centrosema pubescens* germplasm on acid soils

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Abstract

Twenty-three accessions of *Centrosema pubescens* selected for good performance on an infertile, acid soil were tested along with 2 control lines each of *C. pubescens* and *C. acutifolium* at 18 locations in tropical America and one location in tropical China. The sites represent 3 major agroecosystems: tropical semi-evergreen seasonal forest, tropical rainforest and savanna. The evaluation corroborated the poor performance of common centro on acid soils and identified new, superior *C. pubescens* accessions. Of particular interest was the outstanding performance of *C. pubescens* CIAT 15160 across ecosystems. Its dry matter production was superior to that of the *C. pubescens* controls and superior or similar to that of the acid soil-tolerant *C. acutifolium* control accessions CIAT 5277 (except for the rainforest ecosystem) and CIAT 5568. CIAT 15160 produced high seed yields in the seasonal forest and savanna ecosystems, and was selected for advanced testing in all 3 ecosystems. In addition, the following accessions are recommended for further evaluation such as in grass-legume associations under grazing, cut-and-carry systems, protein banks or as soil cover: CIAT 15150, 5172 and 5634 for the tropical semi-evergreen seasonal forest ecosystem; CIAT 15470, 15872 and 5172 for the tropical rainforest ecosystem; and CIAT 15150 and 5169 for the savanna ecosystem.

The aforementioned accessions, with the exception of CIAT 5634 and 15470, were also identified as the most promising regarding DM productivity and environmental adaptation in an analysis of adaptability performed across the three ecosystems. There was a positive correlation (r = 0.61) between DM yields and adaptability indices.

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Introduction

The genus, *Centrosema*, comprises 34 species (Williams and Clements 1990) which are native to the New World's tropics and subtropics. Accessions of 5 species have been released as cultivars: *C. acutifolium* cv. Vichada in Colombia; *C. brasilianum* cv. Oolloo in Australia; *C. pascuorum* cvv. Bundey and Cavalcade in Australia; *C. pubescens* cvv. Centro, El Porvenir and Villanueva in Australia, Honduras and Cuba, respectively; and *C. schiedeanum* cv. Belalto in Australia (Schultze-Kraft *et al.* 1997). *Centrosema pubescens* Q25261 has been proposed for release as cv. Cardillo in Australia (Don Loch, personal communication; February 1998). Of these species, only *C. pubescens* has attained major economic importance as a pasture plant and cover legume in plantation agriculture, mainly in Australia and south-east Asia, respectively (Teitzel and Burt 1976; Chee and Wong 1990; Humphreys *et al.* 1990; Teitzel *et al.* 1990). Commercial experience with *C. pubescens* indicates this species is unsuited for nutrient-poor, acid soils with high Al saturation (Clements *et al.* 1983; Hutton 1983) and has had no impact on the ultisols and oxisols which cover vast areas of tropical South America (Cochrane *et al.* 1985).

Attempts to breed interspecific hybrids which combine the high seed-yielding ability and stoloniferous growth habit of *C. pubescens* with the adaptation to low fertility, acid soil conditions and high disease resistance of *C. macrocarpum* (Hutton 1983; 1985) have not resulted in the release of a cultivar. The *C. pubescens* hybrid CIAT 438 (Grof 1982) is superior to commercial centro (CIAT 1979) but, apart from certain local success as in Peru (Reátegui *et al.* 1985), has had no major impact on nutrient-poor, acid soils.

A germplasm screening trial conducted on an infertile, acid soil (pH 4.1; 1.6 ppm available P; 89% Al saturation) at the CIAT research station Quilichao, Cauca province, Colombia, showed considerable variability among 73 *C. pubescens* accessions for acid soil tolerance (Schultze-Kraft and Keller-Grein 1985). A subsequent evaluation of 575 accessions at the same site revealed great variability in flowering onset, seed production, stolon root development and dry matter (DM) production, and 23 accessions were selected for their outstanding performance on these soils (R. Schultze-Kraft, unpublished data).

This paper describes the agronomic evaluation of these 23 *C. pubescens* accessions along with 4 controls in a number of ecosystems, conducted through the International Tropical Pastures Evaluation Network (RIEPT, its Spanish acronym). The evaluation aimed to describe for each ecosystem the variation within the collection regarding important agronomic and phenological traits and to select the most promising accessions for further studies.

Materials and methods

Accessions studied

The 23 *C. pubescens* accessions and 2 control lines each of *C. pubescens* and *C. acutifolium* used in the evaluation are listed in Table 1, together with environmental characteristics of their respective sites of origin.

Evaluation sites

The evaluation was carried out between 1988–1992 at 18 sites in tropical environments of central and South America, and at one site in tropical China (Table 2). Locations represent 3 major agroecosystems according to Cochrane *et al.* (1985): tropical semi-evergreen seasonal forest, tropical rainforest and savannas (isothermic and isohyperthermic). Since this classification, based on climatic criteria, has commonly been used within the RIEPT, it was kept in the current evaluation. The two sites in Zulia, Venezuela, represent a dry deciduous forest environment. However, in this analysis, they were included in the seasonal forest ecosystem, as this most closely resembles the dry deciduous characteristics.

Experimental procedure

A uniform experimental protocol was largely applied. Some variation existed in the fact that some parameters, considered of minor importance by the respective researchers (*e.g.* flowering onset, rooting at stolon nodes), were not evaluated at all sites. Accessions were sown in single-row plots, with 10 plants/plot at a distance of 0.25 m between plants and 2 m between rows. Three to five seeds scarified with sulphuric acid were placed at each sowing site. About one month after emergence, seedlings were thinned leaving one at each sowing site. Fertiliser was applied according to local recommendations for pasture legumes with low–intermediate nutrient requirements at each site. Since recommendations on inoculation with appropriate strains of rhizobium were not available for most accessions, nitrogen (50 kg/ha N) was applied at establishment. However, at São Carlos, Campo Grande and Paranavaí, Brazil, seeds were inoculated with a mix of rhizobium strains and no nitrogen was applied.

The experimental design consisted of randomised complete blocks with 3 replications. A fourth 'replication', which was not cut, was used to evaluate flowering onset and seed production.

