Tropical Grasslands-Forrajes Tropicales (2023) Vol. 11(2):95–120
doi: 10.17138/TGFT(11)95-120

Review Article

Stylosanthes guianensis CIAT 184 – review of a tropical forage legume*

Stylosanthes guianensis *CIAT 184 – reseña de una leguminosa forrajera tropical*

RAINER SCHULTZE-KRAFT[1], YANG HUBIAO[2], TANG JUN[2] AND LIU GUODAO[2]

[1]*International Center for Tropical Agriculture (CIAT), Cali, Colombia.* alliancebioversityciat.org
[2]*Tropical Crops Genetic Resources Institute (TCGRI), Chinese Academy of Tropical Agricultural Sciences (CATAS), Danzhou, Hainan, PR China.* catas.cn

Abstract

A comprehensive review, based on about 180 references, synthesizing research and development about *Stylosanthes guianensis* accession CIAT 184 is presented. This genotype has been widely tested across the tropics and was developed into commercial cultivars in several countries. Agronomic evaluations in a range of disciplines and other research in numerous countries of tropical America, Africa, Southeast Asia and China, and utilization of the legume by farmers are reported. CIAT 184 is particularly successful in southern China, where it gave origin to 5 cultivars. Its outstanding feature is an apparently durable tolerance of the fungal disease, anthracnose (*Colletotrichum gloeosporioides*), throughout the tropics, with exception of the savanna ecozone in tropical America. Further assets include adaptation to acid, infertile soils, drought tolerance and high production of nutritious dry matter that can be used as traditional forage for ruminants and as leaf meal or pellets to feed monogastrics. CIAT 184 has also found application for soil conservation and improvement (such as erosion control, mulch and green manure), alone or in association with crops and trees. Published work dealing with basic research, mainly conducted in China, is presented. The review concludes with a brief discussion on the current adoption of CIAT 184 and with suggestions regarding future perspectives and research needs.

Keywords: Adoption, anthracnose, multilocational evaluation, multipurpose use, research, stylo.

Resumen

Se presenta una reseña, basada en algo más de 180 trabajos publicados, sobre la leguminosa *Stylosanthes guianensis* CIAT 184, un genotipo ampliamente investigado a través del trópico y del cual se desarrollaron cultivares comerciales en varios países. Se sintetizan los resultados de evaluaciones y otras investigaciones realizadas en numerosos países de América tropical, África, el sudeste asiático y en China, y se informa sobre los diferentes usos de la leguminosa en los sistemas de producción agrícola. CIAT 184 es particularmente exitoso en el sur de China donde dio origen a cinco cultivares. Su característica sobresaliente es la aparentemente duradera tolerancia a la antracnosis (causada por el hongo *Colletotrichum gloeosporioides*) a través del trópico, con excepción de la ecozona 'sabana' en América tropical. La adaptación a suelos ácidos y de baja fertilidad, la tolerancia a sequía y la alta producción de nutritiva materia seca son otras características destacadas del CIAT 184, junto con su potencial para usos distintos al de forraje para rumiantes, como la producción de harina foliar peletizada para monogástricos. Otros usos son para la conservación y el mejoramiento del suelo (control de erosión, mulch, abono verde), solo o en asociación con cultivos y/o árboles. Se presenta una serie de publicaciones sobre

*Dedicated to the memory of two eminent pioneers of *Stylosanthes* research: Dr Bert Grof and Dr Bai Changjun.

Correspondence: R. Schultze-Kraft, International Center for Tropical Agriculture (CIAT), Cali, Colombia.
Email: r.schultzekraft@cgiar.org

investigación básica, conducida especialmente en China. La reseña concluye con una breve discusión de la adopción del CIAT 184 y con sugerencias sobre perspectivas futuras y necesidades de investigación.

Palabras clave: Adopción, antracnosis, evaluación multilocacional, investigación, stylo, uso multipropósito.

Introduction and background

Stylosanthes Sw. [family *Fabaceae* (alt. *Leguminosae*)] is a mainly neotropical genus with currently 40 species accepted by the taxonomy of the Germplasm Resources Information Network (GRIN) of the US National Plant Germplasm System (GRIN 2023). Since many *Stylosanthes* species are found on infertile soils and tolerate drought, the genus, often referred to as 'stylo', has been attracting the attention of tropical forage legume researchers since the 1930s (Burt and Miller 1975).

Owing to its yield potential, a species of particular interest has been *S. guianensis* (Aubl.) Sw., better known up to the late 1960s by practitioners under the name of *S. gracilis* (Tuley 1968; Audru 1971). In addition to var. *guianensis*, 5 botanical varieties are recognized in this species by GRIN taxonomy (GRIN 2023). When no botanical variety is mentioned in this paper, '*S. guianensis*' always refers to *S. guianensis* var. *guianensis*.

S. guianensis has a wide natural distribution ranging from latitude 23° N in Mexico to 27° S in Argentina (Williams et al. 1984) and exhibits a particularly wide morphological diversity (Costa 2006). Wild populations are mostly found on well-drained, low to medium fertility soils at low to medium elevations (10–1,700 masl, occasionally higher), mainly in regions with wet-subhumid climate[1]. Research for cultivar development and use of *S. guianensis*, until the mid 1970s an essentially Australian activity, is documented in the scientific literature. Compilations can be found in 4 key books: Burt et al. (1983); Stace and Edye (1984); de Leeuw et al. (1994); and Chakraborty (2004a). A factsheet summarizing updated information on *S. guianensis* and its botanical varieties was recently published in the database, 'Tropical Forages - an interactive selection tool' (Cook et al. 2020).

From the 1970s onwards, an important issue has been tolerance of the fungal disease, anthracnose (caused by *Colletotrichum gloeosporioides*), the biotic factor constraining the use of all better-known *Stylosanthes* species, including *S. guianensis* (Chakraborty 2004b). The search for genotypes tolerant of this disease and adapted to infertile soils and drought, led to increased efforts, in the 1970s and 1980s, to broaden the genetic diversity available to the research community by exploring the native vegetation and collecting germplasm of *Stylosanthes* in (sub)tropical America. Among the various institutions involved in those collecting and conservation efforts was the International Center for Tropical Agriculture (CIAT), whose genebank conserved a total of 4,200 *Stylosanthes* accessions in May 2020 (Schultze-Kraft et al. 2020). The subject of this review, *S. guianensis* accession CIAT 184, stems from one of CIAT´s early collecting endeavors in Colombia.

In this paper we review CIAT 184 by compiling, in an essentially region- and country-oriented approach, information from research conducted throughout the tropics and subtropics, with the objective to contribute to continuing interest of the research and development (R&D) community in this genotype. The focus is on information from studies that we consider to be of interest to a reasonably broad readership. Wherever possible, we concentrated on accessible published literature as information sources. A brief analyis of the reasons for the success of CIAT 184 in some regions and lack of adoption in others and some thoughts on future perspectives are presented.

Origin of CIAT 184

The origin dates back to 12 October 1973, when one of the authors (R.S.K.) collected seeds from a *S. guianensis* population at a location (03°13'28" N, 76°33'45" W; 975 masl) close to Jamundí town, south of Cali in the Valle del Cauca department, Colombia. The sampled plants were part of occasionally grazed roadside vegetation (major component: native *Paspalum notatum*). Topography

[1]An important exception is the 'tardío' morphotype of *S. guianensis*, which is found in dry subhumid savanna climate on sandy and very acid, infertile soils. This morphotype is also known in the literature as '*S. guianensis* var. *pauciflora* M.B. Ferreira & Sousa Costa', a taxon not accepted as a botanical variety by GRIN taxonomy, where it is referred to as *S. guianensis* var. *guianensis*.

in the area is flat and the soil was recorded as a well-drained clayey Ultisol, acid (pH 4.9 in H_2O) and with low phosphorus (1.8 ppm P; Bray II). Annual rainfall in the area is about 1,900 mm.

The collected seed sample entered the CIAT tropical forages collection as accession CIAT 184. Within subsequent germplasm exchanges with genebanks it was alternatively catalogued under different accession numbers (e.g. 'ILCA/ILRI 164' and 'CPI 133548').

Morphological description

The following description is based on that by Cook et al. (2020) for *S. guianensis* var. *guianensis* in general, and complemented with accession-specific observations and measurements of morphological features provided by one of the authors (Y.H.) and with photographic illustrations (Figure 1).

A robust weakly perennial herb, semi-erect, growing to 1.5 m with a strong taproot and small round root nodules. Stem much branched, herbaceous and, with age, becoming lignified at the base, indumentum nearly glabrous. Leaves trifoliolate; petiole ca. 8 mm, rachis ca. 1 mm long; stipules 8–12 mm, adnate to the petiole, teeth ca. 5 mm long; leaflets lanceolate, ca. 30 mm × 4 mm, indumentum as on stems. Inflorescence a loosely capitate spike, terminal or axillary, with more than 4 flowers. Flower subtended by an outer bract with a 5–9 mm long sheath, a ca. 6 mm long outer bracteole and a ca. 5 mm long inner bracteole; calyx tube ca. 5 mm long; standard ca. 8 mm × 4 mm, yellow with slender reddish-brown stripes; wings and keel 3.5–5 mm long. Pod 1-jointed, the article ovoid, ca. 2.6 mm × 1.5 mm, glabrous, indistinctly veined, with a minute beak, strongly inflexed. Seed oblate-ellipsoid, ca. 2.1 mm × 1.5 mm, color varying from yellow to dark brown. About 400,000 seeds per kg.

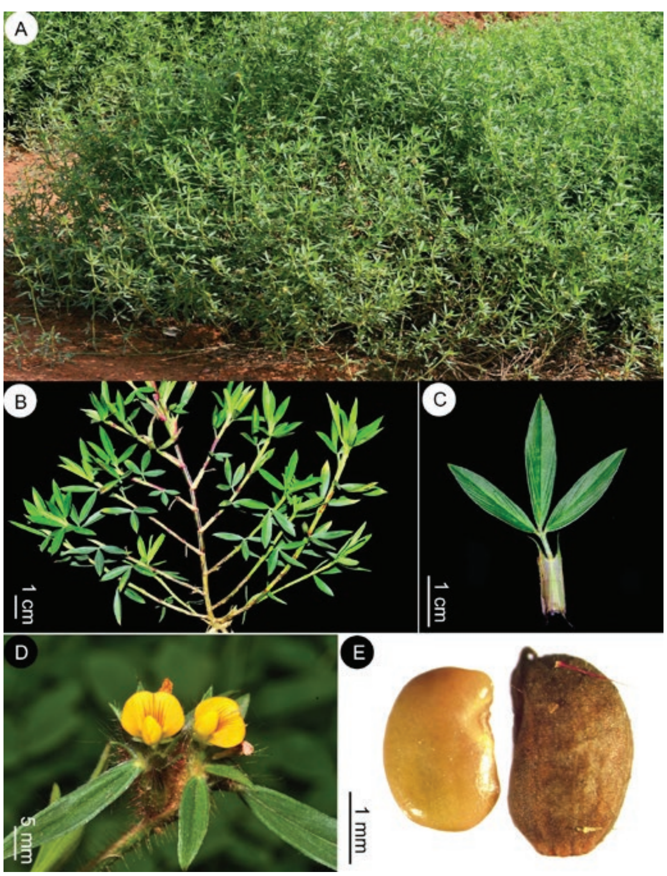

Figure 1. Morphological features of *Stylosanthes guianensis* cultivar 'Reyan No. 2'. **A:** plant habit; **B:** branch; **C:** leaf; **D:** inflorescence; **E:** seed and pod. (Photographs by Yang Hubiao, TCGRI-CATAS).

Evaluation and anthracnose tolerance

Soon after incorporation of CIAT 184 into CIAT´s active germplasm collection, the production potential of this accession and its anthracnose tolerance became evident in field nursery observations and greenhouse studies conducted at the CIAT experimental station in Palmira, Colombia; its adaptation to acid, infertile soils was recorded in plots established in the experimental stations of Carimagua and Quilichao (CIAT 1975–1977).

From 1978 onwards, CIAT 184 was included in the legume germplasm set for evaluation in multilocational trials of the International Tropical Pastures Evaluation Network (RIEPT, its Spanish acronym). These trials were conducted in the humid and subhumid tropics of Latin America and the Caribbean, using a standardized methodology for evaluation of adaptation ('Regional Trials A') and agronomic performance ('Regional Trials B') (Toledo and Schultze-Kraft 1982). In 1982, CIAT 184 was also introduced in tropical China along with a set of other legumes and grasses for evaluation in Hainan (Liu Guodao et al. 2004a), within early cooperation between CIAT and the then South China Academy of Tropical Crops (since 1994: Chinese Academy of Tropical Agricultural Sciences, CATAS).

During 1989–1993 CIAT 184 was one of the 21 herbaceous legume accessions included in evaluation trials at 17 sites in 9 countries of Subsaharan Africa, within the West and Central African Animal Feed Research Project network (RABAOC, its French acronym), also using a standardized methodology (Rippstein 1998). In the 1990s it was part of the forage germplasm tested in 2 CIAT-CSIRO (Commonwealth Scientific and Industrial Research Organization) R&D

cooperation projects in Southeast Asia: the 'South-east Asian Regional Forage Seeds Project' (1992–1994) and the 'Forages for Smallholders Project' (1995–1999), which subsequently continued in the form of 2 CIAT-Asian Development Bank (ADB) projects (2000–2005) conducted in partnership with national R&D institutions in up to 8 countries (Stür et al. 2007).

The most relevant outcome of these early adaptation and agronomic performance studies around the globe was that in addition to adaptation to acid, infertile soils and drought tolerance, CIAT 184 showed a strong tolerance of anthracnose in comparison with the well-known Australian commercial stylo cultivars, such as 'Cook', 'Endeavour', 'Graham' and 'Schofield', and with essentially all other *S. guianensis* germplasm accessions tested in those studies[2, 3].

Regional experiences: Research and development

Tropical America

In the humid tropics, where it was one of 13 accessions from 5 different legume genera (10 species) evaluated in 32 'Regional Trials B' conducted between 1979 and 1991 in Bolivia, Brazil, Colombia, Ecuador and Peru within the RIEPT network system, CIAT 184 proved to be outstanding with respect to environmental adaptation and dry matter production (Amézquita et al. 1991; Keller-Grein et al. 1992). In contrast, in RIEPT trials conducted in a subhumid savanna climate characterized by a distinct dry season, the accession was badly affected by anthracnose (Pizarro 1983; 1985; 1988). The presence of antagonistic bacteria on the tissue of stylo plants and prevailing narrow diurnal temperature fluctuations, both preventing the development and spread of the disease in the humid tropics, were reported to explain this contrast between the 2 ecozones (Lenné 1985).

Results of studies with CIAT 184 in tropical America that we found in the literature, beyond those reported in the aforementioned RIEPT trial compilations (Pizarro 1983; 1985; 1988) and that of Keller-Grein (1990), are as follows:

Argentina. The potential of this accession for subtropical conditions with dry and cold winters became evident based on a 3-yr study on a sandy soil in the northwest of Corrientes province, northeast Argentina, where anthracnose is not a major issue and where CIAT 184 along with *S. guianensis* cultivar 'Graham' had the highest forage and seed yields among 35 accessions from 6 *Stylosanthes* species (Ciotti et al. 1999). In the same area on a phosphorus-deficient soil (3.4 ppm P; Bray I), an almost 100 % DM yield increase was observed in response to P fertilizer application as low as 11 kg P/ha for CIAT 184 (Ciotti et al. 2003).

Colombia. Low P requirements of CIAT 184 and strong response to very low P fertilizer doses in soil from the Colombian Llanos were also shown in the early work at CIAT (Schultze-Kraft 1976). However, since *S. guianensis* in general succumbed to anthracnose in the subhumid savanna ecosystem ('Llanos Orientales'), where CIAT´s pasture research in Colombia was focussed in the 1970s and 1980s, studies on CIAT 184 were not continued at that time and resumed in the 1990s in the humid-tropics part of the country (Caquetá department). There, Velásquez et al. (2004) showed that pre-weaned calves with access to a CIAT 184 pasture drank less milk from their dams, than calves with access to only grass pasture with their dams, allowing 21 % more milk per cow to be sold from the CIAT 184 group, while calves from this group made 30 % higher liveweight gains.

At the basic-research level in Colombia, Sarria et al. (1994), using an *Agrobacterium tumefaciens*-disarmed strain, showed that an efficient transfer of marker genes to CIAT 184 and regeneration of transgenic plants were possible. Subsequently, Kelemu et al. (2005) introduced a chitinase-encoding gene from rice into CIAT 184, which resulted in improved resistance of transgenic plants to foliar blight disease (*Rhizoctonia solani*).

