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Cover photos:
Above: *Cratylia Argentea* Inflorescences, by CIAT.
Below: *Cratylia Argentea*, by CIAT.
Back: *Urochloa* hybrid Mulato II in the Llanos, Colombia, by CIAT.
Source: www.tropicalforages.info

Rainer Schultze-Kraft
(1941-2024)

This issue of the journal is dedicated to the memory of Rainer Schultze-Kraft (1941-2024), a distinguished and dedicated forage scientist who is globally recognized for his contribution to tropical forage research and development and the establishment of this journal.

Este número de la revista está dedicado a la memoria de Rainer Schultze-Kraft (1941-2024), un distinguido y dedicado científico de forrajes, reconocido mundialmente por su contribución a la investigación y desarrollo de forrajes tropicales y por el establecimiento de esta revista.

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Tribute to Rainer Schultze-Kraft (1941-2024)

The international tropical forages community has lost one of its greatest members, Prof. Dr Rainer Schultze-Kraft, who died recently in southwest Germany after a relatively short battle with cancer.

Early life

Rainer was born in Freiburg im Breisgau on 8 November 1941. His father, the first graduate in the family gained his PhD in economics from Heidelberg University and worked for the German electrical engineering company, AEG. Rainer was the third of 5 brothers, Peter (1937), Uwe (1940), Rainer (1941-2024), Andreas (1945-2015), and Thomas (1950). The family lived in Berlin, but moved to the small village of Offnadingen, 15 kms southwest of Freiburg. Rainer's high school studies had him fluctuating between his father's hometown of Heidelberg, where he studied at the Kurfürst-Friedrich humanistisches Gymnasium, and the mountain resort of Hinterzarten in the Black Forest, where he studied at the Birklehof humanistisches Gymnasium. The family moved to Hinterzarten in 1954 to a vacation house that his father had bought a couple of years earlier. Unsurprisingly, Rainer's school grades were outstanding, so much so that at the end of the 1955/56 school year, before returning to Heidelberg, the Hinterzarten school created a special award in recognition of his achievement. He made his Abitur (graduated/matriculated) from Heidelberg in 1961.

During his late teens as a school student in Heidelberg, his favorite hobby was trainspotting and he became a passionate collector of number plates of discarded steam locomotives. He and his friend, Arnd ("Polli") Hildebrand, collected more than 200 such plates. As he sometimes told with a certain boast, some plates were "acquired" by unmounting them from parked locomotives in cloak-and-dagger operations.

Left to Right: Uwe, their mother, Andreas, Rainer. Rear: Peter. c 1951 (Photograph: Schultze-Kraft family).

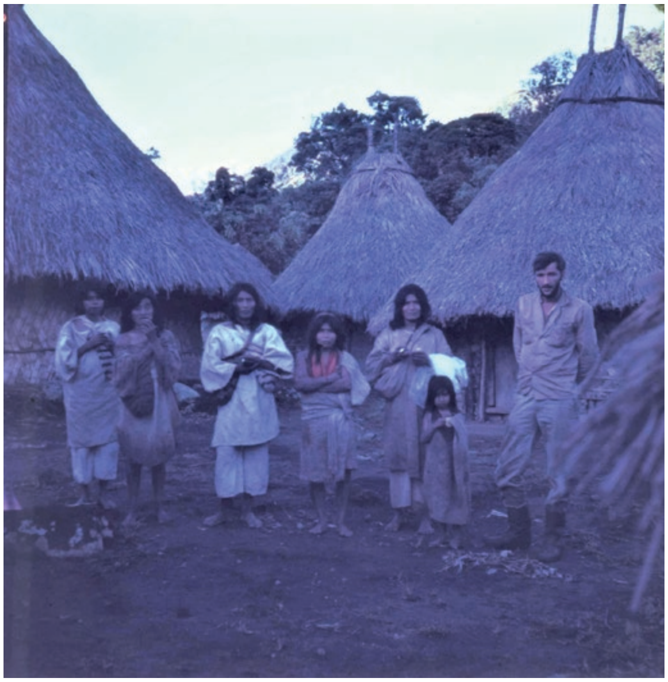
Rainer collecting a number plate from a locomotive, c 1959 (Photograph: Schultze-Kraft family).

Adventurous years

Within weeks of finishing school, Rainer traveled to Santa Marta on the Caribbean coast of Colombia to join his brother, Uwe, who managed a banana farm, "Finca Buritaca", east of the city. Those were both adventurous and formative years for him. Together the brothers bought the farm and often transported banana harvests themselves on cayucos, traditional boats carved out of a single tree. Rainer established a further enterprise producing a paste to seal the cut stems of the banana bunches and hands to avoid the effects of the staining, sticky sap. During those years, he made several trips back to Germany on cargo ships transporting bananas across the Atlantic. On one of those trips to Germany in 1964, he started a course in law, but soon felt the yearning for the liberty of a self-determined tropical way of life against the much narrower, heavily regulated life in Germany. Accordingly, after 1 semester, he followed his heart and returned to Santa Marta. With this overall experience as the catalyst, he increasingly felt a calling to embark on a career in tropical agriculture.

Rainer came close to being lost to the world of science by a near-fatal incident during his time at "Finca Buritaca". Since there was no road from the farm to the harbor of Santa Marta, the bananas had to be transported some 60 km in a cayuco called "El Orgullo (The Pride)", from the mouth of the Rio Buritaca around the Caribbean coast to the port. During one of these trips by night, a heavy storm caused "El Orgullo" to capsize, and Rainer, the captain, a boatman and up to 250 bushels of bananas went overboard. The 3 men were in the water for several hours, at the end of which Rainer was feeling the effects of hypothermia. Fortunately for forage science, he was able to attract the attention of an alert fisherman by constantly signaling with his torch, and the group was saved.

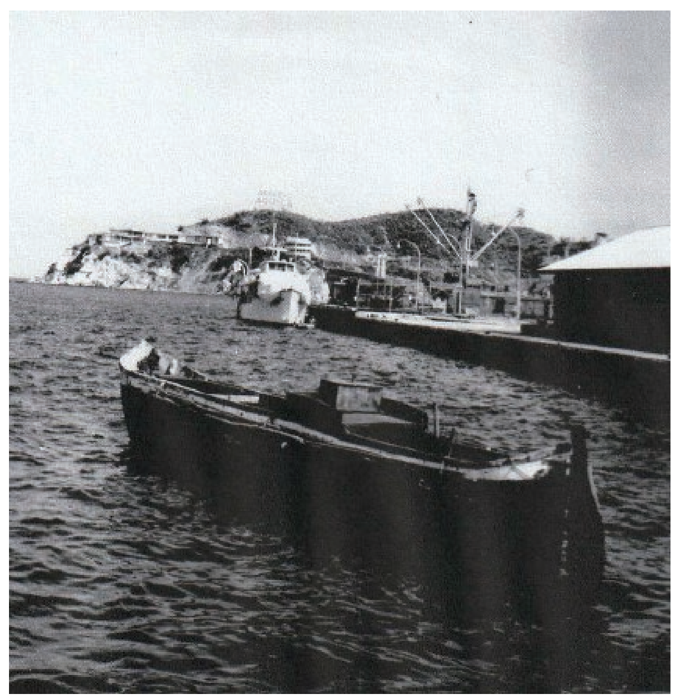
Rainer (front) with his brother Uwe and father on a cayuco, 1961 (Photograph: Schultze-Kraft family).



Rainer in Kogi village (Photograph: D. Leihner).

Challenges of travelling by road in Colombia in the 1960s (Photograph: D. Leihner)

El indio Pedro (Photograph: D. Leihner).



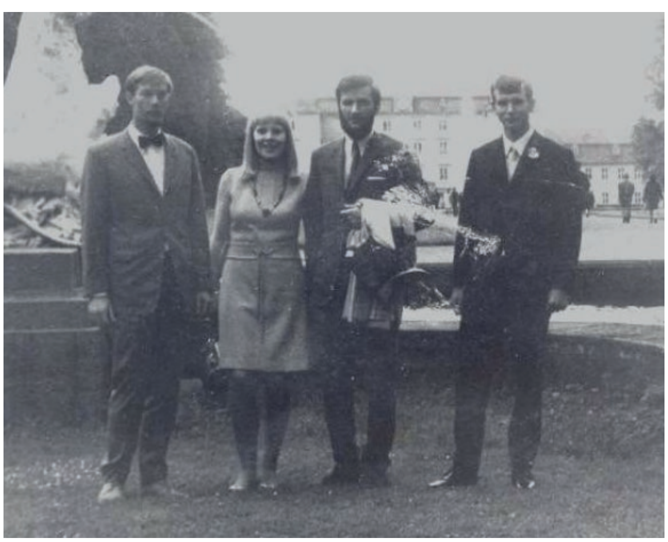
The cayuco boat called "El Orgullo" (Photograph: Schultze-Kraft family).

