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A historical appraisal of the tropical forages collection conserved at CIAT

Rainer Schultze-Kraft [*,a], **Michael Peters** [b] **and Peter Wenzl** [c]

[a] *Emeritus, International Center for Tropical Agriculture (CIAT)*
[b] *Tropical Forages Program, Africa Hub, International Center for Tropical Agriculture (CIAT), Nairobi, Kenya*
[c] *Genetic Resources Program, Headquarters, International Center for Tropical Agriculture (CIAT), Cali, Colombia*

Abstract: A report on the tropical forage germplasm collection conserved in the CIAT genebank is presented. Emphasis is firstly on the assembling of the collection during 1972−1993 through about 70 major and minor collecting missions in tropical America, Africa and Southeast Asia. Along with introductions from existing collections, currently some 1,600 accessions of 134 grass species and 21,000 accessions of 637 legume species are being maintained. Secondly, information on the utilization of the collection, with emphasis on cultivar development based on selection of accessions from the CIAT collection, is presented. Worldwide, a total of 44 grass and 34 legume cultivars derived from germplasm maintained at CIAT are reported. Information on germplasm distribution and knowledge sharing during the last four decades is also presented as well as a brief discussion on future needs.

Keywords: tropics, wild species, grasses, legumes, germplasm, collection, utilization, genebank

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Introduction

Research related to forage genetic resources at the International Center for Tropical Agriculture (CIAT), Cali, Colombia, has been a continuing activity since the inception of the center in 1969. CIAT was the third of the international agricultural research centers established within the Consultative Group on International Agricultural Research (CGIAR), one of its missions being the development of beef cattle production in the lowlands of tropical America (Lynam and Byerlee, 2017). When looking at the development of the CIAT forages collection and its achievements, two phases can be distinguished: the first phase focused on assembling the collection and some initial, however intensive, characterization and utilization of the collected materials (1972−1993); and the second phase consisted of continuing utilization of germplasm, diversity studies and routine germplasm management and its optimization (1993−2020).

This paper summarizes the assembling of the collection during the first phase as well as its utilization and germplasm distribution. Furthermore, research on forage diversity and knowledge sharing, including training, are addressed. Data presented were compiled mainly from information accessible via the CIAT website (https://ciat.cgiar.org/), CIAT annual reports (accessible at https://cgspace.cgiar.org/handle/10568/35699), unpublished reports on germplasm collecting missions, research bulletins of CIAT´s national partner institutions and the like.

It should be noted that in the past years there have been changes in plant nomenclature for numerous taxa of particular interest, even at the genus level (Cook and Schultze-Kraft, 2015). In this paper we are still referring to the earlier used names. Supplemental Table 1 lists new names of species mentioned in this report, following the taxonomy of GRIN, the database of the USDA Genetic Resources Information Network (https://npgsweb.ars-grin.gov/gringlobal/taxon/taxonomysearch).

*Corresponding author: Rainer Schultze-Kraft (Rainer@Schultze-Kraft.de)

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Assembling the forage germplasm collection

At the beginning of research at CIAT in the early 1970s, a focus of the then Beef Production Systems Program was forage-based livestock production on acid, low-fertility soils in humid and sub-humid lowlands of tropical America, particularly savanna areas. The lack of edaphic adaptation of available, mainly Australian commercial pasture grass and legume cultivars, was soon identified as the main constraint to their use in Neotropical savannas. In the case of legumes, diseases, such as anthracnose in the promising genus *Stylosanthes*, were an additional restriction. It was consequently recognized that available species and genotype pools of grasses and legumes needed to be broadened for screening for adaptation to abiotic (mainly soil) and biotic (pests and diseases) constraints.

Missions were thus initiated in 1972/73 to collect germplasm of wild species with forage potential throughout tropical America. The objective was to create a diverse germplasm pool that can be tapped for cultivar development, either by identifying suitable accessions for direct use or through genetic improvement. These collecting missions ranged from short excursions, particularly within the Center´s host country, Colombia, to field expeditions over several weeks. Another source of germplasm material was through opportunistic collecting undertaken by CIAT scientists during field visits. The missions were largely funded by CIAT, at the beginning of the collecting phase, also with support from the former International Board for Plant Genetic Resources (IBPGR; later International Plant Genetic Resources Institute (IPGRI), now part of the Alliance of Bioversity International and CIAT). There was a focus on acid-soil regions and plant genera of known value. Emphasis was on legumes, in many cases including associated rhizobia, taking into account that the Neotropics are the main center of diversification of the Fabaceae (Leguminosae) family. The particular value of legumes lies in their ability of symbiotic fixation of atmospheric nitrogen and the subsequent provision of protein-rich forage to livestock.

From 1979 onwards, collecting missions within the new Tropical Pastures Program expanded to Southeast Asia, a minor yet important center of legume diversification (e.g. the genera *Pueraria* and *Desmodium*), and in 1984/85 and 1989 also to Africa, with focus on grasses (particularly the genus *Brachiaria*). The latter took into account that Sub-Saharan Africa is the main center of diversification of those genera with forage potential in the Poaceae family.

All missions were organized as joint ventures in association with national research institutions. Table 1 provides an overview of the countries where the collecting efforts were undertaken; the main genera collected are summarized in Table 2. The germplasm collectors who participated in the missions are acknowledged in Supplemental Table 2.

Alongside the collecting activities, the introduction of germplasm in the form of donations from existing collections held by national and international research and development (R&D) institutions around the globe has been an ongoing activity since the inception of the CIAT forages collection. It became the sole source of additions to the collection, when germplasm collecting with the involvement of CIAT scientists came to an end in the 1990s. A total of more than 9,000 accessions were received as donations; among them, in 2006, a significant part of the former Australian Tropical Forages Collection of CSIRO (Commonwealth Scientific and Industrial Research Organisation) (Table 3).

Two factors contributed to the cessation of collecting missions: (1) a sustained decline in funding for tropical-forages research and (2) the fact that hardly any tropical-forage species are included in Annex 1 of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA; FAO, 2001), which streamlines germplasm distribution through the use of a Standard Material Transfer Agreement (SMTA). Instead, most tropical forage species are regulated by legal frameworks that require case-by-case negotiations of individual material transfer agreements, which would create unmanageable legal overheads given the frequent germplasm exchange in agricultural research.

Some concluding remarks on the assembling of the forage germplasm collection

With more than 22,000 accessions from a total of 75 countries of origin, the CIAT collection is the largest tropical forages germplasm collection worldwide. Its particular value lies in its focus on: (1) plants adapted to acid, low-fertility soils; (2) legumes; and (3) the large and diverse collection of *Brachiaria*. This grass genus comprises currently the economically most important tropical forage species worldwide. The CIAT *Brachiaria* collection stems mainly from the Center´s collecting activities in the 1980s in East Africa and has become an important source of germplasm for selection and breeding programs throughout the tropics.

It is recognized that there are still important gaps in terms of countries and regions where germplasm has been collected. The collection is likely far from being representative of the geographic diversity of tropical Poaceae and Fabaceae (Leguminosae).

Table 4 provides a summary of the current tropical forages collection conserved at the CIAT genebank. Differences of numbers in Table 4 in comparison with Tables 2 and 3 are due to initial misidentifications and losses of accessions due to a range of reasons, including a limited number (or low viability) of collected seeds, lack of seed setting in the environments available for regeneration, and insufficient funds for regenerating large numbers of accessions between the 1990s and the launch of the CGIAR Research Program on Genebanks in the 2010s.