After a standardisation cut when the legumes were considered to have established (about 6 months after sowing), further cuts followed at 3-month intervals for up to 24 months. Plants in three 0.5 × 0.5 m quadrats/plot were cut with shears at a height of 5–8 cm to measure DM production during the rainy and dry seasons. DM yields are presented as means of all cuts for each season. In the 2 forest ecosystems, especially in the rainforest, the term 'dry season', used for simplicity, does not refer to an actual dry season but to a period of lower rainfall. Immediately prior to each cut, lateral growth was evaluated by measuring, in 3 random plants/plot, the distance between the centre and the outermost points of the plant on both sides of the plot. Rooting capacity at the nodes of trailing stems (referred to as 'rooting at stolon nodes') was assessed after cutting, by means of a rating scale from 0 (no rooting) to 5 (strongly rooting).

Table 1. Origin of *Centrosema* germplasm included in the multilocational evaluation (Source: CIAT data base).

CIAT accession no.[1]	Other accession nos.[5]	Country	Province/State	Latitude	Longitude	Altitude	Annual rainfall	Dry months, < 60 mm	Soil information
						(m.a.s.l.)	(mm)	(no.)	
5006	BRA 014419, ILCA 12269	Dominican Republic	Dist. Nacional	—	—	—	—	—	—
5133	BRA 016993, CPI 087972, ILCA 11218	Colombia	Magdalena	11°17'N	73°54'W	20	2290	4	medium fertility
5167	BRA 017027, CPI 083535	Venezuela	Miranda	10°10'N	66°54'W	190	1080	5	high fertility
5169	BRA 014559, CPI 087983	Venezuela	Aragua	10°04'N	66°56'W	420	1440	4	medium fertility
5172	BRA 010227, CPI 083537	Venezuela	Aragua	09°51'N	66°54'W	230	1120	5	high fertility
5189	BRA 003191, CPI 083544, ILCA 9051	Venezuela	Miranda	10°23'N	66°29'W	60	1300	3	medium fertility
5596	BRA 004537	Brazil	Goiás	11°44'S	47°52'W	400	1500	5	—
5627	BRA 016896	Venezuela	Lara	10°06'N	69°10'W	480	850	5	high fertility
5631	BRA 017019	Venezuela	Trujillo	09°24'N	70°29'W	490	1180	2	medium fertility
5634	BRA 017001	Venezuela	Portuguesa	09°22'N	69°59'W	700	2100	3	high fertility
15043	BRA 016969	Colombia	Antioquia	05°48'N	75°36'W	1100	1800	1	medium fertility
15132	BRA 017051	Venezuela	Trujillo	09°44'N	70°26'W	150	1260	3	low fertility
15133	BRA 017051	Venezuela	Trujillo	09°22'N	70°42'W	900	880	3	pH 4.1
15144	BRA 016977	Venezuela	Zulia	08°43'N	72°32'W	10	2310	0	low fertility
15149	BRA 016926	Venezuela	Táchira	07°33'N	71°49'W	270	2560	3	medium fertility
15150	BRA 016918	Venezuela	Barinas	07°40'N	71°22'W	260	2140	3	medium fertility
15154	BRA 016942	Venezuela	Barinas	08°22'N	70°35'W	210	1710	4	low fertility
15160	BRA 016985	Venezuela	Barinas	08°20'N	69°33'W	180	1560	5	medium fertility
15470	BRA 016934, IDIAP 00248	Panama	Chiriquí	08°31'N	82°47'W	55	3950	2	medium fertility
15474	BRA 016951, IDIAP 00334	Panama	Chiriquí	08°17'N	81°59'W	45	3550	3	medium fertility
15872	BRA 016888	Venezuela	Miranda	10°11'N	66°27'W	320	2400	0	medium fertility
15875	BRA 017043	Venezuela	Miranda	10°13'N	66°15'W	60	2540	0	—
15880	BRA 016900	Venezuela	Bolívar	07°23'N	61°26'W	180	1310	4	medium fertility
Controls									
413[2]	BRA 010111, ILCA 12306	—	—	—	—	—	—	—	—
438[3]	BRA 002151, CPI 078598, ILCA 137, IRFL 6282, IRI 3595	—	—	—	—	—	—	—	—
5277[4]	BRA 004162, CPI 094327, ILCA 12182, IRFL 4850	Colombia	Vichada	04°53'N	68°23'W	150	2130	4	pH 4.3
5568[4]	BRA 004821, CPI 092884, ILCA 12184	Brazil	Goiás	08°51'S	48°20'W	290	1680	5	—

[1]Nos. refer to *C. pubescens* if not stated otherwise.
[2]Australian commercial centro.
[3]*C. pubescens* hybrid.
[4]*C. acutifolium*, CIAT 5277 is cv. Vichada.
[5]BRA = plant introduction no. of EMBRAPA-CENARGEN (Empresa Brasileira de Pesquisa Agropecuária-Centro Nacional de Recursos Genéticos e Biotecnologia, Brazil); ILCA = International Livestock Centre for Africa, Ethiopia; CPI = principal Australian plant introduction no. of CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia); IDIAP = Instituto de Investigación Agropecuaria de Panamá, Panama; IRFL = plant introduction no. of AREC-FP (Agricultural Research and Education Center of the University of Florida, Fort Pierce, FL, USA).

Table 2. Description of sites where *C. pubescens* was evaluated and researchers involved.