Cuba. Based on germplasm evaluations within the RIEPT network (Pizarro 1988) and follow-up studies, CIAT 184 was considered a promising legume for pasture-based livestock production on poor soils. In 5-year seed production studies, 182–318 kg seed/ha/yr were harvested (Suárez and Villavicencio 1988). Although

[2]It should be mentioned that another *S. guianensis* accession, CIAT 136, showed considerable promise in those and other studies. It was collected in 1973 by Pedro J. Argel near the town of Restrepo, Meta department, Colombia. In Africa it is known as ILRI 163 and in tropical China it was released in 2000 as cultivar 'Reyan No. 7'.

[3]Whenever accessions of the 'tardío' morphotype of *S. guianensis* (= 'var. *pauciflora*') were included in those studies, most of them also exhibited strong anthracnose tolerance.

the accession was not formally released, 'cv. CIAT-184' was promoted and used in protein banks. It has been dominating *S. guianensis* research in Cuba during the past 3 decades, with a focus on callus formation/tissue culture for generation of plants and on tolerance of soil salinity (Mesa et al. 1993; Fuentes et al. 2000, 2008, 2015; González et al. 2000; Fuentes Alfonso et al. 2008).

Peru. CIAT 184 showed high productivity on the acid, infertile soils that prevail in the Peruvian humid tropics, with anthracnose tolerance (Pizarro 1983, 1985; Keller-Grein 1990). This resulted in the Instituto Veterinario de Investigaciones Tropicales y de Altura (IVITA) and Instituto Nacional de Investigación y Promoción Agropecuaria (INIPA) releasing CIAT 184 in Peru as cultivar 'Pucallpa' in January 1985 (Reyes et al. 1985). The promoted use was mainly as a pasture legume for association with grass, in pure stands as a protein bank or to rehabilitate degraded pastures.

Subsequently, Reátegui et al. (1995) and Loker et al. (1997) reported from long-term on-farm research in the Pucallpa area (13 farms, 4 years management), where CIAT 184 (cultivar 'Pucallpa') was used as a legume species in grass-legume pastures, that 'Pucallpa' established well, even with no fertilizer input. However, with time its proportion in the mixture declined under farmers´ grazing management. It is noteworthy that, in those cases where the pastures were burnt to control weeds and pests, the persistence of 'Pucallpa' improved.

In more recent research in the Pucallpa area, partial substitution of forage for milk from dam by calves with access to a 'Pucallpa' pasture led to a 23 % increase of milk sold per cow without affecting growth of calves (Vela 2004a). Incorporating stubble of the legume in the soil had the same yield-increasing effect on a subsequent rice crop as 50 kg N/ha fertilizer (Vela 2004b).

Velásquez Ramírez et al. (2021) showed that, when used as cover crop, 'Pucallpa' had a significantly positive effect on soil restoration of alluvial gold mine spoils in the Peruvian Amazon, in terms of several soil chemical, physical and biological parameters.

Puerto Rico. Under commercial dairy farm conditions with 10 acres of stylo in the South Region (Guayama), an average of 10.8 t hay/ha with 25 % moisture content was obtained in 1991/92 in each of three 4-monthly cuts from cultivar 'Pucallpa', with mean CP concentrations of 16–18 %. Fed as a supplement to about 290 kg replacement heifers grazing common guinea grass, a daily ration of 8.7 kg of stylo hay per animal was able to replace 5 kg of commercial concentrate (A. Arias-Pedraza, pers. comm. December 2022).

Tropical Africa

R&D with CIAT 184 in tropical Africa concentrated on West and Central Africa and Madagascar. The accession was, however, not available for fodder bank studies conducted in West Africa by International Livestock Research Institute (ILRI) and partners in the early 1980s (Mohamed-Saleem and Suleiman 1986). In final reports of the RABAOC project on the agronomic evaluation of a set of grass and legume species in humid and subhumid environments in Benin, Cameroon, Central African Republic, Côte d´Ivoire, Ghana, Guinea, Nigeria, Senegal and Togo (NARS-CIRAD/EMVT-CIAT-ILCA 1995; Rippstein 1998), CIAT 184 consistently ranked among the top herbaceous legumes, out of 21 accessions representing 17 species. Further regional studies involving CIAT 184 (de Leeuw et al. 1994) are country-specific and referred to below. In some of the publications on R&D in tropical Africa, the accession is mentioned under its synonym numbers 'ILCA/ILRI 164' or 'FAO 46004'.

Benin. Saito et al. (2010) concluded from a tillage management experiment in southern Benin that manual tillage combined with a CIAT 184 stylo fallow is a recommendable practice for smallholder farmers to improve upland rice productivity.

Cameroon. Several studies with FAO 46004 (CIAT 184) were conducted in the Adamawa Plateau. In an agronomic evaluation of 17 *Stylosanthes* accessions, CIAT 184 was outstanding in terms of dry matter production, anthracnose tolerance and seed yield (400 kg/ha) (Yonkeu et al. 1994). While Pamo and Yonkeu (1994) showed increased grass production of a subsequent *Urochloa ruziziensis* crop after harvesting stylo for hay during 2 years, Enoh et al. (1999) reported from dry-season sampling of 4–5 yrs old on-farm and on-station stylo-grass (*U. ruziziensis*) and stylo-native pasture (mainly *Hyparrhenia* and *Panicum*) paddocks (which they called "fodder banks") increased dry matter yields and nutritive value in comparison with grass-only pastures. Poor management and yearly bush fires were mentioned as major limitations to the promoted stylo-grass technology.

Côte d'Ivoire. Based on a study at 5 benchmark sites representative of upland rice systems with contrasting edaphoclimatic conditions, Becker and Johnson (1998) identified *S. guianensis* (accession CIAT 184 according to M. Becker, pers. comm. February 2022) as a promising soil-improving and weed-suppressing fallow legume species, particularly for acid infertile forest and savanna soils. In feeding studies with rabbits, sun-dried hay of CIAT 184 was successfully included as fiber source up to 30 % in feed pellets (Kouadio et al. 2021; 2022).

DR Congo. Bulakali et al. (2013) tested the seed-production potential of 3 *S. guianensis* accessions at 2 sites on the Batéké plateau and found that, by the soil-sieving method, 600 kg seed/ha could be harvested from CIAT 184, at a total production cost of USD 1.31/kg.

Guinea. CIAT 184 was introduced as part of RABAOC trials and was reported as useful for improvement of natural pastures in Guinea (Elbasha et al. 1999).

Madagascar. In Madagascar, the use of CIAT 184 (and other legumes and grasses) as soil cover in no-till agriculture ('conservation agriculture') is being promoted in a manual including a species factsheet on *S. guianensis* (Husson et al. 2008) and a chapter containing description and discussion of *S. guianensis*-based conservation agriculture systems (Husson et al. 2013). The manual´s explicit recommendation of CIAT 184 is because of anthracnose tolerance.

Examining the relationship between biomass removal for forage and the mulch cover remaining for a subsequent no-till rice crop, a study on 91 farmers´ fields using CIAT 184 and 3 other legumes, showed the interdependence between cover species used, soil cover rate and mulch quantity and quality (Naudin et al. 2011). In a no-till experiment with upland rice, soil cover by CIAT 184 mulch as high as 95 % was necessary to effectively control emerging weeds (Naudin et al. 2012). In another conservation agriculture study, Randrianjafizanaka et al. (2018) found that of 4 cover legumes, CIAT 184 provided the most effective control of the parasitic weed, *Striga asiatica*. Using the natural abundance method, Zemek et al. (2018) measured N fixation in CIAT 184 shoots over 17 months ranging from 96 to 122 kg N/ha.

In a feeding trial, Razafinarivo et al. (2014) showed the potential of CIAT 184 in a mixture with *Urochloa brizantha* for feeding dairy cows. From another feeding trial with dairy cows, Rakotomanana (2021) concluded that, although not increasing milk yields, stylo CIAT 184 silage (in the publication erroneously referred to as 'CIAT 194') contributed to improved physical condition of dairy cows in the dry season.

In 2021, a facility to produce CIAT 184 feed pellets was established at Antananarivo as part of Madagascar-China cooperation.

Nigeria. As Nigeria hosted the Subhumid Research Site and Humid Research Site of ILRI, a considerable portion of the research on *Stylosanthes* in West Africa during the 1980s and 1990s was done in this country. Several evaluation studies in the dry-subhumid Northern Guinea Savanna ecozone were done by Tarawali et al. (1994), who reported that ILRI 164 (CIAT 184) was outstanding in terms of anthracnose tolerance, forage production and persistence. This was complemented by the highest grain yield of a subsequent maize crop, probably due to the accession´s high dry matter production (Tarawali 1994). However, evaluating it in a fodder bank situation, Peters et al. (1994) recorded that ILRI 164 competed poorly with invading native vegetation. In a relative-palatability test under grazing, Peters et al. (2000) reported high palatability of ILRI 164 throughout the year, possibly associated with the greenness and leaf retention of the accession well into the dry season. Seed yields recorded in that area across 3 years ranged between 57 and 106 kg/ha/year (Kachelriess and Tarawali 1994).

In a small-plot grazing experiment conducted in the more humid Derived Savanna ecozone, Tarawali et al. (1999) showed that ILRI 164, in association with native *Megathyrsus maximus*, was particularly valuable in the dry season when it led to higher liveweight gains of grazing calves than grass alone plus rice bran supplement. In the same environment and working with mixtures of legume species under grazing, Peters et al. (2001) reported that ILRI 164 had potential to contribute to stable and productive mixtures. In the same environment, assessing species mixtures primarily used as cover crops and improved fallow, Tarawali (2000) showed that ILRI 164 was a suitable component in several 3-species mixtures.

In that same Derived Savanna zone of subhumid southwest Nigeria, Muhr et al. (1999a; 1999b) conducted several experiments to test and analyze the short-term ley potential of 11 legume species for crop-livestock systems. They reported that ILRI 164 had the highest DM yields and that, in spite of dry-season utilization of the forage, grain yields of a subsequent corn crop exceeded those after natural fallow by up to 147 %, equivalent to 96 kg fertilizer N/ha. In subsequent farmer-controlled trials, ILRI 164 ranked highest under the prevailing low-input management (Muhr et al. 2001).

S. guianensis CIAT 184 was released as 'ILRI-164' in 2000 in Nigeria (Nigerian Seed Portal Initiative).

Southeast Asia

In tropical Asia, network research in the 1990s on forages, including *S. guianensis* CIAT 184 ('Stylo 184'), was conducted mainly within several regional CIAT-CSIRO-ADB R&D projects, in partnership with national institutions in up to 8 countries (Cambodia, China, Indonesia, Lao PDR, Malaysia, Philippines, Thailand and Vietnam). There are several reports and papers informing about the advances and research results of these projects with contributions from individual countries (Stür et al. 1995, 2000a, 2002; Stür 1997, 1998). All documents indicate that, based on multilocational and on-farm trials, of all herbaceous legume germplasm tested, Stylo 184 was consistently among the top legumes regarding adaptation and productivity in a wide range of ecophysical environments, as well as acceptance by farmers. It was ultimately one of the 2 legumes (the other was *Centrosema molle* CIAT 15160 named 'Barinas'), that participants in the Forage Seeds Project recommended in 1994 for release throughout SE Asian countries (Stür et al. 1995). In a final, development-oriented overview, Stür et al. (2007) reported that, of all legume species and accessions tested during the 13 combined project years, the only legume ultimately used by farmers was Stylo 184. The primary use is as cut-and-carry livestock feed.

The most noteworthy country-specific results concerning CIAT 184 include:

Cambodia. Based on a 4-yr R&D project with large-ruminant-keeping smallholder farmer participation in 6 villages in southern Cambodia, including comprehensive forage and livestock production measurements, Bush et al. (2014) found that growing introduced forage species (4 grasses and Stylo 184) was a credible entry point for converting livestock keepers into livestock producers. From a review of forage options to sustainably intensify smallholder farming systems on sandy soils in Cambodia (and southern Laos), Philp et al. (2019) concluded that Stylo 184 was the only forage legume to be recommended for drought-prone areas with acid, sandy soils. At the livestock nutrition level, Pen et al. (2013) reported that supplementation of a basal rice straw-grass diet with 30 % of CIAT 184 significantly increased forage intake and N balance of zebu cattle.

Indonesia. In a 3-yr multilocational trial (6 sites in East, Central and South Kalimantan), CIAT 184 ('Pucallpa'), along with *C. molle* CIAT 15160, stood out as the only well-adapted and productive accessions among a total of 35 legume species and accessions tested (Cameron et al. 1995). Liu Guodao et al. (1997) reported that, in East Kalimantan, Stylo 184 is used to rehabilitate degraded *Imperata cylindrica* uplands. In eastern Indonesia, after 6 years of participatory research supported by the Australian Centre for International Research (ACIAR), the resulting manual recommends CIAT 184 (plus the Australian composite *S. guianensis* hybrid cultivars, 'Nina' and 'Temprano') for use in East Nusa Tenggara province, mainly as a component of fodder banks (Nulik et al. 2013).

Lao PDR. Following a first report by Phengsavanh (1999), Phengsavanh and Phimphachanhvongsod (2007) summarized that, of 118 legume species and accessions tested during several years at 5 sites in upland areas across the country, Stylo 184 showed the broadest adaptation, including dry season tolerance, to different environments; it was ultimately the only legume selected by farmers for use to feed not only ruminants but also pigs. The benefits of the latter use were reduced time for collecting and cooking natural feed and increased growth rates of pigs.

The potential and adoption of Stylo 184 for smallholder pig feeding in Laos were subsequently summarized by Phengsavanh et al. (2008) and Stür et al. (2010). Individual studies were concerned with the role of Stylo 184 for: replacement of rice bran (Keoboualapheth and Mikled 2003); combination with cassava leaves as protein supplements to a basal diet of broken rice (Norachack et al. 2004); mixture with cassava foliage leading to increased DM intake and N retention in comparison with a basal diet (Khoutsavang et al. 2006); use by smallholder farmers in the uplands as locally grown protein supplement (Kopinski et al. 2008); ensiling in mixture with taro leaves (Kaensombath and Lindberg 2013); and replacement of soybean protein (Kaensombath et al. 2013). They were complemented with combined agronomic/nutritive value studies (Kaensombath and Frankow-Lindberg 2012; Phengsavanh and Frankow-Lindberg 2013).

Regarding the potential of Stylo 184 as forage for goats, Keopaseuht et al. (2004) found that forage intake and digestibility were unexpectedly reduced when leaf only was offered rather than branches with intact leaves, while Phengsavanh and Ledin (2003) reported that the inclusion of Stylo 184 in a grass diet (*Andropogon gayanus*) improved the quality of the diet, resulting in higher intake and better growth rates of animals. Stylo 184 as basal diet for growing rabbits was not successful (Phimmmasan et al. 2004), an observation that was at variance with reports from Côte d´Ivoire (Kouadio et al. 2021; 2022).

In northern Laos, Saito et al. (2006) showed the potential of Stylo 184 as improved fallow/relay crop for increased subsequent upland rice production of 0.6 t/ha with 60 % reduced weed population in comparison with natural fallow.

Malaysia. Assessing the production potential of 47 legume accessions, reportedly being shade-tolerant, as weed-controlling soil cover and feed for sheep grazing under young rubber trees, Ng et al. (1997) found that CIAT 184 along with *S. scabra* cultivar 'Seca' presented consistently highest DM yields in 2 experiments with photosynthetically active radiation means of 40 and 70 %, respectively. Chen et al. (1995) reported seed yields, obtained in Northwest Peninsular Malaysia, in the range of 230–390 kg/ha.

Myanmar. Stylo 184 was included in evaluation of 5 herbaceous legumes in a drought-prone environment without fertilizer application and irrigation (Gyue et al. 2021). The authors considered Stylo 184 to be a "good" forage because of its DM yield, high crude protein concentration and gas production and low fiber concentration.

Philippines. Stylo 184 showed excellent adaptation to all environments where it was evaluated, particularly on farms with acid soils (Lanting et al. 1995). Horne et al. (1997) mentioned that in Mindanao it is used to control soil erosion and suppress growth of *Imperata cylindrica*, when establishing forestry plantations. In northern Luzon at about latitude 18° N, Pardinez et al. (2000) reported seed yields from 3 sites and 2 years averaging 201 kg/ ha/ yr. Based on a feeding trial with sheep, Lanting et al. (2003) showed the potential of Stylo 184 as a protein supplement in low-quality (rice straw) basal diets.