Table 1. Forage germplasm collecting missions conducted by CIAT with national research institution partners during 1972−1993. See Supplemental Table 2 for collector names

Year	Region and countries (No. of missions)	Genera collected
1972-73	**South America**: Colombia (2), Venezuela (1)	Legumes: Mainly *Stylosanthes*, also *Centrosema, Desmodium* & others
1974-75	**South America**: Bolivia (1), Brazil (4), Colombia (1), Venezuela (1)	Legumes: Mainly *Stylosanthes*, also *Centrosema, Desmodium* & others
1976-77	**South America**: Brazil (1), Colombia (3), Venezuela (1)	Legumes: Mainly *Stylosanthes*, also *Centrosema, Desmodium* & others
1978-79	**Mesoamerica**: Panama (1) **South America**: Brazil (1), Colombia (1), Venezuela (1) **Southeast Asia**: Thailand (1)	Legumes: *Centrosema, Desmodium, Stylosanthes* & others Legumes: *Centrosema, Desmodium, Stylosanthes* & others Legumes: *Desmodium, Pueraria* & others
1980-81	**South America**: Brazil (3), Colombia (2), Venezuela (1)	Legumes: *Centrosema, Desmodium, Stylosanthes* & others
1982-83	**South America**: Colombia (1), Peru (1) **Southeast Asia**: Malaysia (1), Papua New Guinea (1), Thailand (1)	Legumes: *Centrosema, Desmodium, Stylosanthes* & others Legumes: *Desmodium, Pueraria* & others
1984	**South America**: Brazil (1), Colombia (3), Venezuela (1) **Africa**: Ethiopia (1), Kenya (1) **Southeast Asia**: China (1), Indonesia (1), Thailand (1)	Legumes: *Centrosema, Desmodium, Stylosanthes* & others Grasses: Mainly *Brachiaria* Legumes: *Desmodium, Pueraria* & others
1985	**Mesoamerica**: Panama (1) **South America**: Colombia (1), Venezuela (1) **Africa**: Burundi (1), Rwanda (1), Tanzania (1), Zimbabwe (1) **Southeast Asia**: Indonesia (1)	Legumes: *Centrosema, Desmodium, Stylosanthes* & others Legumes: *Centrosema, Desmodium, Stylosanthes* & others Grasses: Mainly *Brachiaria* Legumes: *Desmodium, Pueraria* & others
1986	**Mesoamerica**: Costa Rica (1), Mexico (1) **South America**: Colombia (3), Venezuela (2) **Southeast Asia**: Indonesia (1)	Legumes: *Centrosema, Desmodium, Stylosanthes* & others Legumes: *Centrosema, Desmodium, Stylosanthes* & others Legumes: *Desmodium, Pueraria* & others
1987-88	**South America**: Brazil (1), Colombia (5) **Southeast Asia**: China (1), Thailand (1)	Legumes: *Centrosema, Desmodium, Stylosanthes* & others Legumes: *Desmodium, Pueraria* & others
1989-90	**Mesoamerica**: Honduras (1) **South America**: Colombia (1) **Africa**: Cameroon (1)	Legumes: *Centrosema, Desmodium* & others Legumes: *Centrosema, Desmodium, Stylosanthes* & others Grasses: *Hyparrhenia, Andropogon* & others
1991-93	**South America**: Colombia (2) **Southeast Asia**: Thailand (1), Vietnam (2)	Legumes: *Centrosema, Desmodium, Stylosanthes* & others Legumes: *Desmodium, Pueraria* & others

Table 2. Most frequently collected genera with numbers of species and samples (accessions) and target countries, obtained through collecting during 1972−1993 (CIAT missions with national research institution partners and opportunistic collecting) and conserved at the CIAT genebank.

Genus	No. of species	No. of accessions	Countries of origin[1]
Legumes			
Aeschynomene	36	821	BDI, BRA, CHN, CMR, COL, CRI, ETH, HND, IDN, KEN, MEX, MYS, PAN, PER, PNG, THA, VEN, VNM
Alysicarpus	6	193	BDI, BRA, CHN, CMR, COL, ETH, HND, IDN, KEN, MYS, PAN, PNG, TGO, THA, VEN, VNM, ZWE
Cajanus	5	75	BRA, CHN, COL, ECU, IDN, PAN, PNG, THA, VNM
Calopogonium	5	446	BOL, BRA, CHN, COL, CRI, ECU, HND, IDN, KEN, MYS, PAN, PER, THA, VEN, VNM
Canavalia	14	185	BRA, CHN, COL, CRI, ECU, HND, MEX, PAN, PER, THA, VEN
Centrosema	33	1,677	BRA, CHN, COL, CRI, DOM, ECU, GTM, HND, IDN, MEX, MYS, PAN, PER, THA, VEN, VNM
Chamaecrista	16	257	BDI, BRA, CHN, COL, CUB, ECU, ETH, HND, KEN, MEX, MYS, NGA, PAN, PER, TGO, VEN, VNM, ZWE
Crotalaria	16	192	BRA, CHN, CMR, COL, CRI, ECU, ETH, HND, IDN, MEX, PAN, PER, PNG, THA, VEN, VNM
Desmanthus	9	110	BRA, COL, ECU, HND, MEX, PAN, PER, VEN
Desmodium	56	2,085	AUS, BDI, BLZ, BOL, BRA, CHN, CMR, COL, CRI, ECU, ETH, GUF, HND, IDN, IND, KEN, MEX, MYS, PAN, PER, PNG, PYF, SLV, TGO, THA, VEN, VNM, ZWE
Dioclea	15	191	BRA, COL, HND, MEX, PAN, PER, VEN
Flemingia	8	130	CHN, CMR, COL, HND, IDN, MYS, PAN, PNG, THA, VNM
Galactia	14	462	BOL, BRA, CHN, COL, CRI, CUB, ECU, HND, MEX, PAN, PER, PNG, VEN, VNM
Indigofera	12	147	BDI, BOL, BRA, CHN, COL, ECU, ETH, KEN, PAN, PER, PNG, TGO, THA, VEN, VNM
Macroptilium	10	445	ATG, BLZ, BOL, BRA, CHN, COL, CUB, DOM, ECU, GTM, HND, MEX, PAN, PER, SLV, THA, VEN,
Phyllodium	5	130	CHN, IDN, PNG, THA, VNM
Pueraria	6	187	BRA, CHN, COL, CRI, ECU, HND, IDN, MYS, PAN, PNG, THA, VEN, VNM
Rhynchosia	17	303	BOL, BRA, CMR, COL, CRI, ECU, ETH, HND, IDN, KEN, MEX, PAN, PER, PNG, RWA, THA, VEN