Site (Institution)[1]	Researcher	Duration[2]	Ecos.[3]	Location			Climate			Soil							
				Latitude	Longitude	Altitude	Mean annual rainfall	Dry months (<60 mm)	Mean annual temp.	Sand	Clay	pH	P	Al sat.	Ca	Mg	K
						(m.a.s.l.)	(mm)	(no.)	(°C)	(%)	(%)		(ppm)	(%)	(meq/100 g)		
BRAZIL																	
Campo Grande, Mato Grosso do Sul (EMBRAPA-CNPGC)	C.D. Fernandes	12.88-10.91	IS	22°27'S	54°37'W	530	1584	3	21.9	88	11	4.6	1.0	77.0	0.3	0.11	0.08
Coronel Pacheco, Minas Gerais (EMBRAPA-CNPGL)	M. de Andrade B.	09.89-09.91	IS	21°33'S	43°06'W	296	1403	6	22.7	—	—	4.7	1.9	1.2	0.21	0.15	0.09
Itabela, Bahía (CEPLAC)	M. Moreno	11.89-08.92	TSSF	16°39'S	39°30'W	100	1311	0	23.2	81	8	4.9	1.0	27.2	0.2	0.15	0.05
Paragominas, Pará (EMBRAPA-CPATU)	M. Simão Neto	01.89-04.91	TSSF	02°58'S	47°27'W	100	1607	6	26.5	4	72	5.5	1.3	—	3.4	0.89	0.26
Paranavaí, Paraná (I. A. Paraná)	S.C. Mella	03.89-06.91	IS	23°05'S	52°26'W	480	1491	2	21.9	80	15	4.2	3.4	16.1	1.1	0.41	0.16
Rio Branco , Acre (EMBRAPA-UEPAE de Rio Branco)	J. Ferreira V.	12.88-02.90	TSSF	09°58'S	67°48'W	16	1890	7	25.0	58	22	6.0	1.0	51.0	1.8	1.10	0.20
São Carlos, São Paulo (EMBRAPA-UEPAE de São Carlos)	N. J. Novaes	02.89-03.91	IS	22°01'S	47°53'W	856	1583	3	20.3	63	36	4.7	1.2	58.3	0.24	0.13	0.05
CHINA																	
Danxian, Hainan Island (SCATC)	Ch. He; L. Guodao	02.88-07.90	TSSF	19°30'N	109°30'E	149	1745	4	23.2	—	—	5.2	3.6	—	—	—	—
COLOMBIA																	
Macagual, Caquetá (ICA)	G. Maldonado	04.89-12.90	TRF	01°51'N	75°41'W	244	3552	0	25.0	28	50	4.8	8.6	40.8	1.20	0.56	0.27
Villavicencio, Meta (ICA-CIAT)	H. Hernández	07.89-04.91	TRF	04°04'N	73°30'W	336	2457	1	25.3	21	48	4.2	2.3	72.9	1.18	0.11	0.12
COSTA RICA																	
San Isidro, San José (CIAT-IICA)	P. Argel; A. Valerio	06.89-09.91	TSSF	09°22'N	83°42'W	703	2954	4	23.0	17	55	5.1	<1.0	50.0	0.40	0.20	0.10
ECUADOR																	
Napo-Payamino, Napo (INIAP-IICA-IDRC)	R. González; A. Anzules	06.89-01.91	TRF	0°27'S	76°59'W	250	3142	0	25.5	90	5	5.9	7.2	—	5.80	1.00	0.18
PERU																	
Pucallpa I, Ucayali (CIAT-IVITA-INIA)	G. Keller-Grein; F. Passoni	10.88-02.91	TSSF	08°39'S	74°54'W	245	1770	2	26.4	19	48	4.5	2.1	80.0	0.70	0.28	0.09
Pucallpa II, Ucayali (CIAT-IVITA-INIA)	G. Keller-Grein; F. Passoni	04.89-01.91	TSSF	08°38'S	74°55'W	250	1770	2	26.4	12	55	4.2	3.6	81.2	1.07	0.59	0.19
Puerto Bermúdez, Pasco (INIA)	G. Cantera	02.89-03.90	TRF	10°18'S	74°54'W	300	3312	0	26.0	—	—	4.1	8.0	91.0	0.27	0.18	0.10
Yurimaguas, Loreto (INIA)	D. Lara	10.88-05.91	TRF	05°56'S	76°05'W	179	2135	0	26.6	73	6	4.8	6.2	65.1	0.93	0.37	0.05
VENEZUELA																	
El Tigre, Anzoátegui (FONAIAP)	A. Flores; I. Rodríguez	07.88-11.90	IHS	08°52'N	64°13'W	265	1028	6	26.5	73	4	4.9	1.7	7.6	0.40	0.03	0.03
La Cañada, Zulia (FONAIAP)	J. Faría Marmol	09.90-09.92	DF	10°32'N	71°42'W	55	549	7	28.4	67	11	5.1	4.6	—	3.60	2.10	0.88
El Laberinto, Zulia (FONAIAP)	J. Faría Marmol	09.90-09.92	DF	10°32'N	72°12'W	82	980	4	28.7	55	15	5.2	8.0	—	8.25	1.71	0.14

[1]EMBRAPA = Empresa Brasileira de Pesquisa Agropecuária; CNPGC = Centro Nacional de Pesquisa de Gado de Corte; CNPGL = Centro Nacional de Pesquisa de Gado de Leite; CEPLAC = Comissão Executiva do Plano da Lavoura Cacaueira; CPATU = Centro de Pesquisa Agropecuária do Tropico Humido; I. A. Paraná = Instituto Agronômico do Paraná; UEPAE = Unidade de Execução de Pesquisa de Ambito Estadual; SCATC = South China Academy of Tropical Crops; ICA = Instituto Colombiano Agropecuario; CIAT = Centro Internacional de Agricultura Tropical; IICA = Instituto Interamericano de Cooperación para la Agricultura; INIAP = Instituto Nacional de Investigaciones Agropecuarias; IDRC = International Development Research Centre; IVITA = Instituto Veterinario de Investigaciones Tropicales y de Altura; INIA = Instituto Nacional de Investigación Agraria; FONAIAP = Fondo Nacional de Investigaciones Agropecuarias.

[2]Month/year of sowing to month/year of last cut.

[3]Ecosystem: IS = isothermic savanna; TSSF = tropical semi-evergreen seasonal forest; TRF = tropical rainforest; IHS = isohyperthermic savanna; DF = deciduous forest (equated to TSSF in data analysis).

Trellises were installed in the seed-production rows. Time to flowering onset, determined at 3 sites only, was the number of days from sowing to when 50% of plants of an accession had started flowering. Ripe pods produced during the first season (at some sites during the second season when there was no seed set during the first) were hand-harvested and cleaned, and the weight of pure seeds was determined.

Problems caused by diseases and insect pests were recorded using a rating scale from 0 (pathogen/insect not present) to 4 (severe damage).

Chemical analyses

Nutritive value (crude protein, P and Ca) of leaves and stems was determined at Pucallpa in a wet season cut (Keller-Grein and Passoni 1993). At Villavicencio, *in vitro* DM digestibility, crude protein, P and Ca concentrations in entire plants were determined in a wet season cut (Hernández Linares 1992). While at Villavicencio analyses were carried out with a mixture of the 3 replications, at Pucallpa samples from each replication were analysed separately.