Thailand. In 1996, the anthracnose-susceptible *S. guianensis* cultivar 'Graham' was replaced by disease-resistant Stylo 184 (Phaikaew and Hare 2005), which was released by the Department of Livestock Development in 1997 as 'Ta Phra' stylo. Research on CIAT 184 concentrated on the northeastern region of the country characterized by infertile, sandy soils. For southern Thailand, Satjipanon et al. (1995) mentioned an adaptation study conducted in Narathiwat, where CIAT 184 showed promise on an acid, infertile soil. In a subsequent cutting management trial at Narathiwat, 50-day cutting frequency and 20-cm cutting height gave the best result for CIAT 184 yield and nutritive value combined (Sukkasem et al. 2003).

In the northeast, Stylo 184 was shown to have potential for intercropping with cassava (Kiyothong and Wanapat 2004a). In a dairy cow feeding trial, supplementing cassava leaf hay with Stylo 184 hay reduced concentrate use and resulted in improved milk yield and quality, and ultimately higher economic returns (Kiyothong and Wanapat 2004b). Stylo 184 can also successfully be used as silage, alone or in mixture with guinea grass (Bureenok et al. 2016). Fermentation quality and nutritive value of the legume could be significantly improved by inoculation with thermotolerant lactic acid bacteria (LAB) isolated from fermented juice of tropical forage crops (Pitiwittayakul et al. 2021). From experiments on inter-row planting of legumes to improve crude protein concentration in pastures of *Paspalum atratum* cultivar 'Ubon', Hare et al. (2004) concluded that *Stylosanthes* species, including 'Ta Phra' stylo, are suitable legumes on infertile upland soils of northeast Thailand. Homma et al. (2008) found in farmers´ field trials that stylo as relay crop, used in the dry season for livestock feeding, did not affect subsequent rainfed-rice yields.

Optimization of 'Ta Phra' stylo seed production and quality was the subject of several studies (Kiyothong et al. 2005a; 2005b). While seed yields of about 1,200 kg/ ha were obtained in one study when the nylon-gauze-bag method was used (Kiyothong et al. 2002), Phaikaew et al. (2004) reported a range of 300–1,400 kg seed/ ha, depending on cutting management, and Hare et al. (2007) reported 365 kg/ha with a 1,000-seed weight of 2.59 g (equivalent to almost 390,000 seeds/kg).

Na Chiangmai et al. (2013) concluded from a field study that 'Ta Phra' stylo was not shade-tolerant. This finding is at variance with the report from Malaysia (Ng et al. 1997).

At the laboratory level, a study on regenerative capacity of Stylo 184 showed that in-vitro culture of this accession is a suitable tool for shoot generation, even after 3 years maintenance of the culture (Veraplakorn et al. 2012). Both the activity of antioxidative enzymes in in-vitro shoots and ion accumulation in seedlings can be used to distinguish between Stylo 184 clones in regard to their salt tolerance (Veraplakorn et al. 2013a; 2013b).

Vietnam. Khanh and Ha (2007) reported that, as a result of regional evaluations of 70 accessions for adaptation to the environmental conditions of the Dak Lak Central Highlands, Stylo 184 was the only herbaceous legume ultimately selected by upland farmers for cattle feeding. Thang et al. (2010) found that Stylo 184 foliage, alone or in mixture with cassava leaves, improved DM intake, digestibility and liveweight gain of cattle fed a basal diet of urea-treated rice straw. As a result of on-station and on-farm research in South Central Coastal Vietnam, where several grasses and Stylo 184 were evaluated on sandy soils, farmers (n=45) preferred high-yielding grasses (on-station DM yields up to 50 t/ha/yr) to the only legume tested (CIAT 184; up to 17 t DM/ha/yr) (Ba et al. 2014).

China

The importance attributed to *S. guianensis* in (sub) tropical China is reflected by a slogan coined in 2011 by the former Minister of Agriculture of the People´s Republic of China, He Kang: *Alfalfa in the North and stylo in the South*. It is also reflected by a large number of studies, mainly on CIAT 184 and cultivars developed from this accession, published in Chinese language. While those studies deserve being categorized and compiled in a separate review or annotated bibliography, in the present document we concentrate on Chinese research published in English and accessible in international journals and databases.

CIAT 184 was introduced into tropical China in 1982 and within a few years had become an important forage legume (He Chaozu and Schultze-Kraft 1988). Thereafter, its continuing good performance and anthracnose tolerance are dealt with in a number of reports on forage R&D (Liu Guodao and Kerridge 1997; Liu Guodao et al. 1997, 2004a; Liu Guodao and Chakraborty 2005; Yi Kexian et al. 2007). It is particularly noteworthy that 40 years after the introduction of CIAT 184, its field resistance to anthracnose seems to have remained unchanged. This suggests an inherent tolerance to the prevailing anthracnose strains, in contrast with most of the Australian *S. guianensis* cultivars (‘Endeavour’, ‘Schofield’ and ‘Cook’), which succumbed to the disease a few years after their introduction in China.

Released as cultivar ‘Reyan No. 2’ in 1991, CIAT 184 developed into being the most widespread *Stylosanthes* cultivar in southern China. ‘Reyan No. 2’ is used for forage for livestock (cut-and-carry and grazing, hay and silage), leaf meal production (for ruminants and monogastrics), soil cover and green manure in perennial crops (rubber, coconut and fruit tree plantations), and soil stabilization and reclamation.

Yi Kexian et al. (2007) reported DM yields of 15–22.5 t/ha and total area planted to cultivar ‘Reyan No. 2’ of more than 150,000 ha at that time in South and Southwest China (provinces Hainan, Guangdong, Guangxi, Fujian, Guizhou, Sichuan and Yunnan), generating an income of 400–1,200 million Yuan (50–150 million USD). Our current estimate (June 2022) for the cumulative area sown to ‘Reyan No. 2’ and ‘Reyan No. 5’ (the latter a selection from ‘Reyan No. 2’) in (sub)tropical China is about 330,000 ha.

Genetic diversity and new cultivars. A Sequence-related amplified polymorphism (SRAP)-based analysis with 148 accessions representing 6 *Stylosanthes* species showed that CIAT 184 and all derived cultivars clustered into 1 subgroup (Huang Chunqiong et al. 2017). CIAT 184 is the origin of a further 3 *S. guianensis* cultivars developed at Tropical Crops Genetic Resources Institute (TCGRI) of CATAS and tested in multilocational trials throughout southern China. Cultivar ‘Reyan No. 5’ (released in 1999) is an earlier-flowering, black-seeded selection from CIAT 184, with similar DM production to ‘Reyan No. 2’, but almost 50 % higher seed yields and improved cold tolerance (Bai Changjun et al. 2004a). More recently, ‘Reyan No. 20’ (2010) and ‘Reyan No. 21’ (2011) were both developed from ‘Reyan No. 2’ via space flight-induced mutation breeding (Liu Guodao et al. 2004a). Another cultivar derived from CIAT 184 is ‘Stylo 907’, developed in Guanxi by ^{60}Co-γ-radiation breeding (Liu Guodao et al. 2004a). Using the same radiation breeding technique, Tan Jiali et al. (2009) produced dwarf-mutant lines of CIAT 184 with improved cold tolerance.

Cold tolerance, higher seed production and durable anthracnose resistance are breeding and selection objectives for new germplasm, alongside improved yield and forage quality. Bai Changjun et al. (2004a) reported ongoing evaluations of new material in this regard, but at that time, CIAT 184 (cultivars ‘Reyan No. 2’ and ‘Reyan No. 5’) was still the first option. Eighteen years later the situation continues the same, in spite of a report of anthracnose on ‘Reyan No. 2’ in Hainan in 2014 (Jia Yanxing et al. 2017) and insufficient winter survival, in comparison with the grasses tested, reported for ‘Reyan No. 5’ (and a multiline *S. guianensis* hybrid cultivar, ‘Ubon stylo’) in Guangxi (He Chengxin et al. 2017).

Seed production and plant propagation. Details of establishment of a Stylo 184 crop for seed production, its management, seed harvesting and subsequent processing were presented by Liu Guodao et al. (1997); yields reported were in the range of 75–520 kg seed/ ha. Yuan Xuejun et al. (2011) successfully developed a micropropagation method for ‘Reyan No. 2’.

Forage. Stylo leaf meal has become an important commercial commodity in southern China (Liu Guodao et al. 2004b) and there are detailed recommendations for the proportion of the legume in rations for different livestock species (Bai Changjun et al. 2004b). Yi Kexian et al. (2007) presented amino acid concentrations in Stylo 184, which for most amino acids were higher than those in alfalfa. Li Mao et al. (2014) showed that ‘Reyan No. 2’, along with another CATAS germplasm (TPRC-90028), had the highest relative feed value among 10 *S. guianensis* accessions.

A number of studies dealt with issues related to making silage from *S. guianensis*, in all cases using cultivar 'Reyan No. 2'. Liu Qinhua et al. (2011) assessed the effects of wilting and storage temperature on silage quality and aerobic stability and Liu Qinhua et al. (2012) tested the effectiveness of 2 LAB strains and concluded that stylo was hard to ensile due to low water-soluble carbohydrates (WSC) concentration and high buffering capacity. Li Dongxia et al. (2019) identified *Lactobacillus* and *Enterobacter* as the genera most probably responsible for the enhanced acetate fermentation in low-DM stylo. Li Mao et al. (2017; 2021) showed that silage fermentation and ruminal degradation could be enhanced by combining LAB inoculation and treatment with cellulase enzyme and by adding melatonine, respectively. Zhang Yage et al. (2018) assessed the best legume proportion in mixtures of stylo with king grass (*Cenchrus* hybrid); He Liwen et al. (2019; 2020) reported on the potential of gallic acid and *Moringa oleifera* leaves, respectively, to improve fermentation of stylo silage and Zi Xuejuan et al. (2022) showed the effects of WSC on the bacterial community.

Non-forage uses. Yi Kexian et al. (2007), citing publications in Chinese, reported on improved soil characteristics after 2 years of stylo cropping and enhanced orange tree growth after 2 years, when stylo was applied as green manure. Long Huying et al. (2017), working on degraded soils in the dry-hot valley area of Yuanmou country (almost 26° N), Yunnan province, showed that 'Reyan No. 2' as soil cover and green manure significantly improved soil fertility and micobiological activity.

Wang Dongmei et al. (2008) found that transgenic 'Reyan No. 2' has potential as a plant-based vaccine against foot-and-mouth disease.

Basic research. Studies on *S. guianensis* conducted in China, including CIAT 184 as a prominent example, addressed: development of molecular markers for diversity analysis (Ding Xipeng et al. 2015), genetic transformation (Guo Pengfei et al. 2019; Wang Linjie et al. 2023), molecular and gene expression mechanisms involved in abiotic and biotic stress tolerances [chilling, drought and salt (Zhou Biyan et al. 2005a, 2005b, 2006; Yang Jinfen and Guo Zhenfei 2007; Zhou Biyan and Guo Zhenfei 2009; Lu Shaoyun et al. 2013; Bao Gegen et al. 2016; Li Kailong et al. 2018), nutrients (Du Yumei et al. 2009; Jiang Caode et al. 2018; Liu Pandao et al. 2019; Chen Zhijian et al. 2021; Song Jianling et al. 2022) and anthracnose (Wang Hui et al. 2017; Gao Mengze et al. 2021; Jiang Lingyan et al. 2021)].

Characteristics of CIAT 184: Positive attributes and shortcomings

There are a considerable number of positive attributes (strengths) that characterize CIAT 184, and several weaknesses:

Strengths

- Tolerance of anthracnose
- Broad environmental adaptation, including to subtropical conditions
- High productivity (up to 22.5 t DM/ha/yr) (Figure 2)
- Adaptation to acid, infertile soils with high levels of Al
- Low P demand, but responsive to P fertilizer application
- N-fixing capability and rhizobium promiscuity
- Ease of establishment
- Tolerance of drought
- High crude protein concentration
- Absence of antinutritive factors
- Suitability for grazing and cut-and-carry (Figure 3)
- Suitability for ruminants and some monogastrics (Figure 4)
- Suitability for hay making and subsequent leaf meal/ pellet production, and ensiling (Figure 5)
- Suitability for intercropping (Figure 6)
- Multi-use potential: feed, soil cover (weed and erosion control), soil improvement (green manure) (Figures 7 and 8)

While most of these attributes are also valid for many other *S. guianensis* genotypes, the outstanding feature of CIAT 184 is its high tolerance of anthracnose in tropical Africa, SE Asia, southern China, some subtropical regions of Latin America (Argentina, Cuba) and the humid tropics of Latin America. As indicated by Chakraborty (2004b), this appears to be related to the physiological races of the fungus prevailing outside the center of diversity of *S. guianensis*, which is the New World tropics. We are unaware of any report that the field resistance of CIAT 184, which in China has lasted since its introduction in 1982, has broken down to a major extent at any location.

In Table 1, an account of the releases of cultivars derived from CIAT 184 is presented.

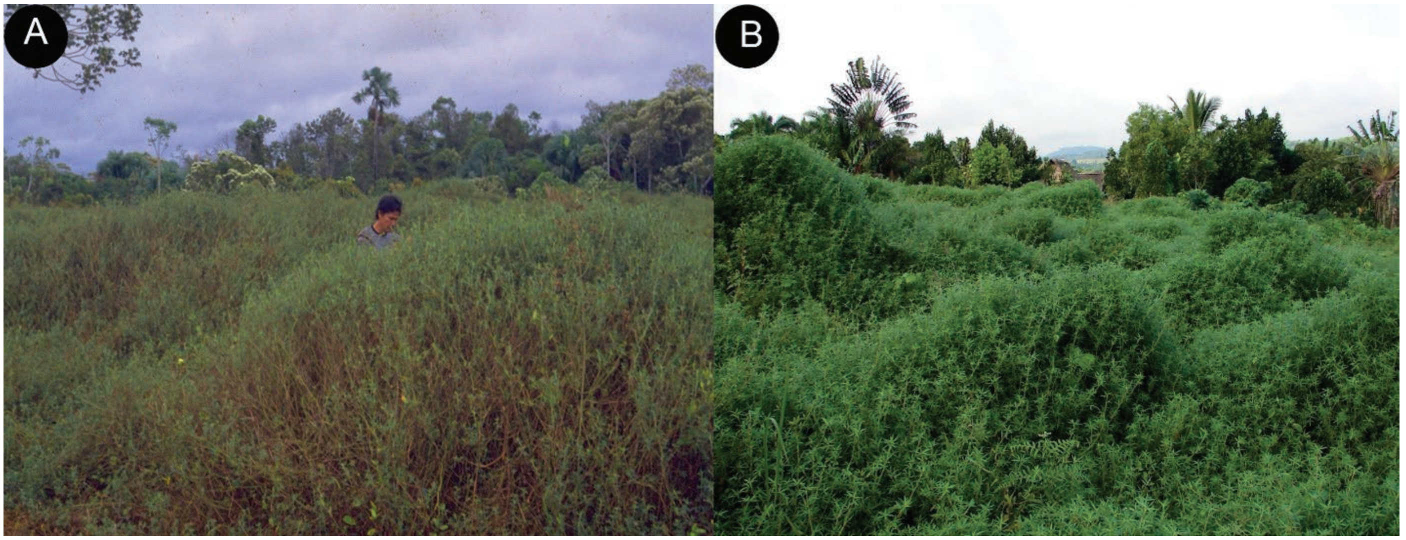

Figure 2. Stylo CIAT 184. **A:** mature stand at Pucallpa, Peru, Sep 1983; **B:** vigorous growth at Manakara, Madagascar, Mar 2007. (Photograph A by Rainer Schultze-Kraft, CIAT; B by Olivier Husson, CIRAD).

Figure 3. Stylo CIAT 184. **A:** grazing of a protein bank by dairy cattle at Pinar del Río, Cuba, Sep 2005 (Photograph by Rolando Núñez, Galeca); **B:** intensively cut plots at Luang Prabang, Laos, Sep 2001; **C:** in a mixture with grass for cattle feeding at Kampong Cham, Cambodia, Feb 2009. (Photographs B and C by Werner Stür, CIAT).