Continued on next page

Table 2 continued

Genus	No. of species	No. of accessions	Countries of origin[1]
Stylosanthes	24	2,263	ATG, AUS, BOL, BRA, CHN, CMR, COL, CRI, DOM, ECU, ETH, GUY, HND, KEN, MEX, MYS, NGA, PAN, PER, RWA, TGO, VEN, VNM, ZWE
Tadehagi	3	99	CHN, IDN, PNG, THA, VNM
Tephrosia	14	112	BDI, BRA, CHN, COL, ECU, ETH, KEN, MYS, PAN, PNG, THA, VEN, ZWE
Teramnus	9	304	BDI, BOL, BRA, CHN, COL, CRI, ECU, ETH, HND, IDN, KEN, MEX, PAN, PER, THA, VEN, ZWE
Uraria	6	109	CHN, IDN, MYS, PNG, THA, VNM
Vigna	39	481	BDI, BRA, CMR, COL, CRI, ECU, ETH, HND, IDN, KEN, MEX, MYS, PAN, PER, PNG, TGO, THA, VEN, ZWE
Zornia	12	812	AUS, BRA, CHN, CMR, COL, ETH, HND, KEN, MEX, MYS, NGA, PAN, PER, TGO, THA, VEN, ZWE
59 further legume genera with a total of:		693	
Total of legume samples		**12,909**	
Grasses			
Andropogon	2	20	BDI, TGO, ZWE
Brachiaria	17	472	BDI, CMR, COL, ECU, ETH, KEN, RWA, TGO, TZA, ZWE
Hyparrhenia	12	35	BDI, ETH, KEN, NGA, TGO, TZA, ZWE
Panicum	5	20	BDI, ETH, COL, KEN, RWA, ZWE
Paspalum	11	55	BDI, BRA, CHN, COL, DOM, IDN, KEN, MYS, PAN, PER, PHL, VEN, ZWE
Pennisetum	5	23	BDI, CHN, CMR, ETH, KEN
24 further grass genera with a total of:		127	
Total of grass samples		**752**	

[1]Country abbreviations: ATG = Antigua and Barbuda; BDI = Burundi; BLZ = Belize; BOL = Bolivia; BRA = Brazil; CHN = China, People's Republic; CMR = Cameroon; COL = Colombia; CRI = Costa Rica; CUB = Cuba; DOM = Dominican Republic; ECU = Ecuador; ETH = Ethiopia; GTM = Guatemala; GUF = French Guyana; GUY = Guyana; HND = Honduras; IDN = Indonesia; IND = India; KEN = Kenya; MEX = Mexico; MYS = Malaysia; NGA = Nigeria; PAN = Panama; PER = Peru; PHL = Philippines; PNG = Papua New Guinea; PYF = French Polynesia; RWA = Rwanda; SLV = El Salvador; TGO = Togo; TZA = Tanzania; THA = Thailand; VEN = Venezuela; VNM = Vietnam; ZWE = Zimbabwe.

Utilization

Germplasm collecting and introduction activities were the responsibility of the former CIAT Beef Production Systems Program (renamed Tropical Pastures Program (TPP) in 1979) until the late 1980s. Maintenance of the collection passed on to the CIAT Genetic Resources Unit (GRU) after its foundation in 1977 (in 2009 renamed Genetic Resources Program, GRP). Maintenance encompasses activities such as seed testing, seed increase, germplasm preservation at different cold storage levels, safety back-ups of the collection, maintenance of living collections, seed distribution, etc. Standard Operating Procedures (SOP) for each of these areas are available upon request. The collection is conserved in the GRP´s genebank at CIAT Headquarters, Cali, Colombia. At the time of writing (2020), 90% of CIAT's tropical forages collection is backed-up in the Svalbard seed vault and 77% at CIMMYT (https://ciat.cgiar.org/what-we-do/crop-conservation-and-use/tropical-forage-diversity/) .

For effective utilization of the germplasm collection, the close interaction between the genebank and CIAT´s TPP (today: Tropical Forages Program, TFP) played a key role, particularly in the 1980s, in view of the TPP's germplasm-focused research agenda and its alliances with national R&D institutions. The main research approaches were:

- Multidisciplinary germplasm characterization and evaluation by the TPP with involvement of specialists in the fields of agronomy, plant pathology, entomology, plant and animal nutrition, legume rhizobiology, soils, pasture establishment, pasture utilization, farming systems, economics, plant breeding, and seed production;
- Stepwise categorization of promising accessions as germplasm evaluations proceeded from small-plot observations to ultimately animal production experiments under grazing;
- Multi-site testing of germplasm in different eco-climatic zones at: CIAT-Quilichao (Colombia), Colombia-Llanos (with ICA, at Carimagua), Brazil-Cerrados (with EMBRAPA, at Planaltina), Peru-Humid Tropics (with IVITA, at Pucallpa), and later Central America (with Ministerio de Agricultura y Ganadería, in Costa Rica);
- Networking: multi-location testing of elite germplasm within the networks:
  - RIEPT (Red Internacional de Evaluación de Pastos Tropicales), with national research institution partners in Latin America and the Caribbean);
  - RABAOC/WECAFNET (Reseau de Recherche en Alimentation du Bétail en Afrique Occidentale et Centrale/West and Central African Forage Evaluation Network), with national research institution partners in West and Central Africa and in cooperation with ILCA/ILRI (International Livestock Centre for Africa/International Livestock Research Institute);
  - SEAFRAD (South East Asian Forage and Feed Resources Network), with national research institution partners in Southeast Asia; this network developed in the 1990s into the ACIAR (Australian Centre for International Agricultural Research) funded Forages for Smallholders project;
- Development, publication and use of network-wide common research methodologies (see section Publications below);
- Publication of research results in RIEPT reports (accessible at https://cgspace.cgiar.org/discover?scope=%2F&query=riept) and the TPP's journal Pasturas Tropicales (accessible at https://tropicalgrasslands.info/index.php/tgft/pages/view/Pasturas).

As a result of the germplasm evaluation and selection research conducted by CIAT and its partners, a number of grass and legume accessions that had been provided by the CIAT forages collection were developed into cultivars by national R&D institutions worldwide, in a few cases after incorporating them in national breeding programs (Table 5). Several issues should be pointed out:

- In relation to cultivars selected from genebank accessions, formal release and/or registration has been and is the exclusive responsibility of national institutions. In the case of bred lines developed at CIAT (not included in Table 5), cultivar release/registration is done by the private sector, with authorization by CIAT.
- Some cases are mentioned where CIAT accessions were adopted by end users without a formal and documented cultivar release; the real number is probably much higher. On the other hand, it is most likely that not all released cultivars were or are actually used by farmers to a major extent. The use of materials from tropical forages genebanks is further discussed by Hanson *et al* (2020) and Duncan *et al* (2020).
- Several important grass varieties, which had been developed by institutions in Brazil [(e.g. *Brachiaria brizantha* cv. Marandu (CIAT 6294) and *Panicum maximum* cvv. Tanzânia (CIAT 16031), Mombaça (CIAT 9692) and Tobiatã (CIAT 6299)] and subsequently introduced to CIAT, are not included in Table 5. Nonetheless, CIAT, within its network evaluation activities in Latin America and SE Asia, was instrumental for eventual release and adoption of these cultivars by non-Brazilian end-users.
- Mentioning of cultivar releases of the accessions *Brachiaria decumbens* CIAT 606 and *B. humidicola* CIAT 679 is restricted to countries other than Brazil: Both accessions represent early Australian cultivars ('Basilisk' and 'Tully', respectively) and,

Table 3. Forage germplasm donations received during 1972−2006 from national and international institutions and conserved at the CIAT genebank, highlighting main genera and number of samples (accessions).