Le Penseur from Kogi excursion (Photograph: R. Schultze-Kraft).

University

Rainer returned to Germany in 1967 to study Agricultural Science (Plant Production) at the Justus Liebig University Giessen in Hesse, where he graduated in 1972. Again, responding to “the call of the tropics”, he traveled back to Santa Marta on 2 occasions, during one of which the below excursion took place.

The following reminiscence to a septuagenarian friend in 2021 demonstrates not only Rainer’s sense of adventure, but also his sense of humor and love of history: “the image of you sitting on a stone stairway in the rainforest, reminded me vividly of a 5-day excursion in 1969 with a friend, (Dietrich Leihner[1]) at a time when you were a young boy, from the Caribbean Sea level up the Sierra Nevada de Santa Marta to an estimated 1,500-1,800 masl, to a village of indigenous Kogi people, descendants of the Tairona who in the 16^{th} Century fought very bravely against the Spanish conquerors but at the end had to surrender. A most amazing culture those people had for several centuries (see the image above of a small – about 30 cm high – stone sculpture which Auguste Rodin must have used as model, with the shortcoming that his Le Penseur does not have a cheek inflated by a small ball of coca leaves which he is chewing). That was an exhausting way up the mountains (all humid rainforest, rainy season) on centuries-old paths which sometimes had stone stairs similar to the one you were sitting on. In those times I was still a



Dietrich Leihner, Jutta Michael, Rainer, Friedhelm Koch at Schwetzingen Schloss, Germany, 1970 (Photographs: Dietrich Leihner).

Rainer and Dietrich, Sta Marta, March, 2020

[1]This University friendship between Rainer and Dietrich Leihner has endured throughout their lives. Dietrich has kindly provided his own account of the above excursion, together with other memories of his and Rainer’s early days, which are attached as an Appendix to this tribute.

smoker, but we were lucky to have a pack-mule with us and to be guided by a young Kogi man who spoke some Spanish. Unforgettable experiences… Nowadays, an old man deeply regrets that back in the 60s he had no time, no major interest, no means etc. to penetrate more into history and the cosmovision of those people. There were other priorities in one´s life… But I am happy to have Le Penseur on my desk and to touch it, sometimes."

After a year as a junior staff member at the University of Giessen, in 1975, Rainer embarked on his PhD program, with Prof. Dr Dieter Bommer (FAO) and Prof. Dr Joachim Alkämper (University of Giessen) as supervisors. The title of his dissertation was "Untersuchungen über die Eignung von Arten und Ökotypen der Leguminosengattung *Stylosanthes* zur Weideverbesserung in tropischen Savannen Südamerikas, am Beispiel der kolumbianischen Llanos Orientales" (English: Investigations into the suitability of species and ecotypes of the legume genus *Stylosanthes* for pasture improvement in tropical Savannahs of South America, using the Colombian Llanos Orientales as an example). He completed his PhD summa cum laude (with highest praise/honors) in record time in 1976.

Career

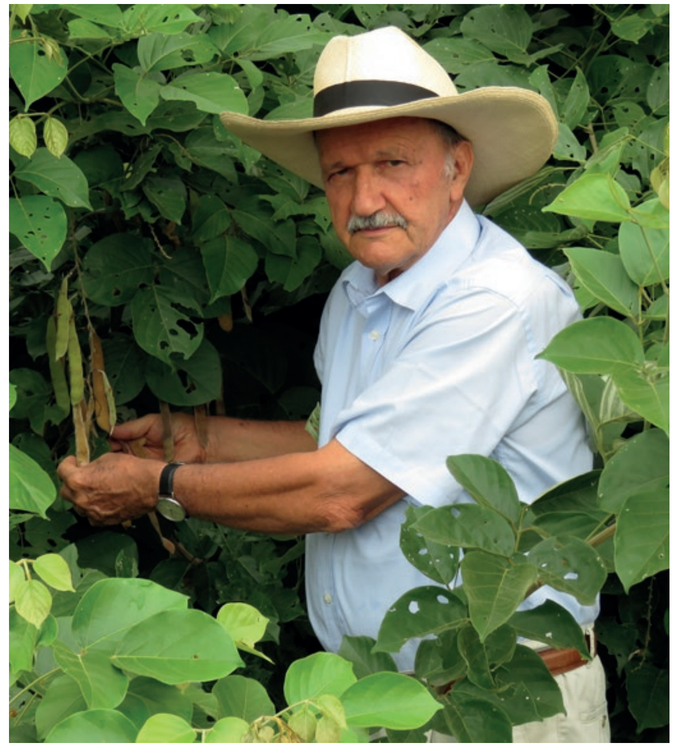
Rainer returned to Colombia in 1973, where he started working as a Visiting Research Associate at CIAT (Centro Internacional de Agricultura Tropical; now The Alliance of Bioversity International and CIAT). In October of that first year at CIAT, he made one of the great discoveries of his career, the plant now known as *Stylosanthes guianensis* CIAT 184. He collected seed of this line on an occasionally grazed roadside about 24 km south of Cali. CIAT 184 has been adopted widely in South America, southern China and southeast Asia, as forage and ground cover, and 5 cultivars have now been created from it in southern China.

On completing his PhD, he was appointed as Germplasm Agronomist of the Beef Production Program (later: Tropical Pastures Program), in which capacity he was mentored by such notable forage scientists as the late Drs Bela "Bert" Grof and José M "Pepe" Toledo. As a founding member of CIAT´s Genetic Resources Unit, he built up the CIAT Tropical Forages collection with >20,000 wild-plant accessions of potential forage plants, almost half of which stem from 39 collecting expeditions that he conducted in 44 countries across Latin America, Asia, and Africa, in partnership with national institutions in those countries. His germplasm collecting activities focused on plants adapted to acid, infertile tropical soils. *The world owes a considerable debt to Rainer and his many collecting colleagues for the conservation of this germplasm, much of which is under threat of extinction.*

Early pot trial work with Stylosanthes at CIAT c 1973 (Photographs: D. Leihner).

Field trials with Stylosanthes at CIAT c 1974

Intrepid plant collectors in the Colombian Llanos in 2010. Left to Right Arsenio Ciprián, Rainer, Javier Belalcázar. (Photograph: Schultze-Kraft family).



Rainer collecting seeds of cratylia. February 2016. (Photograph: Schultze-Kraft family).

He was also involved in characterization, evaluation and cultivar development of the collected and introduced germplasm, particularly forage legumes, where he specialized in the genera, *Centrosema* and *Stylosanthes*, with a strong interest in the genus, *Cratylia*. Besides his plant introduction and evaluation of forage germplasm work, he was involved in activities within 2 international networks for the evaluation of tropical pastures and forages, RIEPT (Tropical America) and RABAOC/WECAFNET (West and Central Africa). His tireless efforts not only enriched our understanding of forage taxonomy, ecology, agronomy, and genetic resources, but also laid the groundwork for future generations of agricultural scientists.

In 1991, Rainer applied and was subsequently appointed to a professorship for Pasture Management in the Tropics and Subtropics, recently created in the Institute for Plant Production and Agroecology of the Tropics and Subtropics at the University of Hohenheim in Stuttgart, Germany. Besides postgraduate-teaching, he led a number of research projects in the area of tropical forages and biodiversity, mainly via MSc and PhD students, in tropical America, Africa and Southeast Asia. After retirement in 2007, he returned to Colombia with continuing links to the CIAT Tropical Forages Program as consultant.

He was instrumental in negotiating the formation in 2012 of the open-access online journal, Tropical Grasslands-Forrajes Tropicales, published by CIAT, in cooperation with the Chinese Academy of Tropical Agricultural Sciences (CATAS) and the Australian Centre for International Agricultural Research (ACIAR). He continued in the role of Managing and Spanish Editor of the journal, in association with his Australian colleague, Lyle Winks, as English editor, until 2020, when both editors felt it was time to pass their roles onto younger colleagues. He worked closely with CATAS in guiding forage research and mentoring young Chinese researchers over a number of years, making the first of his 13 visits to China in 1984.

Rainer is author or coauthor of some 300 scientific research papers, reviews and book chapters on plant germplasm collection, evaluation and characterization, and legume plant taxonomy and ecology. His profound knowledge and understanding of a broad spectrum of forage-related issues made him an essential and key member of the international team of forage specialists that developed the online forage database and selection

Mentoring staff of INIFAP in forage evaluation, Tapachula, Mexico, 2013 (Photographs: INIFAP, Mexico).

Receiving Friendship Award from then Vice Premier Ma Kai of PRC in 2016 (Photograph: R. Schultze-Kraft).

tool, Tropical Forages, released in 2005 and updated for release in 2020. The process involved capturing the knowledge and observations of experienced forage professionals from around the world, and codifying the information so that users could interrogate the tool in a number of ways. This innovative tool has since become an indispensable resource, empowering researchers, extensionists and farmers alike to make informed decisions about which forages to adopt and to optimize forage management practices for the benefit of agriculture and the environment.