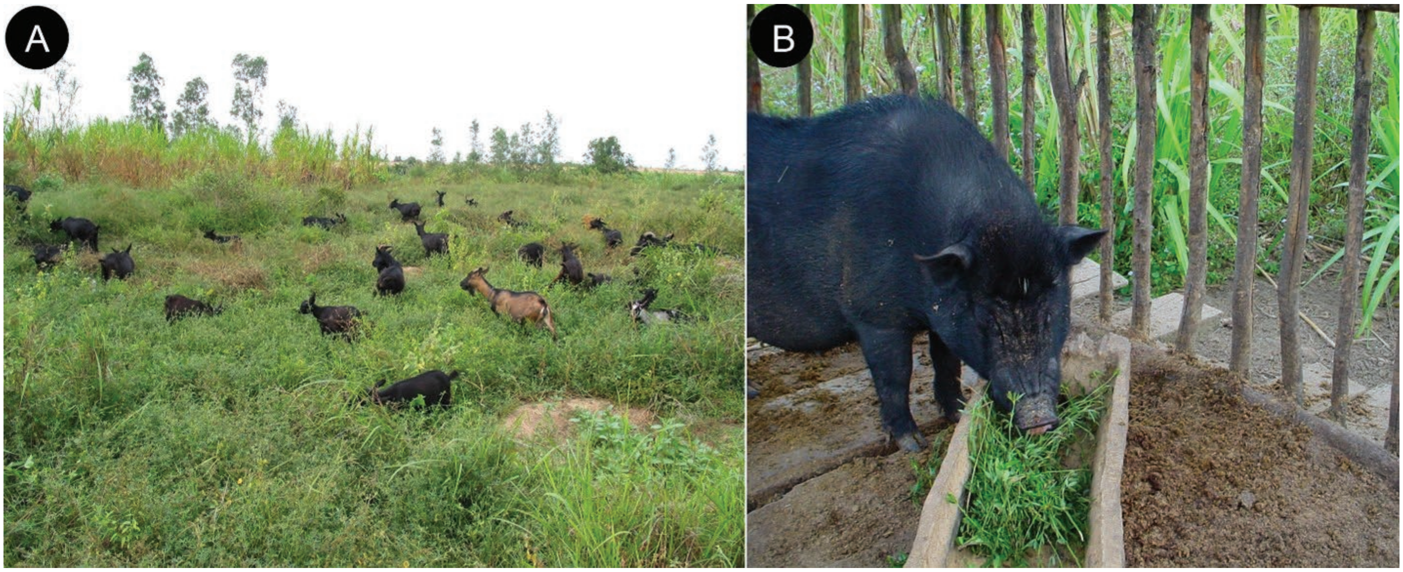

Figure 4. Stylo CIAT 184. **A:** goats grazing 'Reyan No. 2' in Hainan, China (Photograph provided by TCGRI-CATAS); **B:** feeding pigs at Luang Prabang, Laos, Dec 2002 (Photograph by Werner Stür, CIAT).

Figure 5. Stylo CIAT 184 ('Reyan No. 2') in China. **A:** cutting for hay production in Guanxi; **B:** hay production for leaf meal in Hainan; **C:** leaf meal powder; **D:** pellets. (Photographs provided by TCGRI-CATAS).

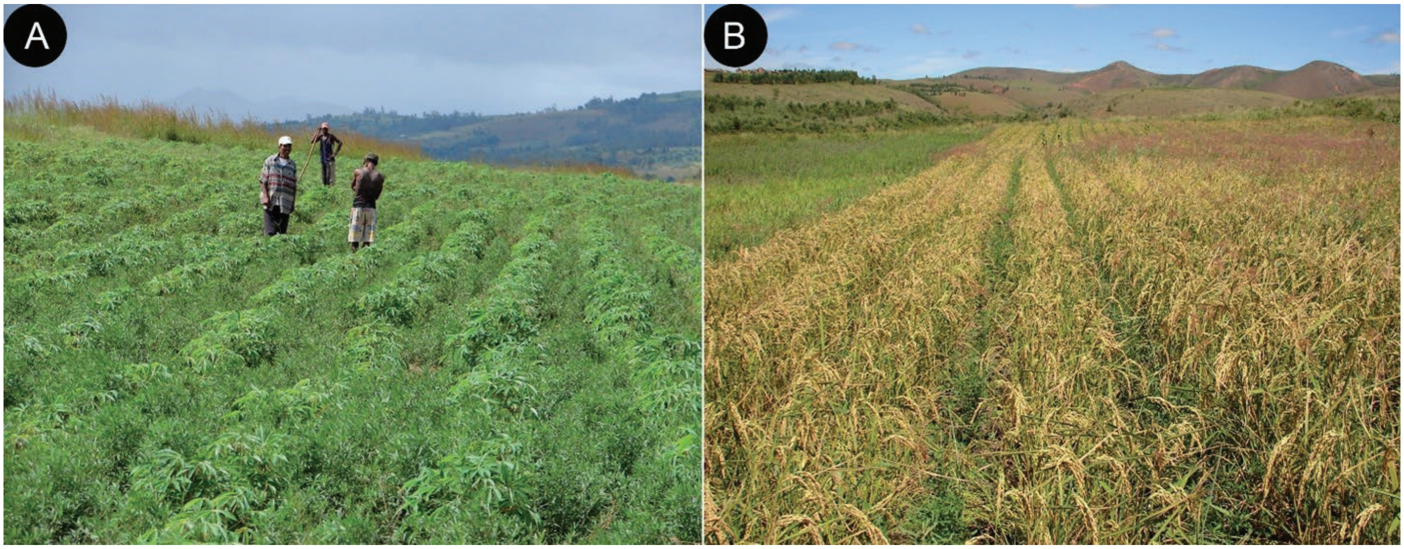

Figure 6. CIAT 184 intercropped with other species. **A:** cassava; **B:** upland rice at Lac Alaotra, Madagascar, Apr 2007. (Photographs by Olivier Husson, CIRAD).

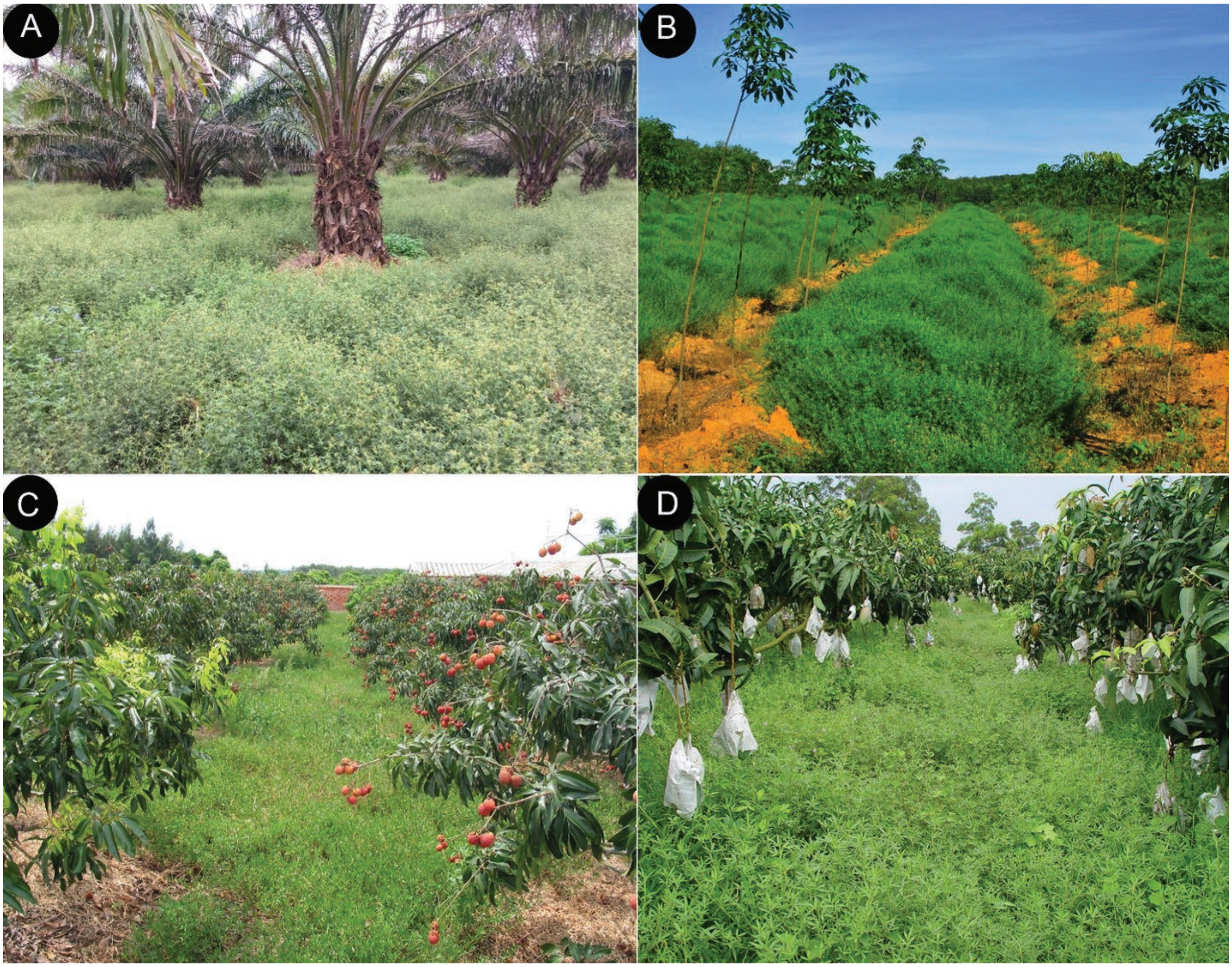

Figure 7. CIAT 184 as live soil cover in tree plantations in Hainan, China. **A:** oil palm; **B:** young rubber; **C:** litchi; **D:** mango. (Photograph A by Rainer Schultze-Kraft, CIAT; B, C and D provided by TCGRI-CATAS).

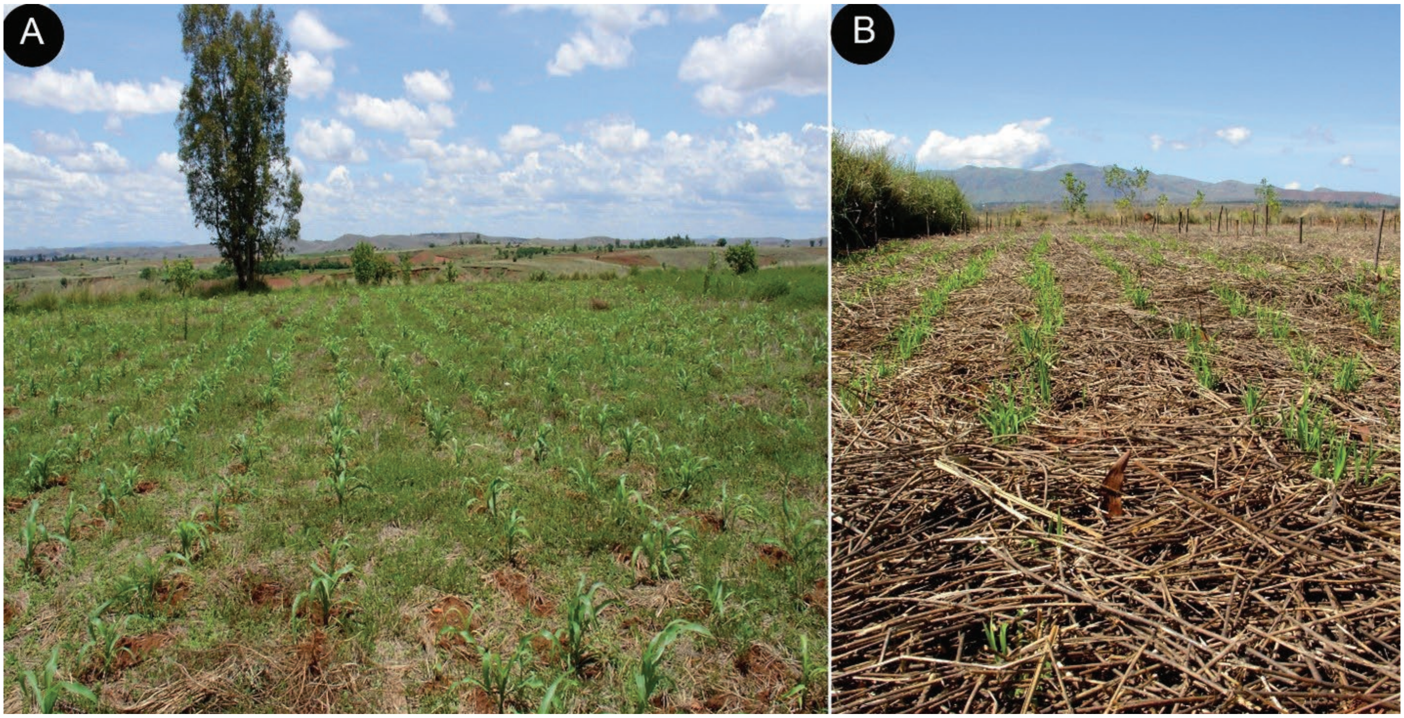

Figure 8. Stylo CIAT 184. A: live mulch; B: dead mulch. Used for establishment of maize and upland rice, respectively, in conservation agriculture, middle-west Madagascar, Dec 2008. (Photographs by Olivier Husson, CIRAD).

Table 1. Releases of cultivars derived from *S. guianensis* CIAT 184.

Country	Cultivar name	Year
Peru	'Pucallpa'	1985
Nigeria	'ILRI-164'	2000
Thailand	'Ta Phra'	1997
Southeast Asia	'Stylo 184'[1]	mid 1990s
China	'Reyan No. 2'	1991
	'907'	1996
	'Reyan No. 5'	2000
	'Reyan No. 20'	2010
	'Reyan No. 21'	2011

[1]No formal release (except for Thailand).

Weaknesses

Insufficient persistence beyond 2–3 years under grazing or cutting is the major shortcoming of CIAT 184 and of *S. guianensis* in general (Cook et al. 2020). This is the most frequently mentioned technical factor responsible for constraining more widespread use of the accession. In this context it has to be pointed out that 'persistence' is the result of a number of inherent plant characteristics, ranging from the location of growing points on the plant to the concentration of palatability-affecting compounds in the forage, as well as utilization management. Low seed production potential and lack of ease of seed production are also mentioned as shortcomings, in comparison with other *Stylosanthes* germplasm, particularly *S. hamata* ('Verano').

Adoption of and perspectives for CIAT 184

We do not intend to engage in a discussion about the (lack of) adoption of new tropical forage technologies in general nor of forage legume technologies in particular. This has been most ably handled in a number of publications by others including Stür et al. (2000b) for tropical forages in general, and Shelton et al. (2005) for forage legumes. Rather, as a conclusion of this review, we offer a few thoughts of technical rather than socioeconomic nature around actual adoption of CIAT 184 and possible future developments. There is no doubt that some of them are also applicable to other tropical legume species and genotypes that have shown promise in R&D projects.

Lack of data

There is a lack of data on the actual use of CIAT 184 to assess the extent of its adoption and impact. Information is required about both the area planted to the legume and the number of adopters. In this context it is regrettable that most R&D projects make no provision for resources and institutional commitments regarding follow-up assessments of technology impacts, in the years after project termination. We consider that ILRI´s ex-post economic impact assessment of the fodder bank project in West Africa (Elbasha et al. 1999) is an example to be followed. Moreover, such assessments should be complemented with the identification and analysis of eventual constraints to adoption and, at the socioeconomic level, impacts on the livelihood of adopters' households.

Regional adoption

Tropical America. Traditionally, neither small- nor large-scale farmers have been accustomed to sowing forages and assuring their proper management in general, less so regarding legumes. In many cases livestock producers are still more animal-oriented ranchers than agriculturalists dealing with pasture plant production. Taking into account that appropriate grazing management for legume persistence is a major issue for pastures in the humid tropics, where CIAT 184 has shown to have potential in tropical America, it could be questioned whether CIAT 184 has any role in current production systems. Miles and Lascano (1997) found that there had been no major adoption in the humid tropics of Latin America, but this might change depending on evolving land use policies and production systems as well as economic pressures, such as the need to replace commercial concentrates.

Tropical Africa. As can be deduced from the above-mentioned impact study of fodder bank technology (Elbasha et al. 1999), there is potential for adoption of CIAT 184 in West Africa. Unfortunately, the accession was not available when the fodder bank research by ILRI and its partners started in the early 1980s. It is regrettable that the RABAOC project was discontinued without considering follow-up activities based on the multisite identification of promising germplasm, CIAT 184 being consistently one of the top-ranking herbaceous legumes.

In tropical Africa, there are 2 different production environments for future use of CIAT 184: in West Africa, where there is a continuing trend for transhumant livestock keepers to become sedentary crop-livestock producers; and in East Africa, where Napier grass dominates planted forages for livestock nutrition.