Period	Total no. of accessions	Main genera	Main donor institutions[1]
1972−75	176	*Centrosema, Desmodium, Stylosanthes, Vigna*	INIAP (Ecuador), CSIRO (Australia), QDPI (Australia), IDRC projects (West Indies, Belize), Univ. Florida (USA), FAO-David (Panama)
1976−80	1,424	*Andropogon, Centrosema, Desmodium, Panicum, Stylosanthes, Zornia*	Instituto de Pesquisas IRI (Brazil), IDRC projects (West Indies, Belize), EPAMIG (Brazil), INIAP (Ecuador), EMGOPA (Brazil), Univ. Florida (USA), EMBRAPA (Brazil), CSIRO (Australia)
1981−85	1,971	*Brachiaria, Calopogonium, Centrosema, Crotalaria, Desmanthus, Desmodium, Galactia, Leucaena, Macroptilium, Macrotyloma, Panicum, Pueraria, Stylosanthes, Vigna, Zornia*	ORSTOM (France), CSIRO (Australia), EMBRAPA (Brazil), EMGOPA (Brazil), INTA (Argentina), QDPI (Australia), EPAMIG (Brazil), FAO-Kitale (Kenya), IBPGR-SE Asia
1986−90	1,238	*Alysicarpus, Brachiaria, Centrosema, Desmodium, Pseudarthria, Pueraria, Stylosanthes, Uraria, Vigna*	EMBRAPA (Brazil), CSIRO (Australia), Instituto de Zootecnia (Brazil), FONAIAP (Venezuela), Univ. Florida (USA), USDA (USA), IBPGR-SE Asia
1991−95	212	*Arachis, Cajanus, Panicum*	EMBRAPA (Brazil), ICRISAT (India), ICA (Colombia)
1996−00	218	*Arachis, Calliandra, Cratylia, Paspalum, Stylosanthes*	EMBRAPA (Brazil), OFI (UK)
2001−06	3,858	*Aeschynomene, Centrosema, Desmanthus, Desmodium, Lablab, Macroptilium, Stylosanthes, Vigna*	CSIRO (Australia)
2007−20	0		
Total	**9,157**		

[1]Abbreviations of main donor institutions: CSIRO = Commonwealth Scientific and Industrial Research Organisation; EMBRAPA = Empresa Brasileira de Pesquisa Agropecuária; EMGOPA = Empresa Goiana de Pesquisa Agropecuária; EPAMIG = Empresa de Pesquisa Agropecuária de Minas Gerais; FAO = Food and Agriculture Organization of the United Nations; FONAIAP = Fondo Nacional de Investigaciones Agropecuarias; IBPGR = International Board for Plant Genetic Resources; ICA = Instituto Colombiano Agropecuario; ICRISAT = International Crops Research Institute for the Semi-Arid Tropics; IDRC = International Development Research Centre; INIAP = Instituto Nacional de Investigaciones Agropecuarias; INTA = Instituto Nacional de Tecnología Agropecuaria; OFI = Oxford Forestry Institute; ORSTOM = Office de la Recherche Scientifique et Technique Outre-Mer; QDPI = Queensland Department of Primary Industries; USDA = United States Department of Agriculture.

unlike the other countries where CIAT-coordinated network evaluations were instrumental for selection and release, adoption in Brazil was an entirely CIAT-independent process.

- *Brachiaria* spp. accessions that were used by CIAT internally to produce *Brachiaria* breeding lines and from which hybrid cultivars were developed by globally operating seed companies (Grupo Papalotla, Dow AgroSciences) within public-private-partnership (PPP) agreements, are not included either. Information on those hybrid cultivars (e.g. 'Mulato', Mulato II', 'Cayman', 'Cobra', 'Camello') is available in Cook *et al* (2020).
- Table 5 also provides information on the timespan between germplasm acquisition (collection or introduction) and cultivar release.

In the early 1990s, CIAT gradually changed its germplasm utilization research priority from development of grass/legume pastures for acid soils to selection of multipurpose plants for smallholders. This adjustment took into account the need for forage plants to maintain and restore soil fertility, including in mixed (crop-livestock) production systems, and to contribute to increased small-farmer livelihoods. Since 2006/07 the research focus of the CIAT Tropical Forages Program was further refined and includes the adaptation of forages to climate change and their potential contribution to ecosystem services, including the mitigation of greenhouse gas emissions. Within these new developments, species selection is benefiting from the broad diversity represented in the CIAT forages collection.

Table 4. The tropical forages collection conserved at the CIATgenebank (as of July 2020).

Genus	**No. of accessions**	**No. of** species
Grasses:		
Brachiaria	592	22
Panicum	544	11
Paspalum	140	19
Andropogon	89	2
Hyparrhenia	44	12
Pennisetum, Cenchrus, Echinochloa, Axonopus, Setaria, Eragrostis and *Chloris* (more than 10 accessions each) and 19 other genera	202	68
Total grasses	**1,611**	**134**
Legumes:		
Stylosanthes	4,198	31
Desmodium	3,484	71
Centrosema	2,849	33
Aeschynomene	1,182	33
Macroptilium	1,052	11
Vigna	1,026	36
Zornia	947	14
Galactia	561	13
Calopogonium	550	4
Rhynchosia	384	13
Teramnus, Chamaecrista, Desmanthus, Crotalaria, Alysicarpus, Pueraria, Canavalia, Dioclea, Leucaena, Indigofera, Flemingia, Uraria, Arachis, Clitoria, Lablab, Tephrosia, Phyllodium, Cajanus and *Tadehagi* (between 100 and 384 accessions each) and 59 other genera	4,848	378
Total legumes	**21,081**	**637**
Grand total	**22,692**	**771**

Table 5. Formally and informally released cultivars developed from accessions provided by the CIAT tropical forages collection.

Species	CIAT Accession no.	Year of acquisition[1]	Cultivar name	Country	Year of registration/ release	Comments
Legumes:						
Aeschynomene americana	CIAT 7026	C: 1978	Lee	Australia	1984	Collected in Panama in cooperation with IDIAP (Instituto de Investigación Agropecuaria de Panamá)
Arachis pintoi	CIAT 17434	I: 1983	Maní Forrajero Perenne	Colombia	1992	Introduced as CPI 58113 from CSIRO; = cv. Amarillo, released 1987 in Australia
			Pico Bonito	Honduras	1993	
			Maní Mejorador	Costa Rica	1994	
	CIAT 18744	I: 1984	Porvenir	Costa Rica	1998	Introduced as BRA-012122 from EMBRAPA
	Mix of CIAT 17434 and CIAT 18744	I: 1983 resp. 1984	Maní Forrajero	Panama	1997	See information on CIAT 17434 and CIAT 18744 above
	CIAT 22160	I: 1993	Reyan No. 12	PR China	2004	Introduced as BRA-031143 from EMBRAPA
Centrosema acutifolium	CIAT 5277	C: 1979	Vichada	Colombia	1987	Collected in Colombia
Centrosema macrocarpum	CIAT 25522; = mix of 12 accessions	C: 1980-84	Ucayali[2]	Peru SE Asia[3]	1992 1990s	Individual accessions collected in cooperation with national institution partners in Colombia (8 accessions), Venezuela (3) and Brazil (1)
Centrosema pubescens	CIAT 15160	C: 1984	Barinas[2]	SE Asia[3]	1990s	Collected in Venezuela in cooperation with FONAIAP
Chamaecrista rotundifolia	CIAT 21565	C: 1989	Minyin 2	PR China	2011	Collected in Colombia in cooperation with ICA; released after introduction as ATF 3248 from Australia to China
Codariocalyx gyroides	CIAT 3001	I: 1975	Belize[2]	SE Asia[3]	1990s	Introduced as CF-29 from IDRC-Belize
			Cora Cora[2]	Colombia	1990s	
Cratylia argentea	Mix of CIAT 18516 and CIAT 18668	I. resp. C.: 1985, 1984	Veranera Veraniega	Colombia Costa Rica	2002 2001	CIAT 18516 introduced from EMGOPA, CIAT 18668 collected in Brazil in cooperation with EMBRAPA