In 1997, he was made a Fellow of the Tropical Grassland Society of Australia, and in 2009 he was granted CIAT Emeritus status. In recognition of his long-standing cooperation with tropical China as a CIAT scientist, Rainer received the Chinese Government Friendship Award in 2016 and the International Science and Technology Cooperation Award of Hainan Province, China in 2022.

Rainer the person

At a retirement function held on 16 February 2007, at the University of Hohenheim honoring Rainer's contribution, a survey of colleagues and staff asking, "How is RSK seen by others?" yielded a range of responses. Some approached the question in terms of his personal qualities (noble courtesy, gentlemanly; not adorning himself with borrowed plumes; appearing a bit stiff, but quickly unfreezing), while others analyzed his professional qualities (a passionate field researcher and traveler; cooperative and a good boss to his staff; appreciating, encouraging, listening, positive; open minded, tolerant to alternative approaches; a bit absent-minded in organizational matters; thankful for being reliant on good co-workers); and finally, his interest in unfamiliar food and drinks (not rejecting strange local drinks and dishes).

Some that were missing are loyal, self-effacing, unassuming, composed, wise, and last but not least, possesses a wonderful sense of humor and sense of the ridiculous.

The family years

While working in CIAT, he met María Cecilia Tascón, a young Colombian who had just returned from the USA, where she had graduated as a bilingual secretary. Rainer and María Cecilia were married on 25 October 1976 in Heidelberg and eventually had 3 children, Matthias (1981), Rafael (1983) and Rosalía (1986). In 1982, the family decided to escape from the busy city of Cali to the country, buying "La Siberia", a farm that had belonged to María Cecilia's family for generations, near Ginebra, in the western foothills of the Andes. As the farm comprised quite some area of land, it was (and still is) used for cattle farming. Here, Rainer implemented his knowledge of tropical pastures, thus producing the presumably best-fed cattle in the region – although on a small scale, just enough to self-sustain the farm economically. The family moved to Stuttgart in 1991, when Rainer took up the professorship at the University of Hohenheim. The family regularly visited their Colombian homeland over the next 16 years.

Finca "La Siberia" 2008

Rainer and sons returning with "La Isabela" harvest in the farm vehicle, a 1950s Willys, 2023 (Photographs: Schultze-Kraft family).

Rainer harvesting plantains at "La Isabela", 2016

His sunset years

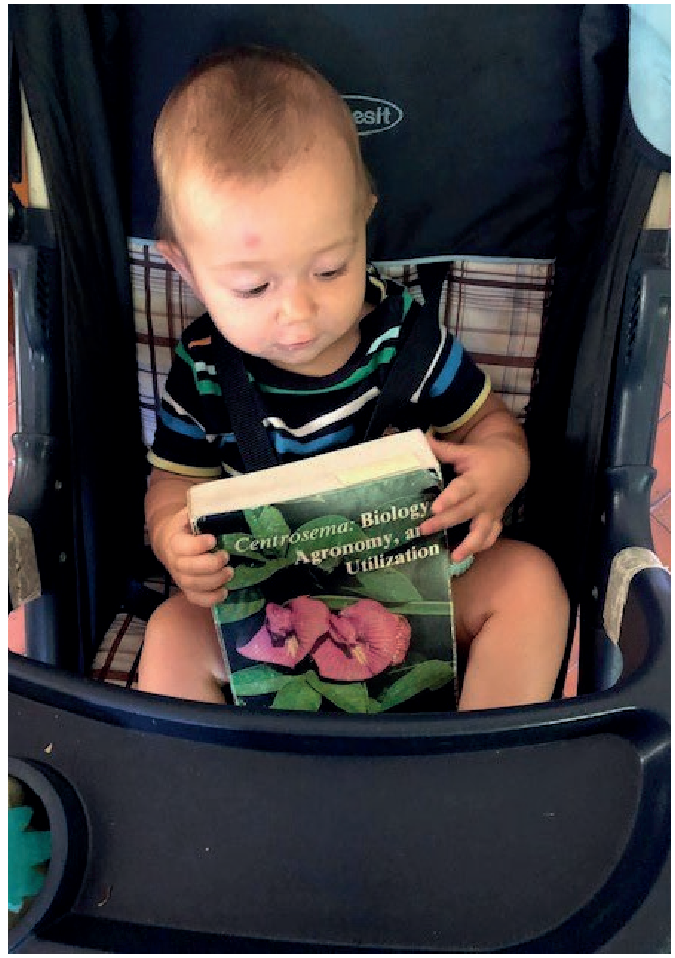
In 2007, Rainer retired from the University of Hohenheim, and he and María Cecilia moved back to Colombia, where they intended to enjoy their sunset years in "La Siberia". Grandchildren born between 2007 and 2023 brought great joy to Rainer's life. Despite the family being separated geographically by thousands of kilometers (since 2011 all children and grandchildren live in Berlin), a strong bond persisted over the years with family visiting each other regularly. Adjacent to the larger dwelling in Hinterzarten where the family had lived in the early 50s, he maintained a small house, which became his main base during visits to Germany. He loved to meet up with 1 or more of his brothers on the trips back to Germany, often travelling with them to other parts of Europe.

In 2013, Rainer acquired a small piece of land in Colombia called "La Isabela" which became his retirement hobby and passion. There, he spent several hours every day cultivating and harvesting bananas, plantains, oranges and other tropical fruits, with great

Five brothers: Thomas, Peter, Andreas, Uwe, Rainer in the childhood home in Hinterzarten, October 1998 (Photograph: Schultze-Kraft family).

Tadeo was busy with trying to forget Covid 19 quarantine, April 2020

Early training is a must, January 2020



At long last I have found somebody who seems to be willing to share my scientific concerns, April 2020

(Photographs: R. Schultze-Kraft).

dedication and a perseverance and strength that were astonishing for his age.

Thanks to his outstanding linguistic talent, Rainer helped his brother, Peter, with many literary translations from Spanish, including some works by Colombian authors, Tomás González and Pedro Badrán.

A COVID-imposed-extended-stay by family with his new grandson, Tadeo Aurelius Schultze-Kraft (TASK), at "La Siberia" in early 2020 provided a pleasant relief and diversion for Rainer during the lockdown, liberating his quirky and creative sense of humor.

"Well, TASK laughs at me when I try to teach him "*Centrosema tapirapoanense*" and "*Stylosanthes sericeiceps*"… so I pulled back and now I am trying to teach him at least "abuelo" (grandpa) but he is reluctant to even repeat the "a" of that word… It looks like I have to wait for a few months to pass by…" Rainer, 29 January 2020.

Epilogue

Rainer leaves behind his loving wife, María Cecilia, his 3 children, and 4 grandchildren. The following passage is their heartfelt farewell to this inspiringly great man.

"In December 2023 the family met in full strength – children, their partners and grandchildren – at "la Siberia", an event that Rainer had been looking forward to for a long time. Tragically, the same month, Rainer was diagnosed with a tumor of the biliary duct and died on February 16th 2024 in his birthplace, Freiburg, from complications of a surgical procedure. He parted much too soon. He often said that he had 2 ambitions as a boy, to be a farmer and to be an explorer, and that he had achieved both: He had spent most of his life as a farmer in "La Siberia" together with his family, and he had been on countless voyages around the world as an explorer, searching for tropical forage legumes. He was the warmest and humblest soul in the world, a haven of tranquility in a chaotic world, an endless source of wisdom, and a loving and devoted father and husband. We will miss him very much."

In the words of Dr Li Jihua, Vice President of CATAS, "Though he may no longer walk among us, his spirit lives on in the countless lives he touched and the pioneering contributions to the international tropical forages industry, and outstanding contributions to the development of the forages industry in China! Dr Schultze-Kraft will be deeply missed but never forgotten." This sentiment is no doubt shared across the forage world.

Compiled by Bruce Cook and Jean Hanson with wonderful support from the Schultze-Kraft family

Rainer in Berlin on his 82nd birthday, 8 November 2023

Top: Rainer, Lola, Rosalia, Ben (TASKs and Lolas father), Emil and Lesia Bottom: Rafael, Matthias, TASK, Maria Cecilia and Sandra

(Photographs: Schultze-Kraft family).