Southeast Asia. It appears that CIAT 184 has found its niche in this region. However, long-term adoption has been limited. We suggest the initial successes were due to the prevailing smallholder production systems operating under the pressure of very limited land resources, in combination with the long-term involvement of what Shelton et al. (2005) called 'champions', and intensive interaction between researchers and farmers (farmer participatory research). Stylo 184 has been successful where R&D projects arranged seed supply but, once projects were completed, the areas of stylo started to decline over time. A recent ACIAR study evaluating critical factors that promote or impede demand-driven uptake of forages in Cambodia, Lao PDR and Vietnam identified poor access to forage seeds as a major factor that impedes uptake of forages in the region (Yadav et al. 2022). This is particularly important for short-lived or weakly perennial forage legumes like Stylo 184 that require some regular replanting in cut-and-carry systems.

China. No doubt the sustained use of CIAT 184 in southern China is due to the outstanding long-term performance of this germplasm and to strong institutional interest and promotion. Adoption has been on both smallholder farms (where the innovative use as leaf meal originated) and in larger holdings, at private as well as state level. However, continuing use of the accession appears to be increasingly influenced by limited availability of seed produced at reasonably low cost, particularly in terms of labor. In this context, lack of machinery suitable for harvesting both seed and forage in hilly areas is seen as a specific limitation to its promotion.

Access to seed

The experience from R&D projects across the tropics has shown that availability of and access to seed constrain the use of CIAT 184, in spite of the technical strengths of this legume. Most likely this impediment to wider adoption also holds for other legumes. It is an issue that was recognized decades ago (Ferguson and Sauma 1993) and we suggest that it requires particular attention by tropical forage R&D policy makers. No doubt, because of eventual seed market implications, regional differences regarding production systems (e.g. smallholders vs. large estates) need to be taken into account. Model examples in tropical America and Southeast Asia are of seed being produced by smallholders in Bolivia and Thailand, respectively, and subsequently commercialized by seed trading companies (Sauma and Pizarro 2007; Hare 2014).

Future perspectives

We see increased opportunities for CIAT 184 (and other *Stylosanthes* species and ecotypes), when:

- R&D resumes a major interest in developing low-input pasture and forage technologies for infertile soils;
- Farmers perceive that soil loss and declining soil fertility are becoming increasing constraints to agricultural production;
- The economic environment favors the replacement, or complementation, of synthetic nitrogen fertilizer with the usage of nitrogen-fixing legumes;
- There is a major recognition and promotion of the multipurpose potential of forage legumes (Schultze-Kraft and Peters 1997). In this context, CIAT 184 in China is an interesting example: A legume, originally selected for extensive South American pastures grazed by cattle, resulted in being used mainly as a soil cover crop and for the production of concentrate to feed pigs and poultry. This points, again, to regional and production system differences regarding the potential role of *S. guianensis*. The versatility of CIAT 184 suggests that R&D should consider its use for both forage for livestock production (cut-and-carry systems, grazed pastures) and a cover crop to regenerate soil fertility and suppress weeds;
- The use for industrial production of leaf meal has become an economic option outside China. In this context, there are promising developments in Madagascar (see above) and in Costa Rica [where 'Legumix' *Stylosanthes* pellets are promoted (Sylvester-Bradley 2019)]. The potential socioeconomic impacts of the technology are to be stressed since importing of costly concentrates is reduced or replaced and rural employment is generated;
- Integrated production systems involving livestock, crops and/or trees (agropastoral, silvopastoral and agrosilvopastoral systems) continue to develop as sustainable land use options. In such systems, a legume like CIAT 184 should have particular potential (livestock feed and soil cover);
- Legume-based conservation agriculture practices expansion (e.g. Madagascar; Husson et al. 2013);
- There is a major recognition and a quantification of the environmental services provided by forage legumes, which could eventually lead to payment for ecosystem services (Schultze-Kraft et al. 2018) and thus result in major adoption incentives.

Research suggestions

In terms of future research on CIAT 184, we suggest the following:

Adoption: Region-specific identification of constraints to major adoption in future R&D activities.

Anthracnose: In spite of the continuing field resistance of CIAT 184, breeding towards a broader and durable genetic resistance, owing to the potential danger of new physiological races of the fungus appearing. This includes the strategy of developing new cultivars derived from CIAT 184, which will have to be compared with more recent composite hybrid cultivars such as 'Nina', 'Ubon' and 'BRS Bela' (Grof et al. 2001; Cook et al. 2020).

Forage quality: To optimize use of CIAT 184 for leaf meal/pellet production, breeding for higher nutritive value (improved leaf:stem ratio, lower fiber concentration).

Seed production: Breeding for increased seed yields, while maintaining herbage production.

Rhizobiology: Taking into account (1) that symbiotic nitrogen fixation is among the economically most important attributes of tropical forage legumes, and (2) that seed inoculation with improved *Rhizobium* strains may well have a place in intensified production systems, screening and selecting more effective and competitive *Rhizobium* strains for CIAT 184.

Environmental adaptation: Breeding for better adaptation to low temperatures and flooding to extend the environmental conditions where CIAT 184 can be grown successfully.

Climate change (CC) implications: Breeding for better adaptation to and mitigation of CC (Schultze-Kraft et al. 2018), not only in the case of CIAT 184 but for tropical forage legumes in general. This would include selecting/breeding for tolerance of flooding, soil salinity, drought and temperature extremes. Suggested research areas for CC mitigation are contribution to carbon accumulation in soil, biological nitrification inhibition and reduction of enteric methane emission.

Acknowledgments

We are grateful to Drs Carlos E. Lascano, Werner W. Stür and Bruce G. Cook for providing valuable comments on an earlier draft of this paper. This work is supported by the National Natural Science Foundation of China (31861143013).

References

(Note of the editors: All hyperlinks were verified 10 May 2023).

Amézquita MC; Toledo JM; Keller-Grein G. 1991. Agronomic performance of *Stylosanthes guianensis* cv. Pucallpa in the American tropical rain forest ecosystem. Tropical Grasslands 25:262–267. bit.ly/42dqCkQ

Audru J. 1971. *Stylosanthes gracilis*. Institut d'Élevage et de Médecine Vétérinaire des Pays Tropicaux (IEMVT), Maisons-Alfort, France. 199 p.

Ba NX; Van NH; Scandrett J; Vy LV; Tung HV; Nghi NT; Tuan D; Lane P; Parsons D. 2014. Improved forage varieties for smallholder cattle farmers in South Central Coastal Vietnam. Livestock Research for Rural Development 26(9):158. bit.ly/3nFpFmx

Bai Changjun; Liu Guodao; Wang Dongjin. 2004a. Selecting high-yielding anthracnose-resistant *Stylosanthes* in Hainan. In: Chakraborty S, ed. High-yielding anthracnose-resistant *Stylosanthes* for agricultural systems. Australian Centre for International Agricultural Research (ACIAR) Monograph 111, Canberra, ACT, Australia. p. 143–151. bit.ly/3NBDHAi

Bai Changjun; Liu Guodao; Wang Dongjin; Daida Krishna; Qudratullah S; Prasad VLK; Rama Rao SV; Parthasarthy Rao P; Ramesh CR; Balagopal R; Gopalan A. 2004b. *Stylosanthes* leaf meal for animal industries in China and India. In: Chakraborty S, ed. High-yielding anthracnose-resistant *Stylosanthes* for agricultural systems. Australian Centre for International Agricultural Research (ACIAR) Monograph 111, Canberra, ACT, Australia. p. 243–252. bit.ly/3AOzWzV

Bao Gegen; Zhuo Chunliu; Qian Chunmei; Xiao Ting; Guo Zhenfei; Lu Shaoyun. 2016. Co-expression of NCED and ALO improves vitamin C level and tolerance to drought and chilling in transgenic tobacco and stylo plants. Plant Biotechnology Journal 14(1):206–214. doi: 10.1111/pbi.12374

Becker M; Johnson DE. 1998. The role of legume fallows in intensified upland rice-based systems of West Africa. Nutrient Cycling in Agroecosystems 53:71–81. doi: 10.1023/A:1009767530024

Bulakali BP; Aloni J; Palata JC; Mergeai G. 2013. Performance assessment of the production of seeds by manual sieving of the soil of three varieties of *Stylosanthes guianensis* (Aublet) Swartz under the conditions of the Batéké Plateau (DRC). Tropicultura 31(4):253–259. (In French). bit.ly/3M3obvO

Bureenok S; Sisaath K; Yuangklang C; Vasupen K; Schonewille J.Th. 2016. Ensiling characteristics of silages of Stylo legume (*Stylosanthes guianensis*), Guinea grass (*Panicum maximum*) and their mixture, treated with fermented juice of lactic bacteria, and feed intake and digestibility in goats of rations based on these silages. Small Ruminant Research 134:84–89. doi: 10.1016/j.smallrumres.2015.12.006

Burt RL; Miller CP. 1975. *Stylosanthes* – a source of pasture legumes. Tropical Grasslands 9:117–123. bit.ly/3p8KWFn

Burt RL; Rotar PP; Walker JL; Silvey MW, eds. 1983. The role of *Centrosema*, *Desmodium*, and *Stylosanthes* in improving tropical pastures. Westview Press, Boulder, CO, USA. 292 p. doi: 10.1201/9780429314377

Bush RD; Young JR; Suon S; Ngim MS; Windsor PA. 2014. Forage growing as an incentive to improve smallholder beef production in Cambodia. Animal Production Science 54(10):1620–1624. doi: 10.1071/AN14136

Cameron AG; Gibson TA; Ibrahim; Winarno H; Hariadi A; Supriyadi. 1995. Performance of forages introduced into Kalimantan, Indonesia, by the South-East Asian Forage Seeds Project. CSIRO Genetic Resources Communication 21:1–38. bit.ly/414cjOa

Chakraborty S, ed. 2004a. High-yielding anthracnose-resistant *Stylosanthes* for agricultural systems. Australian Centre for International Agricultural Research (ACIAR) Monograph 111, Canberra, ACT, Australia. 268 p. bit.ly/3VqKIWx

Chakraborty S. 2004b. Anthracnose disease of *Stylosanthes*. In: Chakraborty S, ed. High-yielding anthracnose-resistant *Stylosanthes* for agricultural systems. Australian Centre for International Agricultural Research (ACIAR) Monograph 111, Canberra, ACT, Australia. p. 113–124. bit.ly/3LskApz

Chen CP; Aminah A; Khairuddin G. 1995. Forage Seeds Project in Malaysia: Activities, results and conclusions. In: Stür WW; Cameron AG; Hacker JB, eds. Forages for smallholders. Proceedings of the third meeting of the Southeast Asian Regional Forage Seeds Project, Samarinda, Indonesia, 23–28 October 1994. CIAT Working Document No. 143, 1995. CIAT, Cali, Colombia. p. 20–32. bit.ly/3APdpD5

Chen Zhijian; Song Jianling; Li Xinyong; Arango J; Cardoso JA; Rao I; Schultze-Kraft R; Peters M; Mo Xiaohui; Liu Guodao. 2021. Physiological responses and transcriptomic changes reveal the mechanisms underlying adaptation of *Stylosanthes guianensis* to phosphorus deficiency. BMC Plant Biology 21:466. doi: 10.1186/s12870-021-03249-2

CIAT (Centro Internacional de Agricultura Tropical). 1975–1977. Annual Reports 1975–1977, Beef Production Program. CIAT, Cali, Colombia.

Ciotti EM; Castelán ME; Tomei CE; Mónaco IP; Benítez JF. 2003. Respuesta de *Stylosanthes guianensis* CIAT 184 a la fertilización con una baja dosis de fósforo. Revista de Investigación Agropecuaria 32(2):137–148. bit.ly/410khrJ

Ciotti EM; Tomei CE; Castelán ME. 1999. Research Note: The adaptation and production of some *Stylosanthes* species in Corrientes, Argentina. Tropical Grasslands 33:165–169. bit.ly/44ulgnc

Cook BG; Pengelly BC; Schultze-Kraft R; Taylor M; Burkart S; Cardoso Arango JA; González Guzmán JJ; Cox K; Jones C; Peters M. 2020. Tropical Forages: An interactive selection tool. 2nd and Revised Edn. International

Center for Tropical Agriculture (CIAT), Cali, Colombia and International Livestock Research Institute (ILRI), Nairobi, Kenya. www.tropicalforages.info

Costa NMS. 2006. Revisão do género *Stylosanthes* Sw. Ph.D. Thesis. Universidade Técnica de Lisboa, Lisboa, Portugal. 470 p.

de Leeuw PN; Mohamed-Saleem MA; Nyamu AM, eds. 1994. *Stylosanthes* as a forage and fallow crop. Proceedings of the Regional Workshop on the Use of *Stylosanthes* in West Africa held in Kaduna, Nigeria, 26–31 October 1992. International Livestock Centre for Africa (ILCA), Addis Ababa, Ethiopia. 340 p. handle.net/10568/2720

Ding Xipeng; Jia Qinglin; Luo Xiaoyan; Zhang Long; Cong Hanqing; Liu Guodao; Bai Changjun. 2015. Development and characterization of expressed sequence tag-derived simple sequence repeat markers in tropical forage legume *Stylosanthes guianensis* (Aubl.) Sw. Molecular Breeding 35:202. doi: 10.1007/s11032-015-0370-x

Du Yumei; Tian Jiang; Liao Hong; Bai Chanjun; Yan Xiaolong; Liu Guodao. 2009. Aluminium tolerance and high phosphorus efficiency helps *Stylosanthes* better adapt to low-P acid soils. Annals of Botany 103(8):1239–1247. doi: 10.1093/aob/mcp074

Elbasha E; Thornton PK; Tarawali G. 1999. An ex post economic impact assessment of planted forages in West Africa. ILRI Impact Assessment Series 2. International Livestock Research Institute (ILRI), Nairobi, Kenya. 61 p. hdl.handle.net/10568/502

Enoh MB; Yonkeu S; Pingpoh DP; Messine O; Maadjou N. 1999. Yield and composition of fodder banks on the Adamawa plateau of Cameroon. Revue d'élevage et de médecine vétérinaire des pays tropicaux 52(1):55–62. doi: 10.19182/remvt.9702

Ferguson JE; Sauma G. 1993. Towards more forage seeds for smallholders in Latin America. In: Proceedings of the XVII International Grassland Congress, 8–21 February 1993, New Zealand and Australia. 2:1751–1756. bit.ly/44RsjpQ

Fuentes L; Domínguez A; Pérez Y; Mesa A; González S; Acebes JL; García-Angulo P. 2015. Monitoring of cell wall modifications during callogenesis in *Stylosanthes guianensis* (Fabaceae) under salt stress conditions. Brazilian Journal of Botany 38:783–793. doi: 10.1007/s40415-015-0196-0

Fuentes L; Mesa A; García P; Fernández M; Sosa D; Llorente A. 2000. Amplificación del marcador molecular Rrn5 en ADN extraído de callos de *Stylosanthes guianensis* cv. CIAT-184. Pastos y Forrajes 23(1):25–31. bit.ly/44xyO0X

Fuentes L; Pérez Y; Domínguez A; Mesa AR; González S. 2008. Influences of the NaCl in biochemical indicators evaluated in callus of *Stylosanthes guianensis* CIAT-184. Pastos y Forrajes 31(1):35–46. bit.ly/419gus6

Fuentes Alfonso L; Pérez Hernández Y; Domínguez Suárez A; Mesa Sardiñas A; González Suárez S. 2008. Evaluation of the anti-rust enzymatic activity in *Stylosanthes guianensis* cv. CIAT-184, during the organogenesis process under conditions of saline stress. Centro Agrícola 35(2):11–16. (In Spanish). bit.ly/3NEl1zH

Gao Mengze; Wan Miting; Yang Liyun; Zhao Meng; Liu Xiaojin; Chen Jiajia; Liu Pandao; Jiang Lingyan; Luo Lijuan. 2021. Molecular and physiological characterization of *Arabidopsis-Colletotrichum gloeosporioides* pathosystem. Plant Pathology 70(5):1168–1179. doi: 10.1111/ppa.13364

González LM; López RC; Fonseca I; Ramírez R. 2000. Crecimiento, frecuencia estomática, rendimiento de MS y acumulación de iones en nueve especies de leguminosas pratenses cultivadas en condiciones salinas. Pastos y Forrajes 23(4):299–308. bit.ly/3HFsHhz

GRIN (Germplasm Resources Information Network). 2023. Species of *Stylosanthes* Sw. GRIN-Global Taxonomy. USDA, Agricultural Research Service, National Plant Germplasm System, National Germplasm Resources Laboratory, Beltsville, MD, USA. bit.ly/3NOMmPZ