Statistical analysis

The data from each location were analysed using the SAS (version 6.12) statistical program package. For each agroecosystem, data were processed by conducting combined analysis of variance over the respective evaluation sites, nesting blocks within sites. Results are presented at a significance level of P < 0.01. *Centrosema*

Table 3. Mean dry matter yield, lateral growth, rooting at stolon nodes, flowering onset and seed production of *Centrosema pubescens* (25 accessions[1]) and *C. acutifolium* (2 accessions) in 3 ecosystems.

Ecosystem and location	Dry matter yield		Lateral growth	Rooting at stolon nodes[2]	Flowering onset[3]	Seed production[4]
	Rainy season	Dry season				
Tropical semi-evergreen seasonal forest	(kg/ha)		(cm)		(days)	(g/plot)
Paragominas, Brazil	2213	2173	—	—	—	50
Coronel Pacheco, Brazil	1805	1398	—	—	—	76
Danxian, China	1524	521	—	—	—	32
Pucallpa II, Peru	1338	1277	—	3.6	—	—
Pucallpa I, Peru	1215	1298	—	3.1	—	195
La Cañada, Venezuela	1209	992	86	1.1	—	208
El Laberinto, Venezuela	1192	1018	84	1.3	—	133
Itabela, Brazil	1112	891	98	—	—	295
Rio Branco, Brazil	1043	989	48	3.7	—	—
San Isidro, Costa Rica	432	489	97	—	—	249
Mean	1308	1105	83	2.6	—	155
LSD (P<0.01)	381	277	9	0.3	—	—
Tropical rainforest						
Puerto Bermúdez, Peru	2112	999	193	3.1	—	—
Villavicencio, Colombia	1810	2037	38	—	165	82
Napo, Ecuador	1213	2101	—	—	—	—
Macagual, Colombia	1461	1521	—	—	—	—
Yurimaguas, Peru	1773	1155	—	—	—	—
Mean	1674	1563	116	—	—	—
LSD (P<0.01)	537	389	7	—	—	—
Savanna						
Paranavaí, Brazil	2367	1540	140	1.1	—	34
São Carlos, Brazil	2123	1878	44	2.1	—	31
Campo Grande, Brazil	1492	960	129	1.7	171	1
El Tigre, Venezuela	1224	469	52	4.6	125	556
Mean	1802	1212	91	2.4	148	156
LSD (P<0.01)	359	356	24	0.3	—	—

[1]23 accessions in the savanna ecosystem.
[2]Rating scale from 0 (no rooting) to 5 (strongly rooting).
[3]Number of days from sowing to 50% of plants flowering.
[4]10 plants/plot.

pubescens accessions CIAT 15872 and 15880 were not included in the analysis for the savanna ecosystem since they were evaluated at 2 sites only. Analyses of variance were also performed for each location and data are reported for some sites. Likewise an analysis of variance was conducted with the data of nutritive value determined at Pucallpa.

In addition, an analysis of adaptability was performed on mean DM yield across ecosystems and seasons using the method described by Eberhart and Russell (1966). Environmental indices (EI), representing mean DM yield of all accessions at a site minus mean yield of all accessions across sites were calculated. Based on these EIs and the yield of each accession at each site, linear regressions ($Y = a + bEI$) were calculated for each accession, where Y represents DM yield of an accession at a site, the intercept (a) represents mean DM yield of an accession across locations, and the slope (b) is the accession's response to the environmental index, representing its degree of adaptability to the given range of environments (adaptability index). In the calculation of EI, the respective accession under consideration was excluded to avoid dependence between the yield of that accession and the values of the EI (Toledo *et al.* 1983).

Results

Tropical semi-evergreen seasonal forest

Mean DM yields differed considerably among the 10 evaluation sites, being highest at Paragominas and lowest at San Isidro (Table 3). Lateral growth was lowest at Rio Branco (48 cm), ranging between 84–98 cm at the other 4 sites. Rooting at stolon nodes was poor at La Cañada and El Laberinto in comparison with the 3 other sites. Seed production varied greatly from 295 g/plot at Itabela to 32 g/plot at Danxian.

Mean DM yields in the combined analysis ranged from 867–1628 kg/ha and 613–1454 kg/ha for the rainy and dry seasons, respectively (Table 4). In both seasons, *C. pubescens* CIAT 15160, 5634, 15150 and 5172, and *C. acutifolium* CIAT 5568 were among the most productive. Commercial centro CIAT 413 and *C. pubescens* CIAT 15880 were least productive.

There was a significant interaction between site and accession. At the more fertile sites, in the absence of toxic levels of Al in the soil, at La Cañada and El Laberinto and also at Coronel Pacheco, *C. acutifolium* CIAT 5277 was one of the two least productive accessions; the other *C. acutifolium* accession (CIAT 5568) was lowly productive at El Laberinto in both seasons and at Coronel Pacheco during the rainy season (data not presented).

Table 4. Dry matter yield, lateral growth, rooting at stolon nodes and seed production of 25 *C. pubescens* and 2 *C. acutifolium* accessions in the tropical semi-evergreen seasonal forest ecosystem (combined analysis over 10 locations).

CIAT accession number	Dry matter yield		Lateral growth[4]	Rooting at stolon nodes[5]	Seed production[6]
	Rainy season	Dry season			
	(kg/ha)		(cm)		(g/plot)
5006	1304	1043	84	2.4	174
5133	1089	939	87	2.2	166
5167	1181	947	82	2.2	201
5169	1346	1142	87	2.4	153
5172	1394	1240	85	2.1	169
5189	1176	1008	87	2.2	300
5596	1085	919	72	2.0	144
5627	1449	1151	89	1.9	162
5631	1247	900	82	2.4	108
5634	1495	1215	87	2.3	152
15043	1104	882	80	2.0	102
15132	1168	966	80	2.3	95
15133	1195	1041	84	2.3	82
15144	1260	1042	90	2.1	154
15149	1298	1034	84	2.3	137
15150	1452	1194	78	2.0	168
15154	1256	1058	83	2.0	152
15160	1628	1359	86	2.2	271
15470	1334	1062	83	2.0	234
15474	1376	1228	87	2.0	184
15872	1187	925	94	1.9	144
15875	1235	1030	92	2.3	156
15880	867	617	85	2.1	70
Controls					
413[1]	920	613	85	1.6	171
438[2]	1384	943	75	1.6	80
5277[3]	1265	1187	68	1.2	85
5568[3]	1476	1454	78	1.9	126
Mean	1265	1042	83	2.1	153
LSD ($P<0.01$)	189	190	9	0.2	—

[1]Australian commercial centro.
[2]*C. pubescens* hybrid.
[3]*C. acutifolium*; CIAT 5277 is cv. Vichada.
[4]Data of 5 locations.
[5]Rating scale from 0 (no rooting) to 5 (strongly rooting).
[6]Data of 8 locations, with 10 plants/plot.