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Table 5 continued

Species	CIAT Accession no.	Year of acquisition[1]	Cultivar name	Country	Year of registration/ release	Comments
C. argentea (cont.)	Mixture of unknown CIAT accessions		Cratilia[2]	Venezuela	2000s	
				Bolivia	2000s	
Desmodium heterocarpon subsp. *ovalifolium*[4]	CIAT 13651	C: 1984	Maquenque	Colombia	2002	Collected in Thailand in cooperation with TISTR (Thailand Institute of Scientific and Technological Research)
	CIAT 350	I: 1973	Itabela	Brazil	1989	Commercial cover crop variety, introduced from FAO Seed Exchange Unit, Rome
			Reyan No. 16	PR China	2005	
Desmodium strigillosum	CIAT 13158	C: 1982	Reyan No. 27	PR China	2010s	Collected in Thailand in cooperation with TISTR
Flemingia macrophylla	CIAT 17403	C: 1982	Chumphon[2]	SE Asia[3]	1990s	Collected in Thailand in cooperation with TISTR
Leucaena leucocephala	CIAT 21888; mix of CIAT 17481, 17482, 17491 and 17492	C. resp. I.: 1982	Romelia	Colombia	1992	CIAT 17481 and 17482 collected as naturalized populations in Brazil; CIAT 17491 and 17492 introduced as K8 and K72, respectively, from University of Hawaii at Manoa
Stylosanthes capitata	CIAT 10280; mix of 5 accessions	C: 1975-77	Capica	Colombia	1983	All accessions (CIAT 1315, 1318, 1342, 1693 and 1728) collected in Brazil in cooperation with EMBRAPA and CSIRO
			Alfalfa Criolla[2]	Venezuela	1990s	
Stylosanthes guianensis var. *guianensis*	CIAT 184	C: 1973	Pucallpa	Peru	1985	Collected in Colombia
			Reyan No. 2	PR China	1991	Also known as 'Pi Hua Dou 184', 'Zhuhuacao'
			Reyan No. 5	PR China	2000	Selected from CIAT 184
			Stylo 184[2]	SE Asia[3]	1990s	
	CIAT 136	C: 1973	Reyan No. 7	PR China	2000	Collected in Colombia
	Unidentified CIAT accession number		Reyan No. 13	PR China	2003	Origin: mislabeled seed bags or a physical contaminant in a sample ("CIAT 1044") of a different species

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Table 5 continued

Species	CIAT Accession no.	Year of acquisition[1]	Cultivar name	Country	Year of registration/ release	Comments
S. guianensis var. *guianensis* (cont.)	CIAT 2340	C: 1980	Ubon stylo	Thailand	2002	Selection (GC 1480) used for the 4-line mix cv. Ubon stylo; see below; original accession CIAT 2340 collected in Colombia
Stylosanthes guianensis var. *pauciflora*[5]	CIAT 11833 (= cross CIAT 10136 × CIAT 2031)	C: 1974 C: 1978 Cross: 1991?	Ubon stylo	Thailand	2002	3 selections from CIAT 11833 (GC 1463, GC 1517, GC 1579) used for the 4-line mix cv. Ubon stylo; see above; original accessions CIAT 10136 and CIAT 2031 collected in Brazil in cooperation with EMBRAPA
	CIAT 1283	C: 1975	Reyan No. 10	PR China	2001	Collected in Brazil in cooperation with EMBRAPA
Stylosanthes seabrana	CIAT 10033	C: 1981	Unica	Australia	2000	Collected in Brazil in cooperation with EMBRAPA
Grasses:						
Andropogon gayanus	CIAT 621	I: 1973	Carimagua 1	Colombia	1980	Original seed sample introduced from Shika Research Station, Nigeria
			Planaltina	Brazil	1980	
			Sabanero	Venezuela	1983	
			Veranero	Panama	1983	
			San Martín	Peru	1984	
			Llanero	Mexico	1986	
			Andropogon	Cuba	1988	
			Veranero	Costa Rica	1989	
			Otoreño	Honduras	1989	
			Gamba	Nicaragua	1989	
			ICTA-Real	Guatemala	1992	
Brachiaria humidicola	CIAT 679	I: 1976	Humidícola	Colombia	1992	CIAT 679 is cv. Tully (Koronivia grass), released 1981 in Australia
			INIAP-NAPO 701	Ecuador	1985	

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Table 5 continued

Species	CIAT Accession no.	Year of acquisition[1]	Cultivar name	Country	Year of registration/ release	Comments
B. humidicola (cont.)	CIAT 679 (cont.)		Chetumal	Mexico	1991	
			Humidícola	Panama	1990	
			Aguja	Venezuela	1989	
	CIAT 26149	C: 1985	BRS Tupi	Brazil	2012	Collected in Burundi in cooperation with ISABU (Institut des Sciences Agronomiques du Burundi)
Brachiaria humidicola (former species name for the accession concerned: *B. dictyoneura*)	CIAT 6133	I: 1978	Llanero	Colombia	1987	Introduced as *B. dictyoneura* CPI 59610 from CSIRO
			Yanero[2]	SE Asia[3]	1990s	
			Ganadero	Venezuela	1992	
			Gualaca	Panama	1992	
			Brunca	Costa Rica	1994	
			Reyan No. 14	PR China	2004	
Brachiaria decumbens	CIAT 606	I: 1973	Brachiaria	Cuba	1986/87	CIAT 606 is cv. Basilisk, released 1966 in Australia
			Señal	Panama	1986	
			Chontalpo	Mexico	1989	
			Barrera	Venezuela	1989	
			Peludo	Costa Rica	1991	
			Reyan No. 3	PR China	1991	
Brachiaria hybrid	CIAT 16309 (*B. brizantha*)	C: 1984	BRS Ipyporã	Brazil	2017	*B. brizantha* CIAT 16309/ILCA 13619 (B4 at Embrapa), collected in Ethiopia in cooperation with ILCA, is one of the parental lines in the hybridization *B. brizantha* × *B. ruziziensis* that led to this Brazilian cultivar
Brachiaria ruziziensis	Unidentified CIAT accession number		Reyan No. 15	PR China	2005	Origin: mislabeled seed bags or a physical contaminant in a sample (“CIAT 6095”) of a different species
Brachiaria brizantha	CIAT 16125/ILCA 13372	C: 1984	BRS Piatã	Brazil	2007	Collected in Ethiopia in cooperation with ILCA