Maria Cecilia and Rainer, Quindio, Colombia, 2014

Rainer with Maria Cecilia, Rafael, Rosalia and Matthias, Malta, 2018

Personal tributes to Rainer

It was with great dismay and sadness that I heard of the death of Prof. Rainer Schultze-Kraft. I still remember him as a rather youthful-looking, active, versatile personality in good physical condition. Just over a year ago, I had a brief e-mail exchange with Rainer, without realizing that he may have already had serious health problems at the time. I have many pleasant memories of Rainer: we went on various (congress) trips together (to Paraguay, Argentina, Brazil, Colombia, Cuba, New Zealand, China, Australia and, of course, Germany). We would have liked to meet up again in Kenya in 2020. Unfortunately, however, the International Grassland Congress planned there did not take place at all due to the pandemic. Rainer has referred several students to me for several pasture related research actions as part of their theses in my projects. We also wrote a few joint publications. We were both members of the editorial board of the journal Tropical Grasslands. I was still hoping to meet Rainer again in the Black Forest when we are both on vacation in Germany at the same time. Unfortunately, such a meeting can no longer take place. Rainer was a very pleasant person to deal with. I will remember him fondly. May he rest in peace.

Albrecht Glatzle
Paraguay

A mi gran amigo Rainer, después de su lamentable partida, no me queda mas que agradecerle por todos los conocimientos que adquiri de usted, sin duda para mi además de ser mi jefe en el programa Germoplasma de forrajes, año 1977- 1989, fue un gran maestro y un gran amigo, me queda la satisfacción de haberle podido colaborar en lo que estuvo a mi alcance y también lo acompañe en la última visita a la estación de Quilichao el 1 diciembre 2023.

Arsenio Ciprian
Cali, Colombia

In our lives, we will encounter many people, but there is "that one encounter that changes everything." Such a day was June 19, 1992, when I met Rainer Schultze-Kraft for the first time after a seminar where I reported on my experiences with pasture management measures in Southwest Queensland. Rainer asked me if I was interested in assisting him as a scientific assistant at his new chair for Pasture Management in the Tropics and Subtropics and writing my thesis there. After that, nothing was the same.

Without Rainer, my life would surely have taken a very different path. Not only did he advance my scientific career and enabled me to conduct fieldwork for my diploma and doctoral thesis at CIAT in Colombia, but he also taught me many other things by his example. Rainer was an extremely courteous, helpful, considerate, and reliable person with whom you could have lively conversations for hours on end during extensive car rides through half of Colombia, only interrupted by "Stop, I saw a Centrosema by the roadside" (how could he spot such a small flower at that speed? Oh, he recognized it even without a bloom!), or during one of his preferred "Wisquicitos" on the porch of his beloved farm La Siberia, where he recounted his travel experiences. He was incredibly hospitable and generous, often inviting us for Sancocho in Ginebra (Photo 1) or for the traditional St. Martin's goose dinner in Hohenheim. Rainer was an endless source of information, memories, experiences, and always seemed to know someone from the past who spoke highly of him. Not only did the words "Doctor Rainer" open all doors in Colombia, but this was also the case in Venezuela, or Cuba, and even in Vietnam, he had his followers.

Rainer taking photos of Grona heterocarpa subsp. ovalifolia in Caquetá, Colombia, 1997 (Photograph: A. Schmidt).

Students from Hohenheim at La Siberia, ready for another Sancocho, 1996 (Photograph: A. Schmidt).

Rainer and Axel traveling through Magdalena Medio in Colombia, 1997 (Photograph: A. Schmidt).

Rainer supported us with advice and action, sacrificed many nights for proofreading, taught us to pay attention to details in texts and presentations, even if his perfectionism sometimes drove us mad – "could we make this a little higher? Don't you think a comma should go there?" Rainer had an extraordinary sense of language, which can also be admired in his translations of contemporary literature.

He allowed room for new ideas and protected us when things didn't go as planned. In his shadow, one could grow. I am grateful and happy to have had Rainer as a mentor and friend.

Over 30 years, I have probably seen him take over 100,000 photos of plants and animals, and his pockets were always filled with seed samples. He just couldn't stop collecting. With Rainer, we have lost a multifacetedly talented and meticulously working friend and colleague, but he leaves deep traces not only in tropical forages science but also in the people who were fortunate enough to share a path with him. ¡Hasta siempre, Rainer!

Axel Schmidt

Dr. Rainer, within my upbringing in the family, I was taught to maintain a distance with my superiors, drawing a line, as a form of space, framed by attention and respect, where the motto "Bosses are not your friends" was forged. That work relationship that sheltered us began in 1990 when you selected me to work under your supervision with germplasm collection databases, thus generating a series of changes in my life of all kinds, as it allowed me to return from the Eastern Plains, Carimagua to Valle del Cauca, and discipline myself under your meticulous guidance in the various tasks you demanded of me. During a large period of your life at the University of Hohenheim, the relationship was punctual, but it was maintained through your students and some projects, and conversations were limited to the beginning and end of a coffee, but with each visit, a detail of chocolate and some task.

After your return from Germany again to Colombia for another great stay, you started activities as the editor of the magazine Tropical Pastures, and our coffee relationship was accompanied by pandebonos, anecdotes, memories, and with them, nostalgia and laughter.

On January 16th, I received your last message from Germany, so today, more than just thanking you, I want to respond to that message I didn't answer and tell you that I also love you very much.

Buen Viaje y Buena Mar

Belisario Hincapie
Alliance of Bioversity International and CIAT

I can't remember when I met Rainer. It was probably in the 1970s – I think he made a visit to Australia in those early years, and he visited the CSIRO Cunningham Laboratory in Brisbane. I remember talking with Ron Williams about this "new" young bloke from CIAT, who Ron was also curious to meet. That is already almost 50 years ago. It may have been in the 1980s. It doesn't matter much. I seem to have known Rainer for most of my professional career. I could say so many things about our collaboration over so many years, but first and foremost I should say he was my good friend. We talked about so many things – not just work, but life in general, as friends do. Each time we met, we picked up the threads as good friends do, and it was as if we had spoken only yesterday. He told me once that as a boy he had 2 ambitions: 1 was to be a farmer and the other was to be an explorer; and he said he had achieved both. The farmer part was the life he shared with Maria Cecilia on her family farm and to a lesser extent the plant introduction nurseries he managed. The explorer part was when he searched for tropical forage legumes around the world. I think Rainer saw this as partly exploration. I remember sharing the excitement when he discovered *Centrosema pascuorum* in the South American Pantanal wetlands in the 1980s. He reported this in his paper on the biogeography of *Centrosema*, published in the proceedings of an international conference on *Centrosem* held at CIAT in 1987. Until Rainer discovered it – I think while in a canoe or perhaps a small boat, and perhaps with Arnildo Pott – I don't think *C. pascuorum* had ever been recorded from the Pantanal.

I don't remember how many times Rainer and I worked together, or how many scientific papers we wrote together – perhaps half a dozen. Recently I pulled from my bookcase the book we edited together, on *Centrosema*. It was published in 1990 – already more than 30 years ago. Later, he insisted on bringing me with him as a co-author in a paper on *Centrosema*, written for the second edition of Simmonds' Evolution of Crop Plants in 1995. I repaid that debt by making him a co-author of a paper in 1997 in which I described the assessment in tropical Australia of 71 collections of *Centrosema pascuorum*; Rainer had collected almost 60 of them, from 5 countries in Central and South America including at least 8 Brazilian States! And so it went on, each of us building on the efforts of the other. In those pre-email days, ours was a collaboration based mainly on letters and exchanges of plant material, with occasional face-to-face meetings when we talked for hours. Most memorable of all were the rare occasions when one could host the other at home. Years later, after Rainer "retired" he motivated me to find some financial support for the new online journal Tropical Grasslands-Forrajes Tropicales that he pioneered; and then I dragged him to attend the International Grassland Congress in Sydney in 2013, where together with Lyle Winks and others we had a great time promoting the new journal. And so it went on, over and over again.

Bob Clements
Australia

I had the good fortune to join with Rainer on 2 collecting missions; in 1977 to the States of Mato Grosso and Para in Brazil, and in 1981 a more detailed mission to the Caribbean coast and adjacent inland of Colombia. Both very memorable for me as he was one of those rare people who was always willing to share both his knowledge and expertise. His enthusiasm for the world of tropical legumes was celebrated by all who knew him, and Tropical Pasture Research is in his debt.

Bob Reid (Retired)
ex CSIRO, IBPGR and Tasmanian Institute of Agriculture

Rainer was an inspiration. My only regret is that our paths didn't cross much earlier. With my almost obsessive interest in forage plants and their application over my 38 years as a pasture agronomist with the Queensland Department of Primary Industries, I of course knew about Rainer Schultze-Kraft and his accomplishments well before I met him. Our first encounter was in the twilight of my career, when Bruce Pengelly (CSIRO) and I were seeking to gather a team of experienced forage researchers from around the world tropics, who could work with us to develop a searchable forage database that was to become Tropical Forages. Rainer was an obvious choice as a potential collaborator. I was rather overawed by his reputation as a giant in the field of tropical forage science, but any concerns were allayed when he proved to be a warm, friendly, and fascinating person with similar general interests to mine, and a shared obsession with plants. From that time in the early 2000s and in the years of "semi-retirement" following my departure from the DPI in 2006, we became close friends, maintaining a steady exchange of emails throughout, and even WhatsApp recorded voice messages from his hospital bed in January this year. Prior to 2019, we were looking into the feasibility of a plant collection expedition to Bolivia, but sanity prevailed in view of our ages and the various impacts of COVID-19. Apart from Tropical Forages, we collaborated in a number of papers, the first highlighting the need for precision in publication of botanical names, and then a series of papers clarifying confusion in *Stylosanthes* taxonomy published in this journal. We were in the process of embarking on our series "pièce de resistance" on the *Stylosanthes guianensis* complex, when illness took its toll.

