A historical appraisal of the tropical forages collection conserved at CIAT

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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).

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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)                                               | Legumes: *Centrosema*, *Desmodium*, *Stylosanthes* & others |
|          | **South America**: Brazil (1), Colombia (1), Venezuela (1)                 | Legumes: *Centrosema*, *Desmodium*, *Stylosanthes* & others |
|          | **Southeast Asia**: Thailand (1)                                          | 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)                                 | Legumes: *Centrosema*, *Desmodium*, *Stylosanthes* & others |
|          | **Southeast Asia**: Malaysia (1), Papua New Guinea (1), Thailand (1)       | Legumes: *Desmodium*, *Pueraria* & others              |
| 1984     | **South America**: Brazil (1), Colombia (3), Venezuela (1)                 | Legumes: *Centrosema*, *Desmodium*, *Stylosanthes* & others |
|          | **Africa**: Ethiopia (1), Kenya (1)                                       | Grasses: Mainly *Brachiaria*                          |
|          | **Southeast Asia**: China (1), Indonesia (1), Thailand (1)                | Legumes: *Desmodium*, *Pueraria* & others              |
| 1985     | **Mesoamerica**: Panama (1)                                               | Legumes: *Centrosema*, *Desmodium*, *Stylosanthes* & others |
|          | **South America**: Colombia (1), Venezuela (1)                            | Legumes: *Centrosema*, *Desmodium*, *Stylosanthes* & others |
|          | **Africa**: Burundi (1), Rwanda (1), Tanzania (1), Zimbabwe (1)            | Grasses: Mainly *Brachiaria*                          |
|          | **Southeast Asia**: Indonesia (1)                                         | Legumes: *Desmodium*, *Pueraria* & others              |
| 1986     | **Mesoamerica**: Costa Rica (1), Mexico (1)                               | Legumes: *Centrosema*, *Desmodium*, *Stylosanthes* & others |
|          | **South America**: Colombia (3), Venezuela (2)                            | Legumes: *Centrosema*, *Desmodium*, *Stylosanthes* & others |
|          | **Southeast Asia**: Indonesia (1)                                         | Legumes: *Desmodium*, *Pueraria* & others              |
| 1987-88  | **South America**: Brazil (1), Colombia (5)                               | Legumes: *Centrosema*, *Desmodium*, *Stylosanthes* & others |
|          | **Southeast Asia**: China (1), Thailand (1)                               | Legumes: *Desmodium*, *Pueraria* & others              |
| 1989-90  | **Mesoamerica**: Honduras (1)                                             | Legumes: *Centrosema*, *Desmodium* & others           |
|          | **South America**: Colombia (1)                                           | Legumes: *Centrosema*, *Desmodium*, *Stylosanthes* & others |
|          | **Africa**: Cameroon (1)                                                  | Grasses: *Hyparrhenia*, *Andropogon* & others         |
| 1991-93  | **South America**: Colombia (2)                                           | Legumes: *Centrosema*, *Desmodium*, *Stylosanthes* & others |
|          | **Southeast Asia**: Thailand (1), Vietnam (2)                             | 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 origin¹ |
|-------------|----------------|-------------------|----------------------|
| **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, 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, PYF, SLV, TGO, THA, VEN, VNM, ZWE |
| Diosclea    | 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, CRI, 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, TGO, THA, VEN, ZWE |
| 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 origin¹ |
|------------|----------------|-------------------|----------------------|
| 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

| Genus      | No. of species | No. of accessions | Countries of origin¹ |
|------------|----------------|-------------------|----------------------|
| 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 Guiana; 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 cv. 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 institutions¹ |
|----------|-------------------------|-----------------------------------------------------------------------------|--------------------------|
| 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                   |                                                                             |                          |