Lateral growth ranged from 68–94 cm (Table 4), with highest values for *C. pubescens* CIAT 15872, 15875, 15144 and 5627 which, with the exception of the last accession, had relatively low DM yields.

Rooting at stolon nodes (Table 4) was rather poor with the control accessions at the lower end of the rating range.

Seed production (Table 4) ranged from 70–300 g/plot (10 plants) being highest for CIAT 5189. While commercial centro produced good seed yields, *C. pubescens* hybrid CIAT 438 and *C. acutifolium* CIAT 5277 produced low seed yields.

Cercospora leaf spot (*Cercospora* spp.) and rhizoctonia foliar blight (*Rhizoctonia solani*) occurred at several evaluation sites causing mostly only slight damage. At Rio Branco, moderate–severe incidence of root and crown rot (*Thanatephorus cucumeris*) affected plant establishment. At San Isidro, in addition to rhizoctonia foliar blight, bacterial blight (*Pseudomonas fluorescens*) and zonate leaf spot (*Cylindrocladium* sp.) occurred in the whole collection, all causing considerable damage, especially during the rainy season. Leaf-eating insects were observed at all evaluation sites but damage was only slight except at Rio Branco where damage was moderate–severe on all accessions during the rainy season.

At Pucallpa, crude protein concentration in leaves varied in a wet season cut between 21.3–27.1%, with values for stems considerably lower (11.1–14.5%). P concentrations were 0.16–22% (leaves) and 0.10–0.16% (stems), and corresponding Ca concentrations were 0.60–0.99% and 0.43–0.66%. Most of the 23 *C. pubescens* accessions had nutritive values similar to those of common centro known for its high forage quality.

Tropical rainforest

Mean DM yields differed among the 5 locations (Table 3), and at 3 of the 5 sites, yields during the dry season were higher than during the rainy season. Mean lateral growth, evaluated at 2 sites only, also differed considerably. Rooting at stolon nodes was recorded at Puerto Bermúdez only, and flowering onset and seed production only at Villavicencio (Table 3).

DM yields differed widely in the combined analysis among accessions during the rainy and dry seasons (1326–2443 kg/ha and 1073–2246 kg/ha, respectively) (Table 5). In both seasons, *C. acutifolium* controls CIAT 5277 and 5568 were high yielding, the former producing significantly more DM than any *C. pubescens* accession evaluated. For *C. pubescens*, accession CIAT 15160 significantly outyielded the low yielding controls CIAT 413 and 438 during both seasons and had similar DM production to the acid soil-tolerant *C. acutifolium* control CIAT 5568.

A noteworthy difference in performance of accessions from this pattern was registered at Napo, which is characterised by a soil with relatively high Ca and Mg concentrations. Here the two *C. acutifolium* accessions were among the lower yielding materials during the rainy season and CIAT 5568 was poor during the dry season. However, the *C. pubescens* controls, CIAT 413 and 438, gave yields above average during the rainy season. At Yurimaguas, CIAT 438 ranked higher than in the combined analysis, especially during the rainy season when it was the second most productive accession (data not presented).

Lateral growth ranged from 35–141 cm and was below average for all control accessions (Table 5). Several of the high DM-yielding *C. pubescens* accessions (*e.g.* CIAT 15160, 15470, 15872 and 15875) also showed good lateral growth.

Rooting at stolon nodes, recorded at one location only, was highest for *C. pubescens* CIAT 5006, 15154 and 15132 (Table 5). The 4 controls were below average; CIAT 438 and 5596 exhibited the least rooting capacity of all accessions evaluated.

Flowering onset was recorded at one location only and occurred at 154–176 days after sowing (DAS), with *C. pubescens* CIAT 413, 5006 and 5596 and *C. acutifolium* CIAT 5277 the earliest flowering (Table 5). However, most accessions started blooming 163 or 169 DAS. Seed production was variable (data for one location only) ranging from 3 g/plot (*C. acutifolium* CIAT 5277) to about 250 g/plot (*C. pubescens* CIAT 5596 and 15043) (Table 5).

Cercospora leaf spot and rhizoctonia foliar blight were recorded but incidence was not severe. Leaf-eating insects were common, causing mostly only slight damage. However, at Puerto Bermúdez, most accessions were moderately affected. In addition, slight incidence of leaf-sucking and mining insects was observed at Villavicencio and Yurimaguas, respectively.

In vitro dry matter digestibility of entire plants ranged in a wet season cut at Villavicencio from 35.5–45.8%, with the highest values for commercial centro and accessions CIAT 5167, 15133, 15132 and 5627. Crude protein concentration

Table 5. Dry matter yield, lateral growth, rooting at stolon nodes, flowering onset and seed production of 25 *C. pubescens* and 2 *C. acutifolium* accessions in the tropical rainforest ecosystem (combined analysis over 5 locations).