Like the rest of the tropical forage world, I will miss Rainer, in particular our often technical, sometimes philosophical, occasionally familial exchanges, all usually tinged with the subtle humor that was such a part of his being.

Bruce Cook

Tropical forages team in Koenigstein, Germany 2017 (Photograph: B. Pengelly).

I first met Rainer in the 1980s during his visit to Bob Clements and Ron Williams at the CSIRO Brisbane but never got to know him to any degree until 2003, when he hosted both the European meeting of the ACIAR-funded Forages database project at University of Hohenheim, and the project's review led by Derrick Thomas (2006). Rainer was a magnificent host and participant in both of these meetings. When Phase II eventuated a decade later, Rainer became an even more important and enthusiastic participant as our small team led by Bruce Cook advanced the database to what it is today. Rainer was one of just a few in tropical pasture science who, when excited by a taxon, was willing and able to critically explore it holistically; from taxonomic treatment, diversity, geography, adaptation and agronomy.

He was a wonderful conversationalist and made an art form of helping others enjoy his regional food. At one of the Hohenheim meetings Rainer arranged for the whole group to eat at a different restaurant every night so we could enjoy a range of very different German cuisines. He put great effort and delight into being able to show visitors diversity of German food. Later during Phase II Rainer was again at the forefront in sharing with the wider group the origins of the local dishes (see photo). He loved food and its origins!

Bruce Pengelly

While Rainer worked in CIAT and after he left, we exchanged many ideas on how to promote the adoption of legumes in livestock production systems. Our relationship was one of personal friendship and interest in forage legumes. We collaborated in several thesis projects of German students from the University of Hohenheim on Flemingia and Cratylia accessions. We shared a common background that we both lived in the Santa Marta area when young. Rainer lived on a banana farm owned by his family in the vicinity of the "Parque Tayrona" and me at the "Prado" where employees of the United Fruit Company lived. Our communication in the last 2 years was frequent, first when he was writing a review on Stylo 184 and later in 2023 when he invited me to write with him a review paper on Cratylia. In this latter task we communicated continuously through the exchange of drafts of the paper, and I was impressed with his ability to search and organize references and thoroughness in editing. This exchange culminated with the review paper on Cratylia, which turned out to be his last contribution, of many, in promoting the utilization of forage legumes.

Carlos E. Lascano
Emeritus, International Center for Tropical Agriculture (CIAT), Cali, Colombia

Although I knew from the literature Rainer´s extraordinary contributions as the scientist enriching the knowledge on tropical forages germplasm, I only met him personally in the late 80´s after becoming an Advisory Committee Member of the International Network for Tropical Pastures Evaluation (RIEPT). Since then, I had the chance to know him as the kind person, sincere friend, tireless researcher, and mentor of many young scientists from Latin-America and the rest of the world. About 2 years ago, I became the Spanish co-Editor of the Tropical Grasslands-Forrajes Tropicales Journal, trying to continue his strong efforts facilitating the publication of articles submitted by Spanish-speaking Latin American forage researchers. We all have lost a visionary and promoter of the use of tropical forage biodiversity -especially legumes- for the sustainability of livestock systems in the developing world. "Vuela alto Rainer/Fly high Rainer"

Danilo Pezo
CATIE

Rainer was a study companion and colleague with whom I had the privilege to develop a profound, deeply trusting friendship. We complimented each other, both having gone through a humanistic school education with arts, history, and languages, including Latin (and in the case of Rainer even Greek) being a common denominator. We organized our university career, time within the CGIAR, Professor duties at Hohenheim University and many private initiatives together. Both of us had a special relationship to Colombia where part of our families lived, where we met our wives and where some of our children were born. Rainer's profound knowledge of the tropical forage sector stemmed from a high degree of constancy and dedication to this main subject, for which I deeply admired him. By contrast, after spending a decade with rice, curiosity led me to venture into durum wheat at CIMMYT and cassava at CIAT, focusing finally on systems approaches to mixed cropping, agroforestry and soil conservation where I could draw on Rainer's experience with forage species that could also play a role in these systems.

Apart from common professional interests, we enjoyed cultural activities and shared a curiosity for the ethnic, cultural and historic background of places and people we met whilst advancing in our professional and private lives. I am deeply saddened by the fact that the opportunity to share and revive with Rainer memories of the thousand and one experiences we had together has disappeared so unexpectedly.

Prof. Dr. Dietrich E. Leihner

Professor Dr. Rainer Scultze-Kraft was a distinguished German scientist who has made outstanding contributions to the development and use of forage genetic resources in tropical agriculture. I worked with him as a colleague in the Tropical Pastures Program at CIAT from 1989-1991. It was a pleasure to contribute to his review article on the environmental benefits of forage legumes. His contributions to tropical forage genetic resources are a matter of meticulous attention to every detail in the critical steps of germplasm collection, agronomic evaluation, and utilization in agricultural systems for the benefit of crop-animal-aquatic food production and the environment.

Idupulapati M. Rao
Scientist Emeritus, CIAT

Rainer was a very special person, scientist, colleague and friend who made an outstanding contribution to tropical forage research. His experience and in depth understanding of tropical forages is a great loss to the forage community. He started the Tropical Grasslands-Forrajes Tropicales journal and it would not have been so successful without him and I would not be current editor without his approval and support. I was very saddened by his untimely death and will miss his support, friendship and mentorship.

Jean Hanson
Emeritus fellow, ILRI

My experience working alongside Dr. Schultze-Kraft over the last five years as the editorial manager of the TGFT Journal was nothing short of transformative. From our first interactions, I was struck by his unwavering commitment to precision and meticulous attention to detail. His mantra of "we must be consistent" became emblematic of the unparalleled quality he demanded in all aspects of our work. Despite my best efforts, I often found myself challenged to match his exacting standards during the article typesetting process. No matter how minor the detail, Dr. Schultze-Kraft's discerning eye never missed a beat, consistently identifying areas for improvement. Yet, far from being disheartened, I found immense value in these experiences, as they provided invaluable opportunities for growth and learning. Moreover, Dr. Schultze-Kraft's proficiency in Spanish, despite not being his native tongue, was truly remarkable and served as a testament to his dedication and breadth of knowledge. In every interaction, I gleaned invaluable insights and skills that have profoundly shaped my professional journey, and for that, I am deeply grateful. Dr. Schultze-Kraft's impact on me, both personally and professionally, will endure as a cherished legacy of his remarkable life and career.

José Luis Urrea-Benítez
Science Communications Specialist, Alliance of Bioversity International and CIAT

Rainer was a colleague, a friend and a brother with whom I had the honor and privilege of traveling and exploring the different Brazilian regions, always with a view to collecting forage legumes to enrich the available genetic variability. Rainer's dedication and enthusiasm in searching for new options for research have always enchanted and moved the members of the collecting expeditions. He always had a special passion for legumes, but the Centrosema genus enchanted him. Rainer has left us, but the success and results of his work will guarantee a bright future for research on forage species.

Lidio Coradín
Brazil

With great shock I learned about the death of Rainer. I met Rainer first in 1989, in Nizza, at the International Grassland Congress, the connection made by our mutual PhD supervisor, the late Prof. Jochen Alkämper. Since then we maintained contact, as colleague, mentor and close friend. From 1992 working with ILCA/ILRI in West Africa as a PostDoc, and then from 1998 at CIAT on multiple projects. Beyond many joint publications highlights were establishing the Tropical Grasslands-Forrajes journal through the initial donation of a former CIAT Tropical Forages staff and then support from CATAS and ACIAR and working together on www.tropicalforages.info. The close connection continued not only professionally but also privately through many visits to his farms in Ginebra and family interactions. He is also fondly remembered by my wife and my two children. Rainer will be remembered as a renowned scientist, as a gentleman and as person with a warm heart, always willing to help and with a high respect for all people independent of their background.

Michael Peters
Tropical Forages Program Leader, Alliance of Bioversity International and CIAT

Rainer, your demise is a huge loss to the forage world across the tropics. It's also a major legacy to celebrate. I value immensely your engagement in forage work in West Africa over many years, and your dedication to the students you nurtured for the next generation of forage scientists. But well beyond, your expertise, practical knowledge and friendship that has enriched us all over many, many decades and will be sorely missed. A true gentleman, an outstanding academician, scientist and mentor, rest in peace.