¹Abbreviations 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 CIAT genebank (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              |
| *Rhynchosis*                       | 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                                                        |
|                          | 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 25277         | C: 1979                     | Vichada        | Colombia    | 1987                         | Collected in Colombia                                                                                                                  |
| *Centrosema macrocarpum* | Mix of 12 accessions | C: 1980-84                  | Ucayali\(^2\)  | SE Asia\(^3\) | 1992                         | 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                                                                                                  |
| *Cratylia argentea*      | Mix of CIAT 18516 and CIAT 18668 | I. resp. C.: 1985, 1984     | Veranera       | Colombia    | 2002                         | CIAT 18516 introduced from EMGOPA, CIAT 18668 collected in Brazil in cooperation with EMBRAPA                                          |
|                          |                    |                             | Veraniega      | Costa Rica  | 2001                         |                                                                                                                                        |

Continued on next page
### Table 5 continued

| Species                        | CIAT Accession no. | Year of acquisition | Cultivar name | Country | Year of registration/release | Comments                                                                                                                                 |
|-------------------------------|--------------------|---------------------|---------------|---------|-----------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|
| *C. argentea* (cont.)         | Mixture of unknown CIAT accessions |                    | Cratilia\(^2\) | Venezuela | 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             | Pucalpa       | 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 | C: 1973        | Reyan No. 13  | PR China | 2003 | Origin: mislabeled seed bags or a physical contaminant in a sample (“CIAT 1044”) of a different species                                                                                   |

Continued on next page
| Species | CIAT Accession no. | Year of acquisition | 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 |
| *S. guianensis* var. *pauciflora* | 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 |
| *S. guianensis* var. *guianensis* (cont.) | CIAT 1283 | C: 1975 | Reyan No. 10 | PR China | 2001 | Collected in Brazil in cooperation with EMBRAPA |
| *S. guianensis* var. *guianensis* (cont.) | CIAT 10033 | C: 1981 | Unica | Australia | 2000 | Collected in Brazil in cooperation with EMBRAPA |

**Grasses:**

| Species | CIAT Accession no. | Year of acquisition | Cultivar name | Country | Year of registration/release | Comments |
|---------|------------------|-------------------|--------------|---------|-----------------------------|----------|
| *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 | Humidicola | Colombia | 1992 | CIAT 679 is cv. Tully (Koronivia grass), released 1981 in Australia |
| | | | INIAP-NAPO 701 | Ecuador | 1985 |

Continued on next page
| Species                  | CIAT Accession no. | Year of acquisition | Cultivar name | Country     | Year of registration/release | Comments                                                                                                                                 |
|--------------------------|--------------------|---------------------|---------------|-------------|-----------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| *B. humidicola*          | 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* | CIAT 6133          | I: 1978             | Llanero       | Colombia    | 1987                        | Introduced as *B. dictyoneura* CPI 59610 from CSIRO                                                                               |
| (former species name for |                    |                     | Yanero²       | SE Asia³    | 1990s                       |                                                                                                                                           |
| the accession concerned: |                    |                     | Ganadero      | Venezuela   | 1992                        |                                                                                                                                           |
| *B. dictyoneura*        |                    |                     | 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         | C: 1984             | BRS Ipyporã   | Brazil      | 2017                        |                                                                                                                                           |
| (*B. brizantha*)        |                    |                     |               |             |                             | **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  |                     | Reyan No. 15  | PR China    | 2005                        | Origin: mislabeled seed bags or a physical contaminant in a sample ("CIAT 6095") of a different species                               |
| accession number        |                    |                     |               |             |                             |                                                                                                                                           |
| *Brachiaria brizantha*  | CIAT 16125/ILCA 13372 | C: 1984            | BRS Piatã     | Brazil      | 2007                        | Collected in Ethiopia in cooperation with ILCA                                                                                           |

*Continued on next page*
| Species | CIAT Accession no. | Year of acquisition | 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 | 2000/01 | |
| | CIAT 6387 | I: 1981 | Serengeti² | SE Asia³ | 1990s | Introduced as K-75232A-E from FAO-Kitale, Kenya |
| | CIAT 16835 | C: 1985 | Karanga² | SE Asia³ | 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 | 2020⁶ | 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 |

¹C = year of collection; ²I = year of introduction of a donated accession; ³no formal release; ⁴several countries; ⁵formerly known as *D. ovalifolium*; ⁶taxon var. *pauciflora* not recognized by GRIN; ⁷release 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.