CIAT accession number	Dry matter yield		Lateral growth[4]	Rooting at stolon nodes[5]	Flowering onset[6]	Seed production[7]
	Rainy season	Dry season				
	(kg/ha)		(cm)		(days)	(g/plot)
5006	1665	1670	120	4.3	154	34
5133	1638	1385	127	3.0	163	113
5167	1370	1526	110	3.3	163	168
5169	1674	1483	79	2.8	163	141
5172	1645	1801	101	2.5	163	127
5189	1741	1502	125	2.2	163	78
5596	1462	1358	103	1.8	154	247
5627	1430	1943	35	-	163	34
5631	1617	1495	141	3.8	169	20
5634	1590	1449	108	2.8	176	14
15043	1431	1500	141	3.2	163	253
15132	1632	1338	123	4.0	176	96
15133	1362	1509	112	3.7	169	33
15144	1700	1428	139	3.8	176	59
15149	1541	1382	87	2.8	163	43
15150	1828	1650	105	2.2	163	91
15154	1574	1507	138	4.0	169	70
15160	1902	1938	126	3.2	169	34
15470	1705	1743	124	3.3	163	139
15474	1630	1571	139	3.5	176	79
15872	1845	1615	128	2.8	169	57
15875	1547	1334	134	3.8	169	112
15880	1326	1073	103	3.7	169	35
Controls						
413[1]	1513	1400	101	2.2	154	67
438[2]	1580	1342	88	1.8	163	48
5277[3]	2443	2246	110	2.2	154	3
5568[3]	2102	2002	85	2.7	163	17
Mean	1648	1563	112	3.1	165	82
LSD (P<0.01)	251	293	19	1.7	—	—

[1]Australian commercial centro.
[2]*C. pubescens* hybrid.
[3]*C. acutifolium*; CIAT 5277 is cv. Vichada.
[4]Data of 2 locations.
[5]Rating scale from 0 (no rooting) to 5 (strongly rooting); data of 1 location.
[6]Number of days from sowing to 50% of plants flowering; data of 1 location.
[7]10 plants/plot; data of 1 location.

varied between 18.6–23.1%, with the highest values for CIAT 15880, 15154 and 15149. P concentration ranged from 0.27% (CIAT 5568) to 0.37% (CIAT 5167, 5627 and 15880) and Ca concentration from 0.71% (CIAT 15880 and 5167) to 1.05% (CIAT 5568).

Savannas

Mean DM yields differed considerably among the 4 evaluation sites, being significantly higher at Paranavaí and São Carlos than at Campo Grande and El Tigre (Table 3). The lowest yields were recorded at El Tigre which probably reflects the relatively low annual precipitation and long dry season of that site. Lateral growth and rooting at stolon nodes also differed widely among sites. In spite of relatively low DM yields and little lateral growth at El Tigre, rooting at stolon nodes was very good at that site while it was poor at the other sites. Flowering commenced later at Campo Grande than at El Tigre. Seed production varied extremely among sites, being high at El Tigre, Venezuela (8°N, 265 m.a.s.l.) and very poor at the 3 Brazilian sites at higher latitudes (21–23°S) and greater altitudes (480–856 m.a.s.l.). At the Brazilian sites, flowering and seed production may be affected by low temperatures like at Paranavaí where seed yields could be determined only in the second year of evaluation due to frost which affected seed set in the first year. Similarly, at Campo Grande, poor seed production was due to late flowering which coincided with a period of low temperatures and rainfall. At São Carlos, flowering was sporadic and many young pods were shed during the first year. In the second and third years, flowering occurred more uniformly and during a longer period resulting in higher seed yields.

Mean DM yields in the combined analysis ranged from 1510–2231 kg/ha during the rainy season and 674–1921 kg/ha during the dry season (Table 6). In both seasons, *C. pubescens* CIAT 15160, 15150 and 5169 were among the highest yielding accessions. CIAT 15160 was the only accession which produced significantly more DM than any of the controls. While DM production of the *C. pubescens* hybrid CIAT 438 was above average in both seasons, yield of commercial centro was below average.

Lateral growth ranged from 59–100 cm but did not differ significantly among most accessions (Table 6). The four controls were at the lower end of the range.

As for the seasonal forest ecosystem, rated stolon root development was poor, ranging from 1.3 for *C. acutifolium* CIAT 5277 to 2.6 for *C. pubescens* CIAT 5169, 5631 and 15132 (Table 6).

Flowering onset showed a variation of 36 days, occurring in most accessions between 138 and 149 DAS (Table 6). *Centrosema pubescens* hybrid CIAT 438 and *C. acutifolium* CIAT 5277 flowered at 160 and 174 DAS, respectively, and were the latest flowering accessions. Seed yields (Table 6) varied considerably among accessions (8–286 g/plot of 10 plants). Highest seed yields occurred in *C. pubescens* CIAT 15875, 15160,

Table 6. Dry matter yield, lateral growth, rooting at stolon nodes, flowering onset and seed production of 23 *C. pubescens* and 2 *C. acutifolium* accessions in savanna ecosystems (combined analysis over 4 locations).

CIAT accession number	Dry matter yield		Lateral growth	Rooting at stolon nodes[4]	Flowering onset[5]	Seed production[6]
	Rainy season	Dry season				
	(kg/ha)		(cm)		(days)	(g/plot)
5006	1829	1421	100	2.4	141	159
5133	1565	1028	89	2.1	140	177
5167	1738	1131	99	2.1	142	162
5169	2115	1517	92	2.6	147	189
5172	1843	1279	68	2.4	147	133
5189	1767	1086	91	2.2	142	249
5596	1760	1126	93	2.1	142	154
5627	1927	900	70	2.0	148	97
5631	1530	956	94	2.6	149	138
5634	1688	1196	91	2.3	139	143
15043	1786	1295	93	2.1	141	122
15132	1510	674	91	2.6	156	103
15133	1713	1160	91	2.0	149	171
15144	1599	1112	96	2.4	149	105
15149	1694	1215	92	1.9	155	102
15150	1909	1711	98	1.8	143	199
15154	2017	1185	88	1.9	149	167
15160	2231	1921	92	2.3	147	259
15470	1731	1373	97	2.2	138	196
15474	1869	1383	92	2.5	145	122
15875	1735	1046	95	2.0	155	286
Controls						
413[1]	1638	770	86	2.1	148	223
438[2]	1857	1361	78	1.6	160	100
5277[3]	1806	864	59	1.3	174	8
5568[3]	1875	1364	64	2.5	141	214
Mean	1789	1203	88	2.2	147	159
LSD ($P<0.01$)	271	420	11	0.5	—	—

[1]Australian commercial centro.
[2]*C. pubescens* hybrid.
[3]*C. acutifolium*; CIAT 5277 is cv. Vichada.
[4]Rating scale from 0 (no rooting) to 5 (strongly rooting).
[5]Number of days from sowing to 50% of plants flowering; data of 2 locations.
[6]10 plants/plot.