Shirley Tarawali
Assistant Director General, ILRI, Kenya.

I met Rainer virtually through my supervisor, Dr. Orlando Guenni (Central University of Venezuela), at the end of last century. During the First National Symposium: Research experiences with the genus *Centrosema* in Venezuela, which took place in El Tigre, Venezuela, on 28 September 2000, I met Rainer personally. At that time, I was interested in pursuing a master's degree in the field of botany and had searched only universities located in the United States of America. Rainer diplomatically suggested to me to gain insight about the benefits of studying in Germany; additionally, he explained to me how much science needed more researchers in the area of forage genetic resources. I maybe was the last doctoral student mentored by Rainer. He not only left an excellent impression on me but also on everyone he interacted with. Students and colleagues at the University of Hohenheim appreciated Rainer for his devotion to the field of forage genetic resources and his enthusiasm for teaching. He will be remembered for his charisma and for fostering students to reach their academic independence. We were fortunate to have had Rainer as a mentor. On the 16 of February 2024, I received a voice message from Rainer's wife telling me that Rainer passed away which was a very sad moment for me. Rainer is survived by his loving wife, a daughter, 2 sons, 4 grandchildren and 3 brothers. Que descanse en paz!

Teo Calles
FAO

Rainer visiting field trials in Caquetá, Colombia (Photograph: Belisario Hincapie).

A privileged friendship: the parallel paths of Rainer Schultze-Kraft and Dietrich Leihner over a 55-year time span

DIETRICH LEIHNER

When and how we met.

Summer semester, 1968 Justus Liebig University Gießen (JLU). A physics lecture, compulsory for students of natural sciences, medicine, veterinary sciences, and agronomy. Two benches in front of me, I heard familiar sounds: two students were having a conversation in Spanish. Having spent considerable time on the rice farm of my family in the Eastern Plains (Llanos Orientales) of Colombia, I was fluent in Spanish myself, and therefore curious to know other Spanish speakers. The two in front of me were Rainer and Pepe, an Ecuadorian student of medicine. It turned out that Rainer, Pepe and I were taking the same basic courses in natural sciences that had to be completed before advanced studies could be undertaken. Both Rainer and I also had a Colombian experience, so from the beginning we had lots of common ground to discuss and started a regular contact and exchange of ideas.

Organized at home – adventurous abroad: Degree studies at JLU

It soon became clear that Rainer and I had similar ideas about how to organize our studies in the most efficient way. We realized there were many lectures where physical presence was not required, but of course you had to assimilate the information the professor was transmitting. So, the two of us quickly decided, we would attend different lectures and then share notes we had taken. However, the sheer volume of information we had to tackle was such that the two of us couldn't cope. The logical step, therefore, was to enlarge the group of co-workers. We screened our fellow students in agriculture, and soon found a third reliable work horse in the person of Friedhelm Koch. And since for oral exams at that time, students had to present themselves in groups of four, we thought, a female student would greatly help to loosen up the otherwise tense examination atmosphere. Jutta Michael was our choice.

Our collaborative practice as well as our social and psychological theories about exams were quickly put to the test, when the first round of examinations had to be passed: The "propaedeuticum" consisted of exams in physics, chemistry, botany, zoology as well as anatomy and physiology of domestic animals. The brilliant results we obtained in all of these matters were proof enough that our collaborative system worked, suggesting we continue along these lines. Also, our formula of success combining solid knowledge with a composition of the group that included feminine charms, proved to be the right way forward. Our group meetings soon resulted in intense working sessions, where we mercilessly cross-examined each other to prepare for upcoming oral or written exams. But they were also social events with lots of coffee and cake consumed during the meetings. Furthermore, we adopted the practice of not studying on the last day before an exam but would take the day off for an excursion or relax on the beaches of the river Lahn in order to calm down and be more concentrated the next day.

Finally, we found out that our lecture notes, carefully redacted and revised, were an asset that could be turned into money: We typed them on spiritus matrixes, of which up to 100 copies could be drawn and sold them to our fellow students, bringing in hundreds and hundreds of Deutsche Marks that could be used for special activities of the group, such as a week-end excursion to Heidelberg and the castle of Schwetzingen.

Studies advanced successfully, and finishing our fourth semester, Rainer and I started to think about how and where to carry out degree thesis work. Since both of us had decided we wanted to take advantage of the tropical agriculture study option at JLU and both of us had ties to Colombia, a trip to South America was organized during the lecture free period after semester IV. In 1969, this was not as easy and as inexpensive as it is today, but somehow, we collected the necessary funds for 2 tickets with Icelandic Airlines, taking off from Luxembourg to the Bahamas, from there to Miami, and from Miami to Bogotá. We enjoyed the lush tropical beaches of the Bahamas for a day, then hopped onto a plane of PanAm to Miami, only to find out that our Aerocondor flight to Bogotá had left before the time we found written in the ticket. An expensive extra ticket to Bogotá had to be purchased from Avianca, but we finally made it to the destinations in our beloved second home country: Rainer headed on to Santa Marta and I to the Llanos Orientales to the family rice farm.

Visiting Rainer in Santa Marta

Rainer and I got up around 5:30 am in total darkness. I remember the velvet-soft, gentle air that enveloped us as we moved to the Center of Santa Marta where we hoped to find transport to the farm on the Buritaca river. The day before, I had arrived from Bogota, and was kindly received by Rainer's brother Uwe and his wife, Gloria, at their home located in the former United Fruit Company residential sector "El Prado" of Santa Marta.

The transport we found was a private car, an old Willys Pick up, on the back of which we were accommodated together with half a dozen other passengers. As the road eastward of Santa Marta (La Marginal del Caribe) was still under construction, we soon found ourselves travelling on a dirt road with lots of mud holes, and an occasional fallen tree, pushed by heavy rains across the road. But Colombia had generously imparted lessons of patience to both Rainer and I in many similar situations before, so that we didn't lose confidence in reaching our destination, sooner or later. The trip ended on the eastern bank of the Buritaca river where a canoe helped us to cross the river and reach the farmhouse.

Since we had no work program, nor a tight schedule of any kind, Rainer enjoyed showing me around the farm, with its 40 ha of coconut on the Caribbean beach, the citrus plantation, and of course the many paddocks, where his brother Uwe raised cattle for milk and meat production.

Days went by peacefully, when all of a sudden Rainer came in a hurry, saying there was an opportunity to join a Kogi family on their way up to their village, high up in the Sierra Nevada. In no time, we packed a few things, clothing, a hammock for each of us and some food onto a mule (la Pantanera) and off we went with the Kogi family. Luckily, one of the Kogi boys (el Indio Pedro, see photo) accompanying the family, had been raised as an orphan by a Colombian family and spoke Spanish, so language-wise we were on the safe side.

The 5-day trip that followed up into the mountains and back to the Caribbean beaches was an unforgettable experience: The all-out covering tropical forest, changing later into mountain forest, consisting partially of solid stands of wild avocado trees, the crystal clear, cold, waterways we had to cross, the stone platforms and paved roads of ancient Tairona settlements that were officially discovered only a number of years later (now known as La Ciudad Perdida) and the emerging mountain panorama with its snowy peaks. All this left an indelible impression in mind and soul, which I know Rainer treasured as much as I did.

Noteworthy was, of course the Kogi village we reached on the afternoon of the third day. Most of the inhabitants, we were told, had left to the farms so that the village was almost unpopulated. But the few inhabitants we met were friendly, and supplied us with food and a place to tie up our hammocks. We, in turn offered them what Rainer had considered necessary to bring along: Aspirin (Mejoral) and other soft drugs, as well as tools, such as files to sharpen their machetes, hoes and shovels. We marveled at the large assembly houses for male and female members of the tribe, and a bridge over a thundering mountain creek, all built without a single nail or piece of wire.

All too fast time flew, and I had to return to the rice farm where I had planted an experiment with various rice varieties and fertilizer levels to study the response of the new germplasm that Instituto Colombiano Agropecuario (ICA) was starting to distribute. Rainer had promised to come and visit me, as I had done weeks before, so I was looking forward to his imminent visit to "Arrocera El Bambú", 70 km down the road from Villavicencio to Puerto Lopez in the Meta Department, Llanos Orientales of Colombia.

Rainer´s first visit to the Llanos

The road from Bogota to Villavicencio, provincial capital and door to the vast Eastern Plains (Llanos Orientales) region of Colombia, was not the same in 1969 as it is today. Rather a curved, narrow mountain trail lined with crosses reminding us of those who had gone over the cliff down into the deep Andean abysses, it nevertheless provided gorgeous views across the mountain ranges. And, finally reaching the foothills of the Eastern Cordillera, at the last turn of the road, a breathtaking view of the plains that stretch from there eastward to the Orinoco is offered to the spectator, resembling a green sea rather than land. Rainer later told me he was fascinated, as this was his first trip across the Eastern Cordillera, down to the Llanos.