Continued on next page

Table 5 continued

Species	CIAT Accession no.	Year of acquisition[1]	Cultivar name	Country	Year of registration/ release	Comments
B. brizantha (cont.)	CIAT 16467/ILCA 12751	C: 1984	BRS Paiaguás	Brazil	2013	Collected in Kenya in cooperation with ILCA
	CIAT 26110	C: 1985	Toledo	Colombia	2002	Collected in Burundi in cooperation with ISABU
				Costa Rica	2001	
			Xaraés, MG5 Vitória	Brazil	2000/01	
	CIAT 6387	I: 1981	Serengeti[2]	SE Asia[3]	1990s	Introduced as K-75232A-E from FAO-Kitale, Kenya
	CIAT 16835	C: 1985	Karanga[2]	SE Asia[3]	1990s	Collected in Zimbabwe in cooperation with Grasslands Research Station Marondera
	CIAT 16315/ILCA 13635	C: 1984	Capiporã	Brazil	2003	Collected in Ethiopia in cooperation with ILCA
	CIAT 16488/ILCA 13079	C: 1984	Arapoty	Brazil	2003	Collected in Kenya in cooperation with ILCA
Panicum maximum	CIAT 6901	I: 1988	Reyan No. 8	PR China	2000	Introduced as K 71 from ORSTOM; origin: Kenya
	CIAT 6172	I: 1988	Reyan No. 9	PR China	2000	Introduced from Ecuador
	CIAT 6799	I: 1983	Agrosavia Sabanera	Colombia	2018	Introduced as G 27 from ORSTOM; origin: Angola
	CIAT 16051	I: 1983	Agrosavia Michaya	Colombia	2020[6]	Introduced as T 90 from ORSTOM; origin: Tanzania
Pennisetum purpureum × *P. glaucum*	CIAT 6263	I: 1979	Reyan No. 4	PR China	1998	King Grass; introduced from IDIAP, Panama

[1]C = year of collection; I = year of introduction of a donated accession; [2]no formal release; [3]several countries; [4]formerly known as *D. ovalifolium*; [5]taxon var. *pauciflora* not recognized by GRIN; [6]release programmed.

Distribution

The basis for effective and efficient utilization of CIAT's forage germplasm has been, and still is, the production and distribution of germplasm samples for plant introduction work by the Center´s GRU/GRP. Since 1980 a total of 93,222 germplasm samples, representing 14,695 accessions, were distributed to 110 countries. Approximately 41% of these samples went to CIAT's TPP/TFP. The remainder was distributed to users in Colombia (33%), Brazil (9%), Peru, China, Venezuela (4% each), Australia, Mexico, USA (3% each), and 102 other countries. Approximately 47% of all externally distributed samples went to national agricultural research institutes, 23% to universities, 16% to farmers, with the remainder going to CGIAR centers, NGOs, companies, regional organizations, and other genebanks worldwide (Figure 1). Seed samples were predominantly used for agronomic evaluations (64%), but also for basic research (13%), capacity building (12%) and other purposes such as applied research, genetic improvement and conservation, in alignment with the ITPGRFA and the SMTA. The list of accessions included in each seed shipment is linked to available passport data and more recently to accession-specific Digital Object Identifiers (DOI).

For evaluation trials and on-farm experimentation with accessions that were considered as highly promising by CIAT, its network partners and/or development agencies, seed in larger amounts has been/is being provided by the Tropical Forages Program (Tropical Pastures Program until 1992). Between 1982 and 2014, the TPP/TFP produced and distributed almost 64 tons of grass and legume seeds, either free of charge for research purposes or at cost price for larger quantities, representing a total of 27,325 samples, to 88 countries worldwide.

Some concluding remarks on the utilization and distribution of the CIAT forage germplasm collection

A strong multidisciplinary research program (TPP/TFP) at CIAT and its alliance with national partners and international networks was instrumental for effective and efficient utilization of the collection. This includes the capacity to supply sufficiently large seed samples for research beyond small-plot level and eventually for on-farm testing.

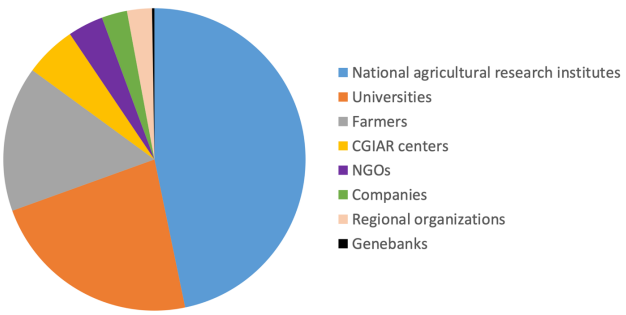

Figure 1. Historical distribution of 51,850 tropical-forage samples to different categories of germplasm users outside CIAT since the inception of CIAT's tropical forages collection.

The PPP arrangements between CIAT and the seed industry are proving to be conducive to increased adoption of improved-forage technology based on breeding lines.

The number of legume species (15), of which cultivars were released (33), contrasts with the number of grass species (9) and released cultivars (44). We suggest that this reflects, on the one hand, the particular focus of CIAT and its research partners on legumes in the past; on the other hand it reflects, to some extent, that the user community of tropical forages seems to be more receptive to grasses as they are easier to manage and have a better developed commercialization pathway.

Diversity in the forage germplasm collection

Basic plant descriptors have been used during both the germplasm multiplication phase by the GRU/GRP and the primary evaluation phase by the TPP/TFP to provide information on phenotypic diversity within a species and subsequent reduction of accession numbers for evaluation (e.g. the formation of core collections). In addition, molecular marker studies have been used to assess the genetic (= intraspecific) diversity and to elucidate species relationships for species of particular interest. On species that are little-known but of interest, basic floral-biology studies have been performed with the objective of optimizing germplasm management and enabling breeding. The main publications resulting from such research are listed below (section Publications).

The need for basic botanical and genetic studies to expand our knowledge about genera and species of forage interest must be stressed. Any future diversity research is recommended to focus on relevance for: (1) enhanced germplasm management and utilization (e.g. identification of duplicates, establishment of core collections); (2) relationships between traits and geographic origin of populations; and (3) identification of genes responsible for particularly important plant traits.

Sharing of knowledge

Training

During the period 1978−1990, the CIAT Tropical Pastures Program, within its coordinating role in the RIEPT network, held a yearly course 'Programa de Capacitación Científica en Investigación para la Producción de Pastos Tropicales'. The course, aimed at researchers from Latin America and the Caribbean, consisted of an intensive multi-disciplinary phase in which all participants were provided with lectures and practical training in all disciplines represented in the TPP (thus including the field of genetic resources of forage plants and germplasm handling) and a

specialization phase. With an average of 20 participants per course, a total of around 250 researchers were trained during the 13-year period, with about 10 specializing in genetic resources. In addition, several dozen students from both Colombian and foreign universities conducted research for their theses (BSc, MSc and PhD) with focus on genetic diversity of forages under the supervision of TPP/TFP scientists.

From 1990 onwards, training activities in forage germplasm management were essentially taken over by CIAT's GRU/GRP, mainly in the area of germplasm management and in the form of field days for Colombian university students and technicians, with demonstrations on field, greenhouse and laboratory activities. Several hundred students, technicians and researchers participated in this scheme.