Grof B; Fernandes CD; Fernandes ATF. 2001. New *Stylosanthes guianensis* for tropical grasslands. In: Proceedings of the XIX International Grassland Congress, 11–21 February 2001, São Pedro, São Paulo, Brazil. p. 526–527. bit.ly/3pbn4Bi

Guo Pengfei; Liu Pandao; Lei Jian; Chen Caihong; Qiu Hong; Liu Guodao; Chen Zhijian; Luo Lijuan. 2019. Improvement of plant regeneration and *Agrobacterium*-mediated genetic transformation of *Stylosanthes guianensis*. Tropical Grasslands-Forrajes Tropicales 7(5):480–492. doi: 10.17138/tgft(7)480-492

Gyue G; Hline NK; Aye NT; Hein B; Naung MT; Thura M; Myint H; Thein SM; Oo LN; Htun MT; Mu KS; Aung A. 2021. Evaluation on dry forage yields and nutritional characteristics of introduced herbaceous legumes in Myanmar. Journal of Scientific Agriculture 5:12–19. doi: 10.25081/jsa.2021.v5.6647

Hare MD. 2014. Village-based tropical pasture seed production in Thailand and Laos – a success story. Tropical Grasslands-Forrajes Tropicales 2(2):165−174. doi: 10.17138/tgft(2)165-174

Hare MD; Gruben IE; Tatsapong P; Lunpha A; Saengkham M; Wongpichet K. 2004. Inter-row planting of legumes to improve the crude protein concentration in *Paspalum atratum* cv. Ubon pastures in north-east Thailand. Tropical Grasslands 38:167–177. bit.ly/3nrKBNR

Hare MD; Tatsapong P; Phengphet S; Lunpha A. 2007. *Stylosanthes* species in north-east Thailand: Dry matter yields and seed production. Tropical Grasslands 41:253–259. bit.ly/425nesj

He Chaozu; Schultze-Kraft R. 1988. Pi Hua Dou 184 (*Stylosanthes guianensis* CIAT 184) – nueva leguminosa forrajera en China tropical. Pasturas Tropicales 10(1):34–35. bit.ly/3ASQOoT

He Chengxin; Mo Ling; Huang Yuqing; Zhang Zhongfeng; Hare M; Zen Danjuan; Pu Gaozhong. 2017. Productivity and the survival rate after winter management of seven tropical forage accessions in subtropical region of

China. Agricultural Sciences 8:451–464. doi: 10.4236/as.2017.85034

He Liwen; Chen Na; Lv Hongjian; Wang Cheng; Zhou Wei; Chen Xiaoyang; Zhang Qing. 2019. Gallic acid influencing fermentation quality, nitrogen distribution and bacterial community of high-moisture mulberry leaves and stylo silage. Bioresource Technology 295:122255. doi: 10.1016/j.biortech.2019.122255

He Liwen; Lv Hongjian; Xing Yaqi; Wang Cheng; You Xiangwei; Chen Xiaoyang; Zhang Qing. 2020. The nutrients in *Moringa oleifera* leaf contribute to the improvement of stylo and alfalfa silage: Fermentation, nutrition and bacterial community. Bioresource Technology 301:122733. doi: 10.1016/j.biortech.2020.122733

Homma K; Mochizuki A; Watatsu E; Horie T; Shiraiwa T; Supapoj N; Thongthai C. 2008. Relay-intercropping of *Stylosanthes guianensis* in rainfed lowland rice ecosystem in Northeast Thailand. Plant Production Science 11(3):385–392. doi: 10.1626/pps.11.385

Horne PM; Stür WW; Gabunada Jr F; Phengsavanh P. 1997. Prospects for introducing forages in Southeast Asia. In: Stür WW, ed. Feed resources for smallholder livestock production in Southeast Asia. Proceedings of a regional meeting held at Vientiane, Lao PDR, 16–20 January 1996. Forages for Smallholders Project, Technical Report No. 1. CIAT Working Document 156, 1997. CIAT, Cali, Colombia. p. 11–19. hdl.handle.net/10568/56455

Huang Chunqiong; Liu Guodao; Bai Changjun. 2017. Polymorphism analysis in identification of genetic variation and relationships among *Stylosanthes* species. 3 Biotech 7(1):39. doi: 10.1007/s13205-017-0705-x

Husson O; Charpentier H; Razanamparany C; Moussa N; Michellon R; Naudin K; Razafintsalama H; Rakotoarinivo C; Rakotondramanana; Seguy L. 2008. *Stylosanthes guianensis*. In: Husson O; Séguy L; Charpentier H; Rakotondramanana; Michellon R; Raharison T et al., eds. 2013. Manuel pratique du semis direct sur couverture végétale permanente (SCV). Application à Madagascar. Volume III, Chapter 2. GSDM/CIRAD, Antananarivo, Madagascar. 12 p. bit.ly/3LT4Zkk

Husson O; Charpentier H; Michellon R; Moussa N; Razanamparany C; Naudin K; Raharison T; Rakotondramanana; Enjalric F; Seguy L. 2013. Systèmes de culture à base de *Stylosanthes guianensis*. In: Husson O; Séguy L; Charpentier H; Rakotondramanana; Michellon R; Raharison T et al., eds. 2013. Manuel pratique du semis direct sur couverture végétale permanente (SCV). Application à Madagascar. Volume V, Chapter 3. GSDM/CIRAD, Antananarivo, Madagascar. 24 p. bit.ly/3LT4Zkk

Jia Yanxing; Yang Maoxia; Wang Hui; Luo Lijuan; Chen Zhijuan; Yu Daogeng; Bai Changjun. 2017. First report of anthracnose on *Stylosanthes guianensis* caused by *Colletotrichum karstii* in China. Plant Disease 101(4):630–631. doi: 10.1094/PDIS-06-16-0931-PDN

Jiang Caode; Liu Lusheng; Li Xiaofeng; Han Rongrong; Wei Yunmin; Yu Yongxiong. 2018. Insights into aluminum-tolerance pathways in *Stylosanthes* as revealed by RNA-Seq analysis. Scientific Reports 8:6072. doi: 10.1038/s41598-018-24536-3

Jiang Lingyan; Wu Pengpeng; Yang Liyun; Liu Chun; Guo Pengfei; Wang Hui; Wang Shaocai; Xu Fupeng; Zhuang Qiwang; Tong Xinzhuo; Liu Pandao; Luo Lijuan. 2021. Transcriptomics and metabolomics reveal the induction of flavonoid biosynthesis pathway in the interaction of *Stylosanthes-Colletotrichum gloeosporioides*. Genomics 113(4):2702–2713. doi: 10.1016/j.ygeno.2021.06.004

Kachelriess S; Tarawali SA. 1994. The effects of row spacing and weed control on seed production of *Stylosanthes* in the subhumid zone of Nigeria. In: de Leeuw PN; Mohamed-Saleem MA; Nyamu AM, eds. *Stylosanthes* as a forage and fallow crop. Proceedings of the Regional Workshop on the Use of *Stylosanthes* in West Africa held in Kaduna, Nigeria, 26–31 October 1992. International Livestock Centre for Africa (ILCA), Addis Ababa, Ethiopia. p. 287–297. handle.net/10568/2720

Kaensombath L; Frankow-Lindberg BE. 2012. Effect of defoliation interval on biomass yield and chemical composition of stylo 'CIAT 184' (*Stylosanthes guianensis* (Aubl.) Sw. var. *guianensis*). Grassland Science 58(4):221–226. doi: 10.1111/grs.12004

Kaensombath L; Lindberg JE. 2013. Effect of additives on ensiling of taro (*Colocasia esculenta* (L.) Schott) leaves and Stylo CIAT 184 (*Stylosanthes guianensis* (Aubl.) Sw. var. *guianensis*) forage. Livestock Research for Rural Development 25(4):69. bit.ly/41gwEjm

Kaensombath L; Neil M; Lindberg JE. 2013. Effect of replacing soybean protein with protein from ensiled stylo (*Stylosanthes guianensis* (Aubl.) Sw. var. *guianensis*) on growth performance, carcass traits and organ weights of exotic (Landrace × Yorkshire) and native (Moo Lath) Lao pigs. Tropical Animal Health and Production 45:865–871. doi: 10.1007/s11250-012-0299-6

Kelemu S; Jiang Changshun; Huang Guixiu; Segura G. 2005. Genetic transformation of the tropical forage legume *Stylosanthes guianensis* with a rice-chitinase gene confers resistance to *Rhizoctonia* foliar blight disease. African Journal of Biotechnology 4:1025–1033. hdl.handle.net/10568/42904

Keller-Grein G, ed. 1990. Red Internacional de Evaluación de Pastos Tropicales RIEPT-Amazonia, I Reunión, 6–9 Noviembre de 1990, Lima, Perú. Documento de Trabajo No. 75, Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia. Vol 1, 119 p. bit.ly/3HEnwye

Keller-Grein G; Amézquita MC; Lema G; Franco LH. 1992. Multilocational testing of grasses and legumes in the humid tropics of South America. CIAT Report. Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia. 9 p. hdl.handle.net/10568/72179

Keoboualapheth C; Mikled C. 2003. Growth performance of indigenous pigs fed with *Stylosanthes guianensis* CIAT

184 as replacement for rice bran. Livestock Research for Rural Development 15(9):63. bit.ly/3ptUew6

Keopaseuht T; Chhay Ty; Bouahom B; Preston TR. 2004. Effect of method of offering foliages of *Gliricida sepium* and *Stylosanthes guianensis* CIAT 184 (Stylo) to goats on intake and digestibility. Livestock Research for Rural Development 16(5):31. bit.ly/42JmUPV

Khanh TT; Ha NV. 2007. Successful forage development for smallholders in Daklak, Central Highlands, Vietnam: The contribution of forages to livestock development and livelihoods of upland farmers. In: Hare MD; Wongpichet K, eds. Forages: A pathway to prosperity for smallholder farmers. Proceedings of an International Forage Symposium, Faculty of Agriculture, Ubon Ratchathani University, Thailand. p. 270–284. ISBN: 9789745231412

Khoutsavang B; Bouahom B; Ogle B. 2006. Effect of including fresh Stylo 184 and cassava foliage (*Manihot esculenta* Crantz), fed separately or in a mixture on digestibility, intake and N retention in growing pigs. The Lao Journal of Agriculture and Forestry Vol. January–June 2006:21–35. (In Lao). bit.ly/41a7mDE

Kiyothong K; Satjipanon C; Namsilee R. 2005a. Effect of dates of closing cut on seed yield and seed quality of *Stylosanthes guianensis* CIAT 184. Songklanakarin Journal of Science and Technology 27(5):983–991. bit.ly/415gIR9

Kiyothong K; Satjipanon C; Pholsen P. 2002. Effect of cutting height and time on seed yield and seed quality of *Stylosanthes guianensis* CIAT 184. Songklanakarin Journal of Science and Technology 24(4):587–593. bit.ly/44waAV6

Kiyothong K; Satjipanon C; Pholsen P. 2005b. Effect of planting dates on seed yield and seed quality of *Stylosanthes guianensis* CIAT 184. Songklanakarin Journal of Science and Technology 27(6):1163–1169. bit.ly/44rYa0j

Kiyothong K; Wanapat M. 2004a. Growth, hay yield and chemical composition of cassava and stylo 184 grown under intercropping. Asian-Australasian Journal of Animal Sciences 17(6):799–807. doi: 10.5713/ajas.2004.799

Kiyothong K; Wanapat M. 2004b. Supplementation of cassava hay and stylo 184 hay to replace concentrate for lactating dairy cows. Asian-Australasian Journal of Animal Sciences 17(5):670–677. doi: 10.5713/ajas.2004.670

Kopinski JS; Keonouchanh S; Cox K; Stür W. 2008. Digestible energy value for pigs of the forage legume *Stylosanthes guianensis* CIAT 184 (Stylo 184). Proceedings of the XIIIth Asian-Australasian Association of Animal Production Societies (AAAP) Animal Science Congress 2008, Hanoi, Vietnam, September 22–26, 2008. Poster session. 4 p.

Kouadio KS; Yapi YM; Kimse M; Alla KJB; Gidenne T; Wandan EN. 2022. Sun-dried stylo hay (*Stylosanthes guianensis* CIAT 184) as dietary fibre source in rabbits. Indian Journal of Animal Research. doi: 10.18805/IJAR.BF-1501

Kouadio KS; Yapi YM; Kimse M; Alla KJB; Sangare S; Gidenne T; Wandan EN. 2021. Effects of sun-dried stylo hay (*Stylosanthes guianensis* cv CIAT 184) on rabbits growth and slaughter performances. Proceedings of the 12th World Rabbit Congress, 3–5 November 2021, Nantes, France. hal.inrae.fr/hal-03649269

Lanting EF; Gabunada F; Ocfemia G; Salamat S; Bugayong A; Marasigan C; Garcia N. 1995. Forage Seeds Project in the Philippines: Activities, results and conclusions. In: Stür WW; Cameron AG; Hacker JB, eds. 1995. Forages for Smallholders. Proceedings of the third meeting of the Southeast Asian Regional Forage Seeds Project, Samarinda, Indonesia, 23–28 October 1994. CIAT Working Document No. 143, 1995. CIAT, Cali, Colombia. p. 33–44. bit.ly/3APdpD5

Lanting E; Sevilla C; Gabunada Jr F. 2003. Stylo 184 as a protein source in rice-straw-based rations for sheep. Poster paper. In: Stür WW; Horne PM; Hacker JB; Kerridge PC, eds. Working with farmers: The key to adoption of forage technologies. Proceedings of an International Workshop held in Cagayan de Oro City, Mindanao, Philippines, 12–15 October 1999. Australian Centre for International Agricultural Research (ACIAR) Proceedings No. 95, Canberra, ACT, Australia. p. 149–151. bit.ly/3LWtZXS

Lenné JM. 1985. Recent advances in the understanding of anthracnose of *Stylosanthes* in tropical America. Proceedings of the XV International Grassland Congress, 24–31 August 1985, Kyoto, Japan. p. 773–775.

Li Dongxia; Ni Kuikui; Zhang Yingchao; Lin Yanli; Yang Fuyu. 2019. Fermentation characteristics, chemical composition and microbial community of tropical forage silage under different temperatures. Asian Australasian Journal of Animal Sciences 32(5):665–674. doi: 10.5713/ajas.18.0085

Li Kailong; Qiu Hong; Zhou Min; Lin Yang; Guo Zhenfei; Lu Shaoyun. 2018. Chloroplast protein 12 expression alters growth and chilling tolerance in tropical forage *Stylosanthes guianensis* (Aublet) Sw. Frontiers in Plant Science 9:1319. doi: 10.3389/fpls.2018.01319

Li Mao; Lv Renlong; Zhang Lidong; Zi Xuejuan; Zhou Hanlin; Tang Jun. 2021. Melatonin is a promising silage additive: Evidence from microbiota and metabolites. Frontiers in Microbiology 12:670764. doi: 10.3389/fmicb.2021.670764

Li Mao; Zhou Hanlin; Zi Xuejuan; Cai Yimin. 2017. Silage fermentation and ruminal degradation of stylo prepared with lactic acid bacteria and cellulase. Animal Science Journal 88(10):1531–1537. doi: 10.1111/asj.12795

Li Mao; Zi Xuejuan; Zhou Hanlin; Hou Guanyu; Cai Yimin. 2014. Short Report: Chemical composition and in vitro digestibility of *Stylosanthes guianensis* varieties. Grassland Science 60(2):125–129. doi: 10.1111/grs.12046

Liu Guodao; Bai Changjun; Wang Dongjin; He Huaxuan. 2004a. *Stylosanthes* cultivars in China: Their development and performance. In: Chakraborty S, ed. High-yielding anthracnose-resistant *Stylosanthes* for agricultural systems. Australian Centre for International Agricultural Research (ACIAR) Monograph 111, Canberra, ACT, Australia. p. 153–158. bit.ly/3NBDHAi

Liu Guodao; Bai Changjun; Wang Dongjin; Ramesh CR; Parthasarthy Rao P. 2004b. Leaf meal production from *Stylosanthes* in China and India. In: Chakraborty S, ed. High-yielding anthracnose-resistant *Stylosanthes* for agricultural systems. Australian Centre for International Agricultural Research (ACIAR) Monograph 111, Canberra, ACT, Australia. p. 253–256. bit.ly/3AOzWzV

Liu Guodao; Chakraborty S. 2005. Stylo in China: A tropical forage legume success story. Tropical Grasslands 39:215. bit.ly/3LWyjGs