We settled into the farmhouse, where my sister Ursula lived together with her husband, Rudi and her 3 children. Rudi was of the opinion that farming could only be productive if the owner lived on the farm, so that my sister had to adapt to a scarcity of amenities, compensated, however, by the many wonders of farm life in the tropics. She also had to resolve the education issues of my 2 nieces and nephew, teaching them on the farm up to 1st grade grammar school, under the skeptical eyes of the German College in Bogota.

As we had done previously on the Schultze-Kraft farm, we set out on multiple excursions to my rice plots, to other rice fields and to the creeks running through the farm. The highly diverse tropical vegetation of the gallery forests along these creeks and their fauna (Colibris or hummingbirds, brilliant blue butterflies, howler monkeys, snakes, including a boa constrictor and an occasional tapir) filled our minds with curiosity to learn more about tropical ecosystems, and our hearts with love for the tropics that Rainer and I never lost thereafter.

We also crossed the Humea river by ferry, visiting a large farm development project in Macapay, where Rudi together with partners wanted to develop 60 ha small farms with irrigation to be donated or sold at modest cost to Colombian small holders under a land reform scheme. To put water on the acid and infertile Llanos soils was a condition for any farming operation, and so the project started digging a huge canal across the Savannah, a welcome opportunity for Rainer and myself to study the profile of a typical Llanos Oxisol.

Apart from learning about the Llanos and rice, Rainer always kept an eye on the savannah surface, looking for forage species he could identify and possibly collect. At that time, he probably did this due to our very general interest and curiosity regarding agricultural and ranching conditions in the tropics. Who would have imagined that Rainer, on that occasion just halfway through degree studies at JLU, would later become a world authority on tropical forage species?

An adventurous journey to the Cauca Valley

My family's rice farm in 1969 possessed a single vehicle only, a Toyota Land Cruiser (long wheelbase) which had been brought up to Bogotá by Rudi for repair. Rudi had travelled out of the country and had left the task of picking up the vehicle in Bogotá to me. So, Rainer and I saw the opportunity to use the vehicle whilst Rudi was away. Rainer wanted to visit the Faculty of Agriculture at the National University in Palmira. He apparently knew the Dean personally. And I was interested in learning what the rice program of ICA was up to. Rudi had alerted us that a new international agricultural research center (CIAT) had recently started activities on a farm adjacent to the ICA research fields. The thing to do therefore was to travel up from the Llanos to Bogotá, pick up the car and organize a journey to the Cauca Valley.

It took us a day to reach Bogotá, but since we had no place to stay in the capital, we decided to drive throughout the night, hoping to reach Palmira the next morning. Things went well as we wound down from cold Bogotá to the Magdalena Valley where heat continued well into the night. Crossing the Magdalena River in Girardot and heading for Ibagué was easy as the night cooled down and roads were in good condition. But the situation changed dramatically as we climbed up the central cordillera with temperatures, declining sharply as we reached almost 3000 masl, and more and more clouds enveloped us as we reached the peak of La Linea, where we had to stop since visibility was less than 5 m. We could see neither rocks on one side nor precipices on the other side of the road. Roads in Colombia at that time were not equipped with any reflecting poles or markings on the pavement so that we considered continuing driving without sufficient visibility as too high a risk. There were no houses nearby nor was there any traffic on the road by about midnight. The only thing we could do was hunker down and wait to see if the clouds would clear or dawn would come. We tried to lie down on the benches in the rear of the car and stretch a bit, but shivering in the cold kept us awake. All of a sudden, however, we heard the sound of a car coming up the mountain, so I quickly hopped into the driver's seat and started the car. The other vehicle turned out to be a bus that drove through the clouds at incredible speed, as if it was equipped with radar. The radar, of course, was the driver himself who apparently knew the road even with closed eyes. Instead of freezing to death, we decided to take the chance and stayed close behind the bus, which safely guided us down below the cloud level where we could let the bus go and adjust our speed to the surprises that these roads have ready for you around every corner. And surprises we did encounter very soon as I realized our car had lost its brakes. We thus had to slow down even more, but having reached the flat bottom of the Cauca Valley, this was not a problem. With good luck, we finally arrived in Palmira and found both a workshop to get the brakes fixed and a hotel to rest.

The visit to the faculty of agriculture and the ICA rice program the next day went indeed very well. The Dean even took us up a tower from where we had a great view over university buildings in a park-like setting, the ICA experimental fields, and the town of Palmira in the background. Both Rainer and I had been previously exposed to the relaxed, gentle treatment Colombians in high positions use to give to visitors, in particular foreigners. But here again, we received a splendid lesson in Colombian courtesy and hospitality. We, 2 nobodies from Germany with just 4 semesters into our university career, were treated almost as colleagues on equal footing. What a difference to how our colleagues in Germany treat visitors of this kind, in particular from developing countries, always surrounding themselves with an air of superiority.

All too soon in that summer of 1969, our 3-month visit to Colombia reached its end. We had seen a lot, learnt a lot and, if not before, by the end of this trip, Rainer and I knew we could not only rely on each other, but help each other in pursuing our professional dreams in true friendship, not competition. In that spirit, we continued to work within the group we had formed in Gießen and finished degree studies with the greatest possible success. For both Rainer and I, it was clear that we would continue with doctoral studies in Gießen, experimental work of course being carried out in Colombia.

Doctoral students in Cali

Starting our doctoral work in Cali as bachelors without any other obligations than producing superb scientific results, we moved around with Rainer brandishing a fairly new Renault R4 and I, an old Willys Jeep. The problem was that my research plots were more than 600 km away in the Llanos so that I could not stay permanently in Cali, whereas Rainer's work was located mainly in CIAT greenhouses and research fields. This allowed him to build a network of acquaintances from which I also profited whenever in Cali. In the end, both of us felt we were much closer to heaven in those days than in any other places we had lived before.

But nothing lasts forever, and I finished experimental work in the Llanos and at CIAT in July 1974 and went back to Germany to write my thesis, pass final exams and get my degree (Feb. 24, 1975) Rainer stayed at CIAT until late 1975, then returned to our alma mater in Giessen to write and present his thesis, with final exams on Oct 15, 1976.

There was a dispute at that time among members of the Faculty of Agriculture in Giessen about the language doctoral dissertations could be written. The rule was "in German", but internationally minded Faculty insisted this should no longer be the only option. I personally saw no point in writing a rice thesis in German, presented my data in English and had the thesis printed. Only to provoke a violent backlash from Faculty Conservatives who made the dean impose an ultimatum: Lest I produced a German version within 2 weeks, my doctoral degree would be annulled. I had no choice but to produce a 'quick and dirty' German version which was distributed to German University libraries, but to my satisfaction, internationally, and foremost in CIAT and IRRI libraries, the English version prevailed.

Of course, I informed Rainer of all the mishaps as he found himself confronted with the same dilemma; writing about *Stylosanthes* for an exclusively German-speaking public simply did not make sense. Rainer, alerted by my case, informed himself carefully about the distribution of power within the faculty council and opted for avoiding drama. He wrote in German and everything went smoothly.

The turmoil at the end of our respective doctoral programs was soon replaced by pure romance. The Cali girls we had lost our hearts to, joined us in Germany. Graciela, a CIAT librarian and my future wife, joined me in Giessen in Oct 74. She had been a Student of the German School in Cali and thus only needed a couple of refresher courses to bring her up to speed in this complicated language. We married in January 1975. Maria Cecilia and Rainer married Oct 26, 1976, 2 weeks after his final doctoral exam. I am sure having had no previous exposure to the German language and people must have been a fairly rough start in this strange new world. Rainer and Maria Cecilia soon moved back to Colombia, whereas Graciela and I started our honeymoon in Mexico, where I had found a post-doc position at CIMMYT.

Years within the CGIAR

Owing to circumstances, Rainer got his doctoral degree a year and a half later than I did, but in hindsight there was little difference between both of us starting work within the CGIAR. Rainer was lucky enough to be accepted by CIAT for a post doc and subsequently a senior staff position in what was later called the Tropical Forages Program. Continuity in the subject of research was thus guaranteed. For me, on the other hand, continuing in rice research didn't appear too attractive as rice was well covered by scientists internationally. More by coincidence than anything else, one of the deputy directors of CIMMYT, Keith Finlay, visited JLU at the very moment I was finishing up my doctorate and by the end of a brief interview pulled out of his case a CIMMYT application form for a post doc in Mexico. Working with wheat instead of rice, although equally well covered internationally, appeared attractive and challenging, so I applied and got the job.