Selected Publications

The following list comprises a selection of publications that, with regard to research topics and regions, we consider representative of the CIAT forage germplasm work during the past four decades:

Botanical studies

Schultze-Kraft, R., Williams, R.J. (1990). Una nueva especie de *Centrosema* (DC.) Benth. (Leguminosae: Papilionoideae) del Orinoco. *Caldasia* 16(77), 133–137. https://revistas.unal.edu.co/index.php/cal/article/view/35508

Torres, A.M. (1996). Un herbario de referencia para la colección de germoplasma de forrajes tropicales conservada por el Centro Internacional de Agricultura Tropical. *Pasturas Tropicales Boletín* 18(3), 71–74. https://cgspace.cgiar/handle/10568/87998

Maass, B.L., Torres González, A.M. (1998). Off-types indicate natural outcrossing in five tropical forage legumes in Colombia. *Tropical Grasslands* 32, 124–130. https://www.tropicalgrasslands.info/public/journals/4/Historic/Tropical%20Grasslands%20Journal%20archive/Abstracts/Vol_32_1998/Abs_32_02_98_pp124_130.ht ml

Bystricky, M., Schultze-Kraft, R., Peters, M. (2010). Studies on the pollination biology of the tropical forage legume shrub *Craylia argentea*. *Tropical Grasslands* 44, 246–252. https://www.tropicalgrasslands.info/public/journals/4/Historic/Tropical%20Grasslands%20Journal%20archive/PDFs/Vol_44%20(1_2_3_4)/Vol%2044%20(4)%20Bystricky%20et%20al%20246.pdf

Calles, T., Schultze-Kraft, R. (2010). Re-establishment of *Stylosanthes gracilis* (Leguminosae) at species level. *Kew Bulletin* 65(2), 233–240. doi: 10.1007/s12225-010-9198-z

Calles, T., Schultze-Kraft, R. (2010). *Stylosanthes* (*Leguminosae, Dalbergieae*) of Venezuela. *Willdenowia* 40, 305–329. doi: 10.3372/wi.40.40211

Germplasm collection and biogeography

Schultze-Kraft, R., Reid, R., Williams, R.J., Coradin, L. (1984). The existing *Stylosanthes* collections. In *The biology and agronomy of* Stylosanthes, eds. H.M. Stace & L.A. Edye. (North Ryde, N.S.W.: Academic Press Australia), p. 125–146. doi: 10.1016/B978-0-12-661680-4.50011-1

Schultze-Kraft, R., Pattanavibul, S., Gani, A., He, C., Wong, C.C. (1989). Collection of native germplasm resources of tropical forage legumes in Southeast Asia. In *Proceedings of the XVI International Grassland Congress, Nice, France*, p. 271–272.

Schultze-Kraft, R., Williams, R.J., Coradin, L., Lazier, J.R., Kretschmer Jr, A.E., Franco, M.A., Hernández, C.A. (1989). *1989 world catalog of* Centrosema *germplasm / Catálogo 1989 mundial de germoplasma de* Centrosema. (Cali, Colombia: CIAT and IBPGR), 319 p. https://hdl.handle.net/10568/53945

Costa, N.M.S., Schultze-Kraft, R. (1990). Biogeografia de *Stylosanthes capitata* Vog. e S. *guianensis* Sw. var. *pauciflora*. *Pesquisa Agropecuária Brasileira* 25(11), 1547–1554. https://seer.sct.embrapa.br/index.php/pab/article/view/13685

Schultze-Kraft, R., Williams R.J., Coradin, L. (1990). Biogeography of *Centrosema*. In Centrosema: *Biology, agronomy, and utilization*, eds. R. Schultze-Kraft & R.J. Clements. CIAT Publication No. 92. (Cali, Colombia: CIAT), p. 29–76. https://books.google.com.co/books?id=MMsSFJwy63gC&lpg=PP1&pg=PA29#v=onepage&q&f=false

Coradin, L., Schultze-Kraft, R. (1990). Germplasm collection of tropical pasture legumes in Brazil. *Tropical Agriculture (Trinidad)* 67(2), 98–100. https://journals.sta.uwi.edu/ta/index.asp?action=viewPastAbstract&articleId=1751&issueId=217

Franco, M.A., Ocampo, G.I., Melo, E., Thomas, R. (Comp.). (1993). *Catálogo de cepas de rizobios para leguminosas forrajeras tropicales / Catalogue of rhizobium strains for tropical forage legumes*. Working Document No. 14, 5th Edn. (Cali, Colombia: CIAT), 123 p. http://ciat-library.ciat.cgiar.org/forrajes_tropicales/pdf/4th/wd14.pdf

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Keller-Grein, G., Maass, B.L., Hanson, J. (1996). Natural variation in *Brachiaria* and existing germplasm collections. In Brachiaria: *Biology, agronomy, and improvement*, eds. J.W. Miles, B.L. Maass, C.B. do Valle, V. Kumble. CIAT Publication No. 259. (Cali, Colombia: CIAT and EMBRAPA-CNPGC), p. 16–42. https://books.google.com.co/books?id=dMF6QpfVdjMC&lpg=PP1&pg=PA16#v=onepage&q&f=false

Diversity studies, including characterization and preliminary evaluation

Schultze-Kraft, R., Costa, N.M.S., Flores, A. (1984). *Stylosanthes macrocephala* M.B. Ferr. et S. Costa – Collection and preliminary agronomic evaluation of a new tropical pasture legume. *Trocpical Agriculture (Trinidad)* 61(3), 230–240. https://jounals.sta.uwi.edu/ta/index.asp?ation=viewPastAbstract&articleId=2322&issueId=243

Pizarro, E.A. (comp.). (1985). *Red de Evaluación de Pastos Tropicales – Resultados 1982−1985*. III Reunión de la RIEPT, Octubre 21−24, 1985. 2 Vols. (Cali, Colombia: CIAT), 1228 p. https://hdl.handle.net/10568/56339

Schultze-Kraft, R., Benavides, G. (1988). Germplasm collection and preliminary evaluation of *Desmodium ovalifolium* Wall. *Genetic Resources Communication No. 12*. (St. Lucia, Qld., Australia: CSIRO, Division of Tropical Crops and Pastures), 20 p. https://www.tropicalgrasslands.info/public/journals/4/GRC/GRC12%5b1792%5d.pdf

Torres González, A.M., Morton, C.M. (2005). Molecular and morphological phylogenetic analysis of *Brachiaria* and *Urochloa* (Poaceae). *Molecular Phylogenetics and Evolution* 37, 36–44. doi: 10.1016/j.ympev.2005.06.003

Andersson, M.S., Peters, M., Schultze-Kraft, R., Gallego, G., Duque, M.C. (2006). Molecular characterization of a collection of the tropical multipurpose shrub legume *Flemingia macrophylla*. *Agroforestry Systems* 68(3), 231–245. doi: 10.1007/s10457-006-9014-9

Andersson M.S., Schultze-Kraft, R., Peters, M., Duque, M.C., Gallego, G. (2007). Extent and structure of genetic diversity in a collection of the tropical multipurpose shrub legume *Cratylia argentea* (Desv.) O. Kuntze as revealed by RAPD markers. *Electronic Journal of Biotechnology* 10(3), 386–399. doi: 10.2225/vol10-issue3-fulltext-2

Research methodologies

Mott, G.O., Jiménez, C.A. (eds.). (1979). *Handbook for the collection, preservation and characterization of tropical forage germplasm resources.* (Cali, Colombia: CIAT), 95 p. https://hdl.handle.net/10568/54059

Paladines, O., Lascano, C.E. (eds.). (1993). *Forage germplasm under small-plot grazing: Evaluation methodologies.* CIAT Publication No. 210. (Cali, Colombia: RIEPT – CIAT), 249 p. https://hdl.handle.net/10568/56518