Liu Guodao; Kerridge PC. 1997. Selection and utilization of *Stylosanthes guianensis*, for green cover and feed meal production in China. Proceedings of the XVIII International Grassland Congress, 8–19 June 1997, Winnipeg-Saskatoon, Canada. ID No. 1215. Vol. 2:19/49–19/50. hdl.handle.net/10568/55902

Liu Guodao; Phaikaew C; Stür WW. 1997. Status of *Stylosanthes* development in other countries. II: *Stylosanthes* development and utilisation in China and south-east Asia. Tropical Grasslands 31:460–466. bit.ly/3NFuN4M

Liu Pandao; Huang Rui; Hu Xuan; Jia Yidan; Li Jifu; Luo Jiajia; Liu Qin; Luo Lijuan; Liu Guodao; Chen Zhijian. 2019. Physiological responses and proteomic changes reveal insights into *Stylosanthes* response to manganese toxicity. BMC Plant Biology 19:212. doi: 10.1186/s12870-019-1822-y

Liu Qinhua; Chen Mingxia; Zhang Jianguo; Shi Shangli; Cai Yimin. 2012. Characteristics of isolated lactic acid bacteria and their effectiveness to improve stylo (*Stylosanthes guianensis* Sw.) silage quality at various temperatures. Animal Science Journal 83(2):128–135. doi: 10.1111/j.1740-0929.2011.00937.x

Liu Qinhua; Zhang Jianguo; Shi Shangli; Sun Qizhong. 2011. The effects of wilting and storage temperatures on the fermentation quality and aerobic stability of stylo silage. Animal Science Journal 82(4):549–553. doi: 10.1111/j.1740-0929.2011.00873.x

Loker W; Vera R; Reátegui K. 1997. Pasture performance and sustainability in the Peruvian Amazon: Results of long-term on-farm research. Agricultural Systems 55(3):385–408. doi: 10.1016/S0308-521X(96)00102-3

Long Huiying; Zhang De; He Guangxiong. 2017. The effects of planted and plowed *Stylosanthes guianensis* on degrading soil fertility in hilly countries of dry-hot valley. Acta Ecologica Sinica 37(5):279–283. doi: 10.1016/j.chnaes.2017.02.004

Lu Shaoyun; Wang Xianghui; Guo Zhenfei. 2013. Differential responses to chilling in *Stylosanthes guianensis* (Aublet) Sw. and its mutants. Agronomy Journal 105(2):377–382. doi: 10.2134/agronj2012.0333

Mesa AR; Lajonchere G; Prieto M; Toral O. 1993. Organogénesis en *Stylosanthes guianensis* cv. CIAT 184. Pastos y Forrajes 16(3):207–210. bit.ly/42snwcq

Miles JW; Lascano CE. 1997. Status of *Stylosanthes* development in other countries. I. *Stylosanthes* development and utilisation in South America. Tropical Grasslands 31:454–459. bit.ly/3NGR5mC

Mohamed-Saleem MA; Suleiman H. 1986. Fodder banks: Dry season feed supplementation for traditionally managed cattle in the subhumid zone. World Animal Review 59:11–17. hdl.handle.net/10568/28631

Muhr L; Tarawali SA; Peters M; Schultze-Kraft R. 1999a. Forage legumes for improved fallows in agropastoral systems of subhumid West Africa: I. Establishment, herbage yield and nutritive value of legumes as dry season forage. Tropical Grasslands 33:222–233. bit.ly/3HKmbpB

Muhr L; Tarawali SA; Peters M; Schultze-Kraft R. 1999b. Forage legumes for improved fallows in agropastoral systems of subhumid West Africa: III. Nutrient import and export by forage legumes and their rotational effects on subsequent maize. Tropical Grasslands 33:245–256. bit.ly/3p9vZ66

Muhr L; Tarawali SA; Peters M; Schultze-Kraft R. 2001. Acceptability of forage legumes for improved fallows – first experiences of agro-pastoralists in subhumid southwest Nigeria. Experimental Agriculture 37(4):495–507. doi: 10.1017/S0014479701000436

Na Chiangmai P; Pootaeng-on Y; Khewaram T. 2013. Evaluation of the shade tolerance of moth bean (*Vigna aconitifolia*) and two tropical legume species. Silpakorn University Science & Technology Journal 7(1):19–31. doi: 10.14456/sustj.2013.2

NARS-CIRAD/EMVT-CIAT-ILCA. 1995. West and Central African Animal Feed Research Project. Results 1990–1994. 5th Annual Meeting, Lomé, Togo, 3–9 April 1995. CIAT Working Document No. 145. CIAT, Cali, Colombia. 258 p. hdl.handle.net/10568/56449

Naudin K; Irintsoa Rasolofo L; Rakotomalala Andriamarosata J; Douzet J-M; Scopel E. 2012. Contrôle de l'émergence des adventices par le paillage en riziculture pluviale à Madagascar. 1ère Conférence Internationale: Systèmes de Production Rizicole Biologique, 27–30 August 2012, Montpellier, France. p. 116–117. bit.ly/3p9vWY5

Naudin K; Scopel E; Andriamandroso ALH; Rakotosolofo M; Andriamarosoa Ratsimbazafy NRS; Rakotozandriny JN; Salgado P; Giller KE. 2011. Trade-offs between biomass use and soil cover. The case of rice-based cropping systems in the Lake Alaotra region of Madagascar. Experimental Agriculture 48(2):194–209. doi: 10.1017/S001447971100113X

Ng KF; Stür WW; Shelton HM. 1997. New forage species for integration of sheep in rubber plantations. The Journal of Agricultural Science 128(3):347–355. doi: 10.1017/S0021859696004248

Norachack B; Keonouchanh S; Chhay Ty; Bouahom B; Preston TR. 2004. *Stylosanthes* and cassava leaves as protein supplements to a basal diet of broken rice for local pigs. Livestock Research for Rural Development 16(10):74. bit.ly/3HOLIhj

Nulik J; Dalgliesh N; Cox K; Gabb S. 2013. Integrating herbaceous legumes into crop and livestock systems in eastern Indonesia. Australian Centre for International Agricultural Research (ACIAR) Monograph No. 154, Canberra, ACT, Australia. 130 p. bit.ly/3M5NXiY

Pamo ET; Yonkeu S. 1994. Effect of *Stylosanthes guianensis* on the production and chemical composition of *Brachiaria ruziziensis* in Adamaoua (Cameroon). Revue d'élevage et de médecine vétérinaire des pays tropicaux 47(1):127–129. (In French). doi: 10.19182/remvt.9124

Pardinez V; Cabaccan C; Darang S; Pascua R. 2000. Pilot seed production studies of *Stylosanthes guianensis* CIAT 184 in the Northern Philippines. Poster paper. In: Stür WW; Horne PM; Hacker JB; Kerridge PC, eds. Working with farmers: The key to adoption of forage technologies. Proceedings of an International Workshop held in Cagayan de Oro City, Mindanao, Philippines, 12–15 October 1999. Australian Centre for International Agricultural Research (ACIAR) Proceedings No. 95, Canberra, ACT, Australia. p. 168–169. bit.ly/3LWtZXS

Pen M; Savage DB; Nolan JV; Seng M. 2013. Effect of *Stylosanthes guianensis* supplementation on intake and nitrogen metabolism of *Bos indicus* cattle offered a basal diet of mixed rice straw and tropical grass. Animal Production Science 53(5):453–457. doi: 10.1071/AN11307

Peters M; Tarawali SA; Alkämper J. 1994. Evaluation of tropical pasture legumes for fodder banks in subhumid Nigeria. 2. Accessions of *Aeschynomene histrix*, *Centrosema acutifolium*, *C. pascuorum*, *Stylosanthes guianensis* and *S. hamata*. Tropical Grasslands 28:74–79. bit.ly/42nlD0P

Peters M; Tarawali SA; Schultze-Kraft R. 2000. Relative palatability and seasonal agronomic performance of selected pasture legumes for species mixtures in dry-subhumid West Africa. Experimental Agriculture 36(3):353–368. doi: 10.1017/S0014479700003070

Peters M; Tarawali SA; Schultze-Kraft R; Smith JW; Musa A. 2001. Performance of legume mixtures under small-plot periodic grazing. Journal of Agronomy and Crop Science 182(1):25–35. doi: 10.1046/j.1439-037x.1999.00254.x

Phaikaew C; Hare MD. 2005. Stylo adoption in Thailand: Three decades of progress. Tropical Grasslands 39:216. bit.ly/3pcALjl

Phaikaew C; Ramesh CR; Yi Kexian; Stür W. 2004. Utilisation of *Stylosanthes* as a forage crop in Asia. In: Chakraborty S, ed. High-yielding anthracnose-resistant *Stylosanthes* for agricultural systems. Australian Centre for International Agricultural Research (ACIAR) Monograph 111, Canberra, ACT, Australia. p. 65–76. bit.ly/3LskApz

Phengsavanh P. 1999. Forage evaluation in the Lao PDR. The Lao Journal of Agriculture and Forestry 2:31–39. (In Lao).

Phengsavanh P; Frankow-Lindberg BE. 2013. Effect of harvesting interval on biomass yield and nutritive value of five tropical forage legumes (*Aeschynomene histrix* BRA 9690, *Canavalia brasiliensis* CIAT 17009, *Stylosanthes guianensis* CIAT 184 and 'Composite' and *Vigna unguiculata* CIAT 1088-4) in Lao PDR. Grassland Science 59(2):80–86. doi: 10.1111/grs.12017

Phengsavanh P; Ledin I. 2003. Effect of Stylo 184 (*Stylosanthes guianensis* CIAT 184) and Gamba grass (*Andropogon gayanus* cv. Kent) in diets for growing goats. Livestock Research for Rural Development 15(10):71. bit.ly/3Mh4von

Phengsavanh P; Phimphachanhvongsod V. 2007. Forage development in Lao PDR: Emerging impacts from planted forages in the upland of Lao PDR. In: Hare MD; Wongpichet K, eds. Forages: A pathway to prosperity for smallholder farmers. Proceedings of an International Forage Symposium, Faculty of Agriculture, Ubon Ratchathani University, Thailand. p. 263–269. ISBN: 9789745231412

Phengsavanh P; Stür W; Keonouchanh S. 2008. Adoption of the forage legume 'Stylo 184' (*Stylosanthes guianensis* CIAT 184) in smallholder pig systems in Lao PDR. Proceedings of the XIIIth Animal Science Congress of the Asian-Australasian Association of Animal Production Societies, 22–26 September 2008, Hanoi, Vietnam.

Philp JNM; Vance W; Bell RW; Ty Chhay; Boyd D; Phimphachanhvongsod V; Denton MD. 2019. Forage options to sustainably intensify smallholder farming systems on tropical sandy soils. A review. Agronomy for Sustainable Development 39:30. doi: 10.1007/s13593-019-0576-0

Phimmmasan H; Kongvongxay S; Chhay Ty; Preston TR. 2004. Water spinach (*Ipomoea aquatica*) and Stylo 184 (*Stylosanthes guianensis* CIAT 184) as basal diets for growing rabbits. Livestock Research for Rural Development 16(5):34. bit.ly/3LLYej7

Pitiwittayakul N; Bureenok S; Schonewille JT. 2021. Selective thermotolerant lactic acid bacteria isolated from fermented juice of epiphytic lactic acid bacteria and their effects on fermentation quality of stylo silages. Frontiers in Microbiology 12:673946. doi: 10.3389/fmicb.2021.673946

Pizarro EA, ed. 1983. Red Internacional de Evaluación de Pastos Tropicales. Resultados 1979–1982. Segunda Reunión de la RIEPT, Septiembre 27–29, 1982. Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia. 459 p. hdl.handle.net/10568/56305

Pizarro EA, ed. 1985. Red Internacional de Evaluación de Pastos Tropicales. Resultados 1982–1985. Tercera Reunión de la RIEPT, Octubre 21–24, 1985. Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia. 2 vols., 1,228 p. hdl.handle.net/10568/56339

Pizarro EA, ed. 1988. Primera Reunión de la RIEPT-CAC, Noviembre 17–19, 1988, Veracruz, México. INIFAP and CIAT, Cali, Colombia. 495 p. hdl.handle.net/10568/56307

Rakotomanana OR. 2021. Effect of *Stylosanthes* pit silage on dairy cows. International Journal of Agriculture Extension and Social Development 4(2):102–105. bit.ly/42uAPcn

Randrianjafizanaka MT; Autfray P; Andrianaivo AP; Ramontaa IR; Rodenburg J. 2018. Combined effects of cover crops, mulch, zero-tillage and resistant varieties on *Striga asiatica* (L.) Kuntze in rice-maize rotation systems. Agriculture, Ecosystems & Environment 256:23–33. doi: 10.1016/j.agee.2017.12.005

Razafinarivo DT; Rakotomanana O; Razanamparany L. 2014. Intégration agriculture-élevage: Valorisation de *Stylosanthes* CIAT 184 pour l'alimentation des vaches laitières. Bulletin de l'Académie Malgache XCIII/1:229–238. hal.archives-ouvertes.fr/hal-03342046

Reátegui K; Vera RR; Loker WL; Vásquez M. 1995. On-farm grass-legume pasture performance in the Peruvian rainforest. Experimental Agriculture 31(2):227–239. doi: 10.1017/S0014479700025308

Reyes C; Ordóñez H; Pinedo L. 1985. *Stylosanthes guianensis* cv. "Pucallpa", leguminosa forrajera para la Amazonía. Boletín Técnico No. 3. Instituto Veterinario de Investigaciones Tropicales y de Altura (IVITA) and Instituto Nacional de Investigación y Promoción Agropecuaria (INIPA), IVITA Estación Principal del Trópico, Pucallpa, Peru. 13 p. bit.ly/42n3iRs

Rippstein G, ed. 1998. RABAOC (Réseau de recherches en alimentation du bétail en Afrique Occidentale et Centrale). Rapport de synthèse, Rapport No. 98-044. CIRAD-EMVT, Montpellier, France and CIAT, Cali, Colombia. 88 p. hdl.handle.net/10568/54549

Saito K; Azoma K; Oikeh SO. 2010. Combined effects of *Stylosanthes guianensis* fallow and tillage management on upland rice yield, weeds and soils in southern Benin. Soil and Tillage Research 107(2):57–63. doi: 10.1016/j.still.2010.03.001

Saito K; Linquist B; Keobualapha B; Phanthaboon K; Shiraiwa T; Horie T. 2006. *Stylosanthes guianensis* as a short-term fallow crop for improving upland rice productivity in northern Laos. Field Crops Research 96(2-3):438–447. doi: 10.1016/j.fcr.2005.09.005

Sarria R; Calderón A; Thro AM; Torres E; Mayer JE; Roca WM. 1994. Agrobacterium-mediated transformation of *Stylosanthes guianensis* and production of transgenic plants. Plant Science 96(1-2):119–127. doi: 10.1016/0168-9452(94)90228-3

Satjipanon C; Chinosang W; Susaena W; Gobius N; Sivichai S. 1995. Forage Seeds Project in Thailand: Activities, results and conclusions. In: Stür WW; Cameron AG; Hacker JB, eds. Forages for Smallholders. Proceedings of the third meeting of the Southeast Asian Regional Forage Seeds Project, Samarinda, Indonesia, 23–28 October 1994. CIAT Working Document No. 143, 1995. CIAT, Cali, Colombia. p. 45–58. bit.ly/3APdpD5

Sauma G; Pizarro EA. 2007. A novel approach for seed production by small farmers in South America: SEFO story. In: Hare MD; Wongpichet K, eds. Forages: A pathway to prosperity for smallholder farmers. Proceedings of an International Forage Symposium, Faculty of Agriculture, Ubon Ratchathani University, Thailand. p. 89–102. ISBN: 9789745231412

Schultze-Kraft, R. 1976. Untersuchungen über die Eignung von Arten und Ökotypen der Leguminosengattung *Stylosanthes* zur Weideverbesserung in tropischen Savannen Südamerikas, am Beispiel der kolumbianischen Llanos Orientales. Ph.D. Thesis. Justus Liebig-Universität Giessen, Germany. 244 p.

Schultze-Kraft R; Peters M. 1997. Tropical legumes in agricultural production and resource management: An overview. Giessener Beiträge zur Entwicklungsforschung 24:1–7.