5189, commercial centro (CIAT 413) and *C. acutifolium* CIAT 5568. *Centrosema pubescens* hybrid CIAT 438 was among the least productive accessions; an extremely low seed yield was recorded for *C. acutifolium* CIAT 5277.

Cercospora leaf spot occurred during the first year of evaluation at Paranavaí causing moderate damage. At Campo Grande, cercospora leaf spot and phoma leaf spot (*Phoma* sp.), a potyvirus and a mycoplasma-like organism were registered in the whole collection with the exception of accessions CIAT 5568 and 15132. Leaf-eating and sucking insects were observed during both years of evaluation at Paranavaí but damage was slight–moderate. At Campo Grande, high incidence of leaf-eating and sucking insects (*Diabrotica speciosa* and *Cyrtocapsus femoralis*, respectively) was registered temporarily on all accessions.

General adaptability

An adaptability analysis, based on DM yields, was conducted across ecosystems for the rainy and dry seasons. Since performance of accessions showed a similar tendency in both seasons, a combined analysis was carried out (Figure 1). CIAT 15160 proved to be very promising, with the highest DM yield and a high adaptability index. A group of 4 accessions (CIAT 15150, 5172, 15872 and 5169) also had high adaptability indices. Their DM yields were lower than for CIAT 15160 but were at the upper end of the range and they had, together with CIAT 15160, the highest adaptability indices of all accessions evaluated.

Centrosema acutifolium controls CIAT 5568 and 5277 had the second and third highest DM yields, respectively, but adaptability indices were rather low (Figure 1). While CIAT 5568 had an adaptability index below 1 in both seasons, the adaptability index of CIAT 5277, though similar in the rainy season, was considerably higher in the dry season (data not presented). The *Centrosema* hybrid CIAT 438 had a DM yield slightly below average and a low adaptability index. Commercial centro (CIAT 413) was among the poorest performing accessions with very low DM yield and adaptability index (Figure 1). DM yields were positively correlated with adaptability indices ($r = 0.61$, $P < 0.0008$).

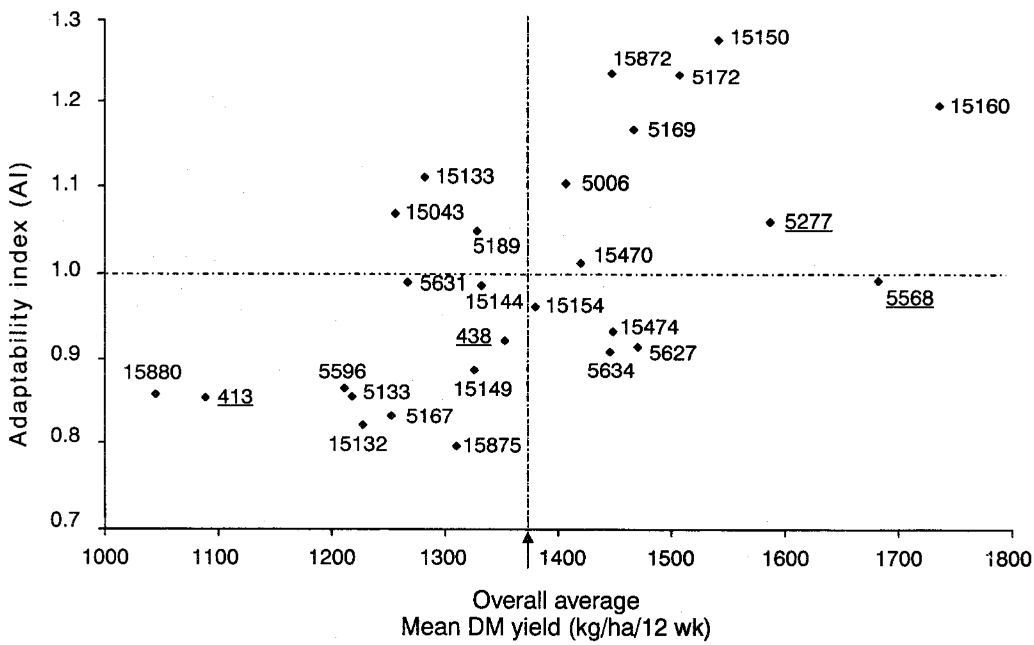

Figure 1. Classification of germplasm of *Centrosema pubescens* and *C. acutifolium* used in the multilocational evaluation by DM productivity level and adaptability index; combined analysis across ecosystems and seasons. Numbers within quadrants refer to CIAT accessions; underlined numbers refer to controls.

Discussion

Common centro performs poorly on oxisols and ultisols in tropical America due to its lack of adaptation to acid, infertile soils. Increased use of *C. pubescens* on such soils will depend on the development of lines tolerant of acidity/Al toxicity and low fertility.

This evaluation has corroborated the poor performance of common centro on acid soils and has identified *C. pubescens* accessions that are superior to commercial centro CIAT 413 and the *C. pubescens* hybrid CIAT 438. In the 3 ecosystems, considerable variation was detected among sites and among accessions for the variables studied. The great variation among sites may be due not only to environmental differences but also to some degree to variation in experimental procedure. It may also question the criteria (mainly wet season potential evapotranspiration) on which the classification of ecosystems by Cochrane *et al.* (1985) is based.

Of particular interest is the outstanding performance of *C. pubescens* CIAT 15160 in all ecosystems, indicating a broad range of adaptation of this accession. It originates from a forest ecosystem in Barinas, Venezuela, characterised by 1560 mm annual rainfall, a dry season of 5 months and a soil of moderate fertility. This accession proved very promising in other evaluation trials in south-east Asia where it was recommended for release by the S. E. Asian Regional Forage Seeds Project (CIAT 1995).

In the tropical semi-evergreen seasonal forest ecosystem, DM yields varied more among locations than in the other ecosystems. Low yields at San Isidro, Costa Rica, seemed to be related to the high incidence of diseases which considerably affected plant growth at that site. DM yields tend to be lower than those registered for *C. pubescens* germplasm in regional evaluation trials under similar ecological conditions at various locations in Colombia (Pizarro 1985) but compare favourably with yield data obtained under seasonal forest conditions in other countries (Pizarro 1985, 1988; Keller-Grein 1990). In this ecosystem, CIAT 15160 was the most promising *C. pubescens* accession, combining high DM yields with high seed production. Other *C. pubescens* accessions which appear promising in this ecosystem are CIAT 15150 from Barinas, Venezuela, and CIAT 5634 from Portuguesa, Venezuela, which originated in seasonal forest ecosystems with a relatively high annual precipitation of 2100 mm and a dry season of 3 months. Another promising accession that performed particularly well during the dry season is CIAT 5172 which originates from a site in Aragua, Venezuela, with a precipitation of 1120 mm and a pronounced dry season of 5 months.