Toledo, J.M. (ed.). (1982). *Manual para la evaluación agronómica: Red Internacional de Evaluación de Pastos Tropicales (RIEPT)*. (Cali, Colombia: CIAT), 150 p. https://hdl.handle.net/10568/54148

Schultze-Kraft, R., Mannetje, L.'t. (2000). Evaluation of species and cultivars. In *Field and laboratory methods for grassland and animal production research*, eds. L.'t Mannetje & R.M. Jones. (Wallingford, UK: CAB International), 179–204. doi: 10.1079/9780851993515.0179

Monographs

Schultze-Kraft, R., Clements, R.J. (eds.). (1990). Cen-trosema: *Biology, agronomy, and utilization*. CIAT Publication No. 92. (Cali, Colombia: CIAT), 667 p. https://hd l.handle.net/10568/54383

Toledo, J.M., Vera, R., Lascano, C., Lenné, J.M. (eds.). (1990). Andropogon gayanus *Kunth – a grass for tropicalacid soils*. CIAT Publication No. 90. (Cali, Colombia: CIAT), 381 p. https://hdl.handle.net/10568/54190

Kerridge, P.C., Hardy, B. (eds.). (1994). *Biology and agronomy of forage* Arachis. CIAT Publication No. 240. (Cali, Colombia: CIAT), 209 p. https://hdl.handle.net/10568/54359

Miles, J.W., Maass, B.L., Valle, C.B. do, Kumble, V. (eds.). (1996). Brachiaria: *Biology, agronomy, and improvement.* CIAT Publication No. 259. (Cali, Colombia: CIAT and EMBRAPA-CNPGC), 288 p. https://hdl.handle.net/10568/54362

Cook, B.G., Pengelly, B.C., Schultze-Kraft, R., Taylor, M., Burkart, S., Cardoso Arango, J.A., González Guzmán, J.J., Cox, K., Jones, C., Peters, M. (2020). Tropical Forages: An interactive selection tool. 2nd and revised Edn. (Cali, Colombia and Nairobi, Kenya: CIAT and ILRI). www.tropicalforages.info

Some thoughts about the value of the CIAT tropical forages germplasm collection

Having safeguarded the germplasm is a major achievement in view of increasing world-wide genetic erosion due to habitat destruction and land use changes. The very availability of conserved germplasm represents an option value whose potential impact cannot be calculated and should not be underestimated.

Given that the CIAT tropical forages collection is an in-trust collection, held by CIAT on behalf of the countries of origin of the accessions, another incalculable option value is that all accessions stored in the genebank are available to users under an SMTA at any time. In this context, an important potential benefit to the 75 countries of origin of the germplasm conserved at CIAT's genebank is that it is available for repatriation.

The present report has to content itself with showing the number of released cultivars developed from CIAT's forages collection. An estimation of the total economic benefits derived from the collection is beyond the possibilities of genebank managers or scientists engaged in developing varieties. For this, field studies are suggested to be necessary, which have to involve resource economists for the assessment of acreages planted to the new cultivars, resulting livestock production increases, benefits to the environment (e.g. soil conservation and improvement) and estimates of increased livelihoods of end users.

Some considerations for the future

Although this report is concerned with both past and present, a couple of thoughts related to the future seem to be appropriate. Funding for tropical-forage research and deployment has declined considerably

over the last decades. *Ex situ* conservation of forages is substantially more expensive on a per-accession basis than conservation of other crops such as grains and pulses because cross-pollinating, wild and/or weedy accessions with long, asynchronous life cycles are substantially more expensive to regenerate thaninbred crops with short, synchronous life cycles (Koo *et al*, 2003), yet funding for tropical-forage research and deployment has declined considerably over the last decades. Accordingly, to ensure the long-term conservation and availability of critically important tropical-forage genetic resources, genebanks need to focus on the species with the greatest forage potential. A panel of well-known tropical-forage experts has grouped the species conserved at the CIAT and ILRI collections into priority categories based on the species' proven or suspected forage potential (Pengelly, 2015). Lowpriority accessions of both collections will be archived to focus conservation efforts on more promising species, with a view towards multiplying selected groups of 'bestbet' accessions so that larger quantities of starter seeds can be provided for research projects to shorten the path between the genebank and germplasm use in the field.

Compared with tropical-forage collections at ILRI in Ethiopia (17K accessions), USDA in the US (15K accessions), KARI (Kenya Agricultural Research Institute) in Kenya (15K accessions), the Australian Pastures Genebank (APG) in Australia (13K accessions), EMBRAPA in Brazil (9K accessions), INTA in Argentina, and IGFRI (Indian Grassland and Fodder Research Institute) in India, CIAT's collection is particularly rich in legumes adapted to infertile, acid soils. A full list of accessions, including passport data, photos of plants, flowers and seeds and images of herbarium specimens, can be accessed on the Genesys web portal by filtering for 'COL003' for CIAT and 'forages' as a crop (https://www.genesys-pgr.org).

In 2021, the CIAT genebank will achieve all the CGIAR Genebank Platform's 'performance targets' for its forage collection (Crop Trust, 2016). One of these targets is making more than 90% of all accessions available for immediate distribution, which means the genebank holds sufficient numbers of seeds that have been tested and found to be free of more than 40 different pathogens of quarantine importance. The collection, therefore, will qualify for long-term funding from the Endowment Fund of the Global Crop Diversity Trust to ensure its in-perpetuity conservation.

Although increasing germplasm collections by further collecting is currently difficult to justify, the policy framework may change over time, for example through an expansion of the ITGPRFA's scope to include all plant genetic resources for food and agriculture. Efforts to identify the most important collection gaps, therefore, are indicated to prepare for future collections. As suggested above, the forage germplasm collections currently conserved at the aforementioned genebanks, in addition to those at the CGIAR centers ICARDA (International Center for Agricultural Research in the Dry Areas) and World Agroforestry Centre (ICRAF) cannot be considered adequately representative of the geographic and taxonomic/genetic diversity of the tropical and subtropical Poaceae and Fabaceae (Leguminosae), neither at the level of the individualcollections nor at that of their consolidated total. It is suggested that such gap analyses:

- Consider both neglected areas/regions and genera/species of particular interest with emphasis on potential as forage and for environmental services.
- Be based on ecogeographical surveys paying particular attention to regions where biodiversity loss (including danger of genetic erosion) has been identified and/or is likely to occur.
- Consider the need for germplasm with focus on adaptation to the particular environmental challenges of the future in terms of the effects of climate change, such as increasing soil salinity, rising water table (including flooding), drought, temperature extremes etc. Collecting is suggested in areas of currently similar conditions under the assumption that germplasm occurring there has genetic adaptation to the respective limiting factors.

Such gap analyses can be the basis for future internationally coordinated collecting actions — when they become feasible — but independently may also stimulate immediate plans of action at national levels.

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Supplemental data

Supplemental Table 1: Recent nomenclatural changes of tropical forage species mentioned in this document under their previous names, based on the taxonomy accepted by the USDA Genetic Resources Information Network (GRIN).

Supplemental Table 2: Plant collectors who participated in the collecting missions mentioned in Table 1.

Author contributions

R.S.K. contributed to the conception and design of the submitted manuscript. All authors contributed to data gathering and analysis and to the drafting, revision and final approval of the submitted manuscript. The views expressed in this publication are those of the authors and do not necessarily reflect the views of CIAT, now part of the Alliance of Bioversity International and CIAT.

Conflict of interest statement

The Authors declare no conflict of interest.

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