Schultze-Kraft R; Peters M; Wenzl P. 2020. A historical appraisal of the tropical forages collection conserved at CIAT. Genetic Resources 1(2):51–68. doi: 10.46265/genresj.KZEW5023

Schultze-Kraft R; Rao IM; Peters M; Clements RJ; Bai Changjun; Liu Guodao. 2018. Tropical forage legumes for environmental benefits: An overview. Tropical Grasslands-Forrajes Tropicales 6:1–14. doi: 10.17138/tgft(6)1-14

Shelton HM; Franzel SC; Peters M. 2005. Adoption of tropical legume technology around the world: Analysis of success. Tropical Grasslands 39:198–209. bit.ly/3nvW3rC

Song Jianling; Zou Xiaoyan; Liu Pandao; Cardoso JA; Schultze-Kraft R; Liu Guodao; Luo Lijuan; Chen Zhijian. 2022. Differential expressions and enzymatic properties of malate dehydrogenases in response to nutrient and metal stresses in *Stylosanthes guianensis*. Plant Physiology and Biochemistry 170:325–337. doi: 10.1016/j.plaphy.2021.12.012

Stace HM; Edye LA, eds. 1984. The biology and agronomy of *Stylosanthes*. Academic Press, North Ryde, NSW, Australia. 636 p. doi: 10.1016/B978-0-12-661680-4.X5001-X

Stür WW, ed. 1997. Feed resources for smallholder livestock production in Southeast Asia. Proceedings of a regional meeting held at Vientiane, Lao PDR, 16–20 January 1996. Forages for Smallholders Project, Technical Report No. 1. CIAT Working Document 156, 1997. CIAT, Cali, Colombia. 93 p. hdl.handle.net/10568/56455

Stür WW, ed. 1998. Forages for Smallholders Project. Technical Report No. 4. Proceedings of the Third Regional Meeting of the Forages for Smallholders Project held at the Agency for Livestock Services of East Kalimantan, Samarinda, East Kalimantan, Indonesia, 23–26 March 1998. CIAT Working Document No. 188. CIAT, Cali, Colombia. 220 p. bit.ly/3LZ4eWQ

Stür WW; Cameron AG; Hacker JB, eds. 1995. Forages for Smallholders. Proceedings of the third meeting of the Southeast Asian Regional Forage Seeds Project, Samarinda, Indonesia, 23–28 October 1994. CIAT Working Document No. 143, 1995. CIAT, Cali, Colombia. 149 p. bit.ly/3APdpD5

Stür WW; Horne PM; Gabunada Jr FA; Phengsavanh P; Kerridge PC. 2002. Forage options for smallholder crop–animal systems in Southeast Asia: Working with farmers to find solutions. Agricultural Systems 71(1–2):75–98. doi: 10.1016/S0308-521X(01)00037-3

Stür WW; Horne PM; Hacker JB; Kerridge PC, eds. 2000b. Working with farmers: The key to adoption of forage technologies. Proceedings of an International Workshop held in Cagayan de Oro City, Mindanao, Philippines, 12–15 October 1999. Australian Centre for International Agricultural Research (ACIAR) Proceedings No. 95, Canberra, ACT, Australia. 325 p. bit.ly/3LWtZXS

Stür WW; Horne PM; Phengsavanh P; Gabunada F; Khanh TT; Connell J. 2007. Planted forages – the key for making money from smallholder livestock production: Experiences from CIAT´s forage R&D in Southeast Asia. In: Hare MD; Wongpichet K, eds. Forages: A pathway to prosperity for smallholder farmers. Proceedings of an International Forage Symposium, 5–7 March 2007, Faculty of Agriculture, Ubon Ratchathani University, Thailand. p. 313–331. ISBN: 9789745231412

Stür WW; Ibrahim T; Tuhulele M; Le Hoa Binh; Gabunada F; Ibrahim; Nakamanee G; Phimphachanhvongsod V; Liu Guodao; Horne PM. 2000a. Adaptation of forages to climate, soils and use in smallholder farming systems in Southeast Asia. In: Stür WW; Horne PM; Hacker JB; Kerridge PC, eds. Working with farmers: The key to adoption of forage technologies. Proceedings of an International Workshop held in Cagayan de Oro City, Mindanao, Philippines, 12–15 October 1999. Australian Centre for International Agricultural Research (ACIAR) Proceedings No. 95, Canberra, ACT, Australia. p. 112–119. bit.ly/3LWtZXS

Stür W; Phengsavanh P; Keonouchanh S; Phimphachanvongsod V; Phengvilaysouk A; Kopinski J. 2010. Final Report: Forage legumes for supplementing village pigs in Lao PDR. Project No. AH/2004/046. Australian Centre for International Agricultural Research (ACIAR), Canberra, ACT, Australia. 74 p. bit.ly/42r970q

Suárez JD; Villavicencio C. 1988. Producción de semillas en *Brachiaria decumbens* CIAT-606, *Stylosanthes guianensis* CIAT-184 y varios cvs. en la región central de Cuba. In: Pizarro EA, ed. 1a Reunión de la RIEPT-CAC, 17–19 Noviembre 1988, Veracruz, México. INIFAP and CIAT, Cali, Colombia. p. 480–481. bit.ly/4278wRz

Sukkasem P; Mungmeechai S; Bruakeaw P. 2003. Effect of cutting interval and height on yield and chemical composition of *Stylosanthes guianensis* CIAT 184 in Ban-thon soil series. Animal Nutrition Division Annual Research Report 2003, Department of Livestock Development, Bangkok, Thailand. p. 114–125. (In Thai). bit.ly/3nIw8NL

Sylvester-Bradley R. 2019. “Legumix” *Stylosanthes* pellets: A healthier and more sustainable animal feed. Outlook on Agriculture 48(3):229–236. doi: 10.1177/0030727019870835

Tan Jiali; Tang Huashan; Niu Yuejing; Chen Youguang; Lu Shaoyun; Guo Zhenfei; Li Haihang. 2009. Isolation and characterisation of gamma radiation-induced dwarf mutants of *Stylosanthes guianensis*. Tropical Grasslands 43:53–61. bit.ly/42nNeig

Tarawali SA. 1994. Evaluating selected forage legumes for livestock and crop production in the subhumid zone of Nigeria. The Journal of Agricultural Science 123(1):55–60. doi: 10.1017/S0021859600067770

Tarawali SA. 2000. An approach for the evaluation of herbaceous legumes with multiple benefits. In: Carsky R; Eteka A; Keatinge J; Manyong V, eds. Cover crops for natural resource management in West Africa – Plantes de couverture et gestion des ressources naturelles en Afrique occidentale. Proceedings of a workshop organized by IITA and CIEPCA, 26–29 October 1999, Cotonou, Benin. International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. p. 71–94. hdl.handle.net/10568/92678

Tarawali SA; Peters M; Jama AA. 1994. Species screening and multi-locational testing of *Stylosanthes* species in West Africa. In: de Leeuw PN; Mohamed-Saleem MA; Nyamu AM, eds. *Stylosanthes* as a forage and fallow crop. Proceedings of the Regional Workshop on the Use of *Stylosanthes* in West Africa held in Kaduna, Nigeria, 26–31 October 1992. International Livestock Centre for Africa (ILCA), Addis Ababa, Ethiopia. p. 81–95. handle.net/10568/2720

Tarawali SA; Peters M; Schultze-Kraft R. 1999. Forage legumes for sustainable agriculture and livestock production in subhumid West Africa. Experiment 1: Evaluation of selected grass-legume combinations for supplementation of young calves. ILRI Project Report. International Livestock Research Institute (ILRI), Nairobi, Kenya. p. 29–38. hdl.handle.net/10568/49704

Thang CM; Ledin I; Bertilsson J. 2010. Effect of feeding cassava and/or *Stylosanthes* foliage on the performance of crossbred growing cattle. Tropical Animal Health and Production 42:1–11. doi: 10.1007/s11250-009-9378-8

Toledo JM; Schultze-Kraft R. 1982. Metodología para la evaluación agronómica de pastos tropicales. In: Toledo JM, ed. Manual para la evaluación agronómica: Red Internacional de Evaluación de Pastos Tropicales (RIEPT). Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia. p. 91–110. hdl.handle.net/10568/54148

Tuley P. 1968. *Stylosanthes gracilis*. Review Article. Herbage Abstracts 38:87–94.

Vela J. 2004a. Use of *Stylosanthes guianensis* for strategic supplementation of pre-weaned calves. In: Holmann F; Lascano C, eds. Feeding systems with forage legumes to intensify dairy production in Latin America and the Caribbean: A project executed by the Tropileche Consortium. CIAT (Centro Internacional de Agricultura Tropical), Tropileche Consortium, Cali, Colombia; SLP (System-wide Livestock Programme), Addis Ababa, Ethiopia; and ILRI (International Livestock Research Institute), Nairobi, Kenya. p. 71–72. bit.ly/44rZDDX

Vela J. 2004b. Rice (*Oryza sativa*) yield as an indicator of soil fertility after the incorporation of *Stylosanthes guianensis* stubble. In: Holmann F; Lascano C, eds. Feeding systems with forage legumes to intensify dairy production in Latin America and the Caribbean: A project executed by the Tropileche Consortium. CIAT (Centro Internacional de Agricultura Tropical), Tropileche Consortium, Cali, Colombia; SLP (System-wide Livestock Programme), Addis Ababa, Ethiopia; and ILRI (International Livestock Research Institute), Nairobi, Kenya. p. 12–13. bit.ly/44rZDDX

Velásquez J; Ruiz G; Lascano C. 2004. Feeding pre-weaned calves with *Stylosanthes guianensis* in dual-purpose production systems. In: Holmann F; Lascano C, eds. Feeding systems with forage legumes to intensify dairy production in Latin America and the Caribbean: A project executed by the Tropileche Consortium. CIAT (Centro Internacional de Agricultura Tropical), Tropileche Consortium, Cali, Colombia; SLP (System-wide Livestock Programme), Addis Ababa, Ethiopia; and ILRI (International Livestock Research Institute), Nairobi, Kenya. p. 73–74. bit.ly/44rZDDX

Velásquez Ramírez MG; del Castillo Torres D; Guerrero Barrantes JA; Vásquez Bardales J; Thomas E; Cusi Auca E; Chinen Gushiken M; Muñoz Diaz B; Russo R; Corvera Gomringer R. 2021. Soil recovery of alluvial gold mine spoils in the Peruvian Amazon using *Stylosanthes guianensis*, a promising cover crop. Land Degradation & Development 32(18):5143–5153. doi: 10.1002/ldr.4118

Veraplakorn V; Na Nakorn M; Kaveeta L; Suwanwong S; Bennett IJ. 2012. Variation and long term regenerative capacity of two important tropical forage legumes: Cavalcade (*Centrosema pascuorum* cv. Cavalcade) and Stylo 184 (*Stylosanthes guianensis* CIAT 184) in vitro. African Journal of Biotechnology 11:15843–15851. doi: 10.5897/AJB11.2412

Veraplakorn V; Nanakorn M; Kaveeta L; Suwanwong S; Bennett IJ. 2013a. Variation in ion accumulation as a measure of salt tolerance in seedling and callus of *Stylosanthes guianensis*. Theoretical and Experimental Plant Physiology 25(2):106–115. doi: 10.1590/S2197-00252013000200003

Veraplakorn V; Nanakorn M; Bennett IB; Kaveeta L; Suwanwong S. 2013b. Antioxidant enzyme activity in salt tolerant selected clones of stylo 184 (*Stylosanthes guianensis* CIAT 184), an important forage legume. Kasetsart Journal (Natural Science) 47(4):516–527. bit.ly/42pXVS2

Wang Dongmei; Zhu Jianbo; Peng Ming; Zhou Peng. 2008. Induction of a protective antibody response to FMDV in mice following oral immunization with transgenic *Stylosanthes* spp. as a feedstuff additive. Transgenic Research 17:1163–1170. doi: 10.1007/s11248-008-9188-1

Wang Hui; Chen Zhijian; Liu Guodao; Bai Chanjun; Qiu Hong; Jia Yanxing; Luo Lijuan. 2017. Alterations of growth, antioxidant system and gene expression in *Stylosanthes guianensis* during *Colletotrichum gloeosporioides* infection. Plant Physiology and Biochemistry 118:256–266. doi: 10.1016/j.plaphy.2017.06.024

Wang Linjie; Wang Wenqiang; Ye Miao; Peters M; Schultze-Kraft R; Liu Guodao; Chen Zhijian. 2023. Development of transgenic composite *Stylosanthes* plants to study root growth regulated by a β-expansin gene, SgEXPB1, under phosphorus deficiency. Plant Cell Reports 42(3):575–585. doi: 10.1007/s00299-023-02978-y

Williams RJ; Reid R; Schultze-Kraft R; Costa NMS; Thomas BD. 1984. Natural distribution of *Stylosanthes*. In: Stace HM; Edye LA, eds. The biology and agronomy of *Stylosanthes*. Academic Press Australia, North Ryde, NSW, Australia. p. 73–101. doi: 10.1016/B978-0-12-661680-4.X5001-X

Yadav LP; Boyd D; Stür W; Cramb R. 2022. Forages – taking stock and identifying research needs. Final Report FR2021-079. Australian Centre for International Agricultural Research (ACIAR), Canberra, ACT, Australia. bit.ly/3NOeCC0

Yang Jinfen; Guo Zhenfei. 2007. Cloning of a 9-cis-epoxycarotenoid dioxygenase gene (SgNCED1) from *Stylosanthes guianensis* and its expression in response to abiotic stresses. Plant Cell Reports 26:1383–1390. doi: 10.1007/s00299-007-0325-8

Yi Kexian; Luo Ping; Chen Helong; Tang Jun. 2007. Tropical forage technologies development and multiple utilization in China. In: Hare MD; Wongpichet K, eds. Forages: A pathway to prosperity for smallholder farmers. Proceedings of an International Forage Symposium, Faculty of Agriculture, Ubon Ratchathani University, Thailand. p. 248–262. ISBN: 9789745231412

Yonkeu S; Pamo ET; Rippstein G. 1994. An evaluation of some accessions and varieties of *Stylosanthes* introduced in Adamawa Plateau, Cameroon. In: de Leeuw PN; Mohamed-Saleem MA; Nyamu AM, eds. *Stylosanthes* as a forage and fallow crop. Proceedings of the Regional Workshop on the Use of *Stylosanthes* in West Africa, held in Kaduna, Nigeria, 26–31 October 1992. ILCA (International Livestock Centre for Africa), Addis Ababa, Ethiopia. p. 97–102. handle.net/10568/2720

Yuan Xuejun; Liao Li; Liu Guodao; Wang Zhiyong. 2011. Plant regeneration system from cotyledons-derived calluses cultures of *Stylosanthes guianensis* cv. 'Reyan 2'. African Journal of Biotechnology 10:11919–11924. ajol.info/index.php/ajb/article/view/96225

Zemek O; Frossard E; Scopel E; Oberson A. 2018. The contribution of *Stylosanthes guianensis* to the nitrogen cycle in a low input legume-rice rotation under conservation agriculture. Plant and Soil 425:553–576. doi: 10.1007/s11104-018-3602-0

Zhang Yage; Li Mao; Zhou Hanlin; Hu Lin; Li Wei; Xu Tieshan. 2018. Associative effects of stylo and king grass silage different ratios on in vitro rumen fermentation. Legume Research 41(4):584–588. doi: 10.18805/LR-335

Zhou Biyan; Guo Zhenfei. 2009. Calcium is involved in the abscisic acid induced chilling resistance, ascorbate peroxidase and superoxide dismutase in *Stylosanthes* *guianensis*. Biologia Plantarum 53:63–68. doi: 10.1007/s10535-009-0009-z

Zhou Biyan; Guo Zhenfei; Liu Zhiling. 2005a. Effects of abscisic acid on antioxidant systems of *Stylosanthes guianensis* (Aublet) Sw. under chilling stress. Crop Science 45(2):599–605. doi: 10.2135/cropsci2005.0599

Zhou Biyan; Guo Zhenfei; Lin Lin. 2006. Effects of abscisic acid application on photosynthesis and photochemistry of *Stylosanthes guianensis* under chilling stress. Plant Growth Regulation 48:195–199. doi: 10.1007/s10725-006-0005-7

Zhou Biyan; Guo Zhenfei; Xing Jinpeng; Huang Bingru. 2005b. Nitric oxide is involved in abscisic acid-induced antioxidant activities in *Stylosanthes guianensis*. Journal of Experimental Botany 56(422):3223–3228. doi: 10.1093/jxb/eri319

Zi Xuejuan; Liu Yue; Chen Ting; Li Mao; Zhou Hanlin; Tang Jun. 2022. Effects of sucrose, glucose and molasses on fermentation quality and bacterial community of stylo silage. Fermentation 8(5):191. doi: 10.3390/fermentation8050191

(Received for publication 29 August 2022; accepted 30 March 2023; published 31 May 2023)