In the tropical rainforest ecosystem, CIAT 15160 was the only *C. pubescens* accession which produced in both seasons significantly ($P<0.01$) more DM than commercial centro and the hybrid line, reaching a yield similar to that of the acid soil-tolerant, high yielding *C. acutifolium* control CIAT 5568. Other promising accessions for this ecosystem seem to be CIAT 15470 and 15872 which originate from rainforest locations in Chiriquí, Panama, and Miranda, Venezuela, respectively. As in the seasonal forest ecosystem, CIAT 5172 had good dry season performance and relatively high seed production. DM yields of the accessions tested were within the range of those reported for *C. pubescens* germplasm evaluated in regional trials under similar ecological conditions (Pizarro 1985). With the exception of 2 sites, DM yields were higher during the dry or low rainfall season. This coincides with results obtained in other agronomic evaluation experiments conducted with germplasm of *Centrosema* spp. and other legumes under tropical rainforest conditions (Pizarro 1985; Keller-Grein 1990). The lower yields during the high rainfall season seem to be related to a heavy cloud cover which reduces photosynthetic activity, and to excess soil moisture and high weed competition.

In the savanna ecosystem, seasonal differences in DM production, especially at El Tigre, were more pronounced than in the other ecosystems, registering in the dry season a considerable decrease in productivity. DM yields tended to be higher than those recorded for *C. pubescens* CIAT 438 and 5189, and for *C. acutifolium* CIAT 5277 and 5568 evaluated in previous regional trials in savanna ecosystems (Pizarro 1985; 1992). CIAT 15160 again proved to be the most promising *C. pubescens* accession giving high DM and seed yields. Other promising accessions were CIAT 15150 which also performed well in the seasonal forest ecosystem, and CIAT 5169 which originates from a forest ecosystem in Aragua, Venezuela, with an annual precipitation of 1440 mm and a well defined dry season of 4 months.

Besides high DM production and environmental adaptation, early flowering and high seed production, and high capacity for rooting at stolon nodes are important characteristics for persistence of trailing legumes with exposed growing points like *C. pubescens*, in pastures. The variation observed in this regard among the germplasm evaluated, provides ample scope for selection within these parameters to improve pasture productivity and/or soil protection.

Flowering onset was evaluated at only one site in the rainforest ecosystem and at two savanna sites, with a variation of 22 and 36 days among accessions, respectively. These are shorter periods than the 50 days recorded for *C. pubescens* accessions at Fort Pierce, South Florida, USA (Kretschmer 1977).

Mean seed yields were almost identical in the seasonal forest and savanna ecosystems and considerably higher than those in the rainforest ecosystem. This is probably due to the high annual precipitation and the lack of a well defined dry season in the rainforest ecosystem which does not favour flowering and seed formation. Assuming 10 000 plants per ha, seed yields expressed in g/10 plants might be considered equivalent to kg/ha. Thus, in the forest ecosystems, seed yields of most accessions were within the range of 109–315 kg/ha recorded for 10 *C. pubescens* accessions under forest conditions in Tracuateua, Pará, Brazil (Cruz and Simão Neto 1995). Seed yields of common centro and the *C. pubescens* hybrid in the 3 ecosystems were generally lower than those listed by Ferguson *et al.* (1990) and Schultze-Kraft and Keller-Grein (1999) for these accessions.

Lateral growth indicates the capacity of a plant to spread and invade new areas and is thus of relevance regarding the potential use of the accessions tested as cover legumes. Several *C. pubescens* accessions were superior in this regard to the controls which showed little lateral growth. However, this characteristic did not seem to be positively related with DM production. Accessions with high yields in general appeared to grow more erectly and expand less laterally than lower yielding accessions.

Good rooting capacity at stolon nodes is desirable since it gives rise to new plants and favours persistence of trailing legumes like *C. pubescens* in grazed pastures. This characteristic also is important in relation to the suitability of the legume as soil cover for erosion control. In all ecosystems, some *C. pubescens* accessions were identified with a rooting capacity superior to that of controls CIAT 413 and 438.

The measurements of nutritive value, conducted at 2 sites only, showed that *in vitro* DM digestibility was lower than values recorded for *Centrosema* species by Lascano *et al.* (1990). Crude protein in general was higher at Pucallpa, while P levels were higher at Villavicencio and Ca also tended to be higher at Villavicencio than at Pucallpa. At both sites, however, the 'new' *C. pubescens* accessions compared favorably in terms of crude protein, P and Ca concentrations, with commercial centro known for its good forage quality and with data from the literature for *C. pubescens* (Skerman *et al.* 1988; Lascano *et al.* 1990).

Development of a *C. pubescens* cultivar for infertile, acid soils should be based on germplasm with a wide range of environmental adaptation. The adaptability analysis performed across locations and ecosystems is useful for the selection of such germplasm. This analysis corroborated the poor–moderate performance of controls CIAT 413 (commercial centro) and CIAT 438 (*Centrosema* hybrid) on acid soils. It also showed the potential of *C. acutifolium* controls CIAT 5277 and 5568 on such soils due to their high productivity levels although their adaptability indices were rather low. Five new *C. pubescens* accessions were identified which combine high DM productivity with high adaptability indices indicating a high response in DM yield to improved environmental conditions. The positive correlation that was found between adaptability indices and DM yields suggests that the best adapted accessions express better their production potential and without restrictive factors are more sensitive to environmental changes than less adapted accessions. The less adapted accessions face limitations (edaphic, climatic or biotic) which tend to impede the full expression of their production potential making them less sensitive to minor changes in the environment.

The accessions which should be considered for further evaluation, *e.g.* in grass-legume associations under grazing, cut-and-carry systems, protein banks or as cover crops are: CIAT 15160 (most promising), then CIAT 15150, 5172, 15872 and 5169.

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