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 Oriñoco. 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. Pasturazgo Tropical Reportes 32, 124–130. https://www.tropicalgrasslands.info/public/journals/4 /Historic/Tropical%20Grasslands%20Journal%20archive/Abstracts/Vol_32_1998/Abs_32_02_98_p-p124_130.html

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%202010.pdf

Calles, T., Schultze-Kraft, R. (2010). Re-establishment of Stylosanthes gracilis (Leguminosae) at species level. Revestaz. Tropical 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., Patannavibul, 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 mundial de germoplasma de Centrosema. (Cali, Colombia: CIAT and IBPGR), 319 p. https://hdl.handle.net/10568/35945

Costa, N.M.S., Schultze-Kraft, R. (1990). Biogeografía de Stylosanthes capitata Vog. e S. guianensis Sw. var. pauciflora. Pesquisas Agropecuárias Brasileiras 25(11), 1547–1554. https://seer.embraer.br/index.php/pab/article/view/13685

Schultze-Kraft, R., Williams R.J., Coradin, L. (1990). Germplasm collection of tropical pasture legumes in Brazil. Tropical Agriculture (Trinidad) 67(2), 98–100. https://journals.sota.uwi.edu/ta/index.asp?action=viewPastAbstract&articleId=1751&issueld=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/forrages_tropicales/pdf/4th/wd14.pdf

Flores, A.J., Schultze-Kraft, R. (1994). Recolección de recursos genéticos de leguminosas forrajeras tropicales en Venezuela. Agronomía Tropical 44(3), 357–371.

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=DMFQOpVdjMC&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). Stylolotes macrocephala M.B. Ferr. et S. Costa – Collection and preliminary agronomic evaluation of a new tropical pasture legume. *Tropical Agriculture (Trinidad)* 61(3), 230–240. [https://journals.sata.uwi.edu/ta/index.aspx?ation=viewPastAbstract&amp;articleId=2322&amp;issuedId=243](https://journals.sata.uwi.edu/ta/index.aspx?ation=viewPastAbstract&amp;articleId=2322&amp;issuedId=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](https://hdl.handle.net/10568/56339)

Schultze-Kraft, R., Benavides, G. (1988). Germplasm collection and preliminary evaluation of *Desmodium ovalifolium* Wall. collection and preliminary agronomic evaluation of a new tropical pasture legume. *Tropical Agriculture (Trinidad)* 61(3), 230–240. [https://journals.sata.uwi.edu/ta/index.aspx?ation=viewPastAbstract&amp;articleId=2322&amp;issuedId=243](https://journals.sata.uwi.edu/ta/index.aspx?ation=viewPastAbstract&amp;articleId=2322&amp;issuedId=243)

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., Schultz–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., Schultz–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 *Cratyli a 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](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](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](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). *Centrosema: Biology, agronomy, and utilization*. CIAT Publication No. 92. (Cali, Colombia: CIAT), 667 p. [https://hdl.handle.net/10568/54383](https://hdl.handle.net/10568/54383)

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

Kerridge, P.C., Hardy, B. (eds.). (1994). *Biological and agronomy of forage Arachis*. CIAT Publication No. 240. (Cali, Colombia: CIAT), 209 p. [https://hdl.handle.net/10568/54359](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](https://hdl.handle.net/10568/54362)

Cook, B.G., Pengelly, B.C., Schultz–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](http://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 than inbred 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). Low-priority 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 ITGPRFAs 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 individual collections 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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