Two scientists influenced and guided my future professional direction greatly: Dr. Norman Borlaug at CIMMYT and maize breeder Prof. Dr. Gerhard Pollmer of Hohenheim University. Norman Borlaug, then director of the international wheat program, instilled in me a deep feeling of mission and responsibility for guaranteeing world food supply and a broad understanding of the role of science to attain that goal. Prof. Pollmer opened my eyes with respect to the benefits a German university professor enjoys. Although I had no immediate intention to leave the international science environment, he motivated me to initiate a process unique for German universities, the habilitation, which opens the way to Professor positions at German universities.

When I, after 2 years at CIMMYT, arrived at CIAT, starting to learn about yet another crop (Cassava), Rainer had already been building a reputation as a forage germplasm specialist, earning a recognition in his field that I would probably never attain myself, being a newcomer to Cassava research. Rainer didn't have a mentor with a Nobel Peace Prize, but I am sure that colleagues such as Mark Hutton, Bert Grof, Gustavo Nores, Pepe Toledo and others inspired him in a similar way as Norman Borlaug did in my case.

As years went by and the CGIAR moved into the 1980s, funding became an issue and generalists like myself were of course upfront on a list of possible cuts, whereas Rainer as a specialist was in a much safer position. He had acquired a piece of land with a beautiful traditional Colombian farmhouse, not too far away from CIAT and family life played out there in a relaxed way. Also, Maria Cecilia's family lived close by, an additional factor of support for raising a family difficult to find elsewhere. Rainer thus had little intention or motivation to move. For me, on the other hand, after 7 years with CIAT, the search started again looking for alternatives. A newly created professor position for Plant Production in the Tropics and Subtropics at Hohenheim University was opened and my application was submitted during 1983 and I started on the job the 1st of April 1984, leaving the CGIAR for good on that date. Not so Rainer, who stayed at CIAT for another 7 years until he finally joined me at the Institute for Plant Production and Agroecology in the Tropics and Subtropics, taking responsibility for the subject area Pasture Management in the Tropics and Subtropics.

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Review Article

Cratylia argentea – review of a tropical shrub legume: Biology and agronomy[1]

Cratylia argentea – *revisión de una leguminosa tropical arbustiva: Biología y agronomía*

THE LATE RAINER SCHULTZE-KRAFT AND CARLOS E. LASCANO

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Abstract

A comprehensive review, based on about 170 references, synthesizing research and development about *Cratylia argentea*, is presented to expand interest in its dissemination and use in animal production systems. The species has been widely evaluated, mainly in tropical America, with the objective to develop it as a shrub legume and an alternative to the fertility-demanding species, *Leucaena leucocephala* and *Gliricidia sepium*. The review on cratylia is presented in 2 separate parts covering biology and agronomy and quality and utilization. This paper focuses on the (1) description of the species, (2) biogeography and information on germplasm collections and genetic diversity, synthesis, (3) discussion of results from agronomic research, reproductive biology, seed production and (4) multipurpose uses of cratylia. Some strengths of the species as a forage shrub are adaptation to the acid, infertile soils that prevail in the tropics and drought tolerance in subhumid climates with a pronounced dry season. Major shortcomings are slow establishment and rapidly declining seed quality. Research resulted in the release of a blend of 2 germplasm accessions (CIAT 18516 and CIAT 18668) as a commercial forage legume cultivar in Costa Rica and Colombia. Finally, recommendations for future research are proposed.

Keywords: Adaptation, cultivar, genetic variability, performance, seed production.

Resumen

Se presenta una reseña, basada en cerca de 170 referencias, que sintetiza la investigación y el desarrollo de *Cratylia argentea*, con miras a incrementar el interés en su difusión y uso en sistemas de producción animal. La especie ha sido evaluada ampliamente, principalmente en América tropical, con el objetivo de desarrollarla como una leguminosa arbustiva para regiones tropicales con suelos ácidos y de baja fertilidad, como alternativa a *Leucaena leucocephala* y *Gliricidia sepium* que requieren suelos de mayor fertilidad. La revisión sobre *Cratylia* se divide en dos partes separadas; biología y agronomía, y calidad y utilización. Este artículo se concentra en: (1) la descripción de la especie, (2) su biogeografía e información sobre colecciones de germoplasma y diversidad genética, (3) una síntesis y discusión de resultados de investigación agronómica, biología reproductiva y producción de semillas y (4) su uso como especie multipropósito. Algunas fortalezas particulares de esta leñosa son su adaptación a los suelos ácidos de baja fertilidad que prevalecen en los trópicos y la tolerancia a la sequía en climas subhúmedos con una estación seca pronunciada. Las principales deficiencias son su lento establecimiento y la rápida disminución de la viabilidad de las semillas. Las investigaciones realizadas en la región culminaron en la liberación de una mezcla de dos accesiones (CIAT 18516 y 18668) de cratylia como cultivar comercial en Costa Rica y Colombia. Esta parte de la reseña concluye con sugerencias para futuras investigaciones.

Palabras clave: Adaptación, cultivar, producción de semilla, rendimiento, variabilidad genética.

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[1]This review article is dedicated to the memory of Dr. Jorge Ramos de Otero, Brazilian pioneer in research on tropical forage plants in the 1940s and 1950s, and the first to recognize the potential of *Cratylia argentea*.

Introduction

Until a few decades ago, *Cratylia argentea* (Desv.) Kuntze was mainly known under its synonym, *Cratylia floribunda* Benth. Otero (1952) highlighted its potential as a tropical forage over 70 years ago because of its drought tolerance and high protein concentration. Interest in the species for evaluation and cultivar development by researchers increased when seed became available after the first systematic forage germplasm collecting activities in Brazil, mainly in the 1970s. Since then, *C. argentea* has been the subject of numerous research projects and of a comprehensive review of research conducted in tropical America in the period 1978–1995 (Pizarro and Coradin 1996).

The objective of this review on biology and agronomy, genetic resources, reproductive biology, germplasm evaluation, cultivar development and alternative uses of *C. argentea* is to contribute to the continuing interest of the research and development (R&D) community in the species while giving credit to the many scientists involved in research on this legume. Wherever possible, accessible literature as information sources is used and some thoughts on future research needs are presented.

In this paper *C. argentea* is mostly referred to as cratylia, its common name in English. In Brazil, depending on the region, several common names can be found in the literature, such as camaratuba[2], cipó-malumbe, cipó-prata, cipó-de-manacá, copada, cratília, fava-de-papagaio, feijão bravo, feijão-de-boi and mucunã-de-prata. Cratilia is increasingly being used as the common name in Spanish-speaking countries.

Taxonomy and morphological description

Cratylia Mart. ex Benth. is a small neotropical genus closely related to genera such as *Canavalia* Adans., *Dioclea* Kunth and *Galactia* P. Browne, belonging to the family Fabaceae (alt. Leguminosae), subfamily Faboideae, tribe Phaseoleae, subtribe Diocleinae. Seven species of *Cratylia* are currently recognized: *C. argentea* (Desv.) Kuntze; *C. bahiensis* L. P. Queiroz; *C. hypargyraea* Mart. ex Benth.; *C. intermedia* (Hassl.) L. P. Queiroz & R. Monteiro; *C. isopetala* (Lam.) L. P. Queiroz; *C. mollis* Mart. ex Benth.; and *C. spectabilis* Tul. (GRIN 2023).

It is now known that there are 2 distinct morphotypes of *C. argentea*. The common shrub is represented by the commercial Costa Rican *C. argentea* cultivar 'Veraniega' (Veraniega), also released as *C. argentea* cultivar 'Veranera' (Veranera) in Colombia, selected from 2 accessions of germplasm (CIAT 18516 and CIAT 18668) collected in central Brazil. The other morphotype called 'Yapacaní' (Yapacaní) is a strongly climbing herbaceous vine, which is so far only known from a few populations in central Bolivia. Unless differently stated, the following description refers to the shrub morphotype. It is based on Cook et al. (2020), complemented with some descriptive elements taken from Pizarro and Coradin (2016) and Queiroz (2020), and illustrated in Figure 1.

Cratylia is a perennial, deep-rooting, erect shrub reaching between 1.5 and 3 m in height. Well established plants have an extraordinarily strong plant crown with numerous regrowth meristem points at ground level and below. When associated with taller vegetation and undisturbed, the shrub can attain a voluble liana habit with a remarkable intertangling of lignified branches. Leaves are stipulate, trifoliolate; leaflets papyraceous, elliptic to broadly ovate; central leaflet generally 9–12 × 6.5–8 cm, the laterals being smaller and slightly asymmetric; indumentum generally silvery-sericeous on the undersurface. Flowers are arranged in an elongated, many-noded pseudoraceme up to >30 cm long; 6–9 flowers per node. Size of flowers ranging from 1.5 to 3 cm (length and width); petals lilac, very rarely white. Pods pubescent, straight, flat, to 20 cm long and 1–2 cm broad, dehiscent, containing 4–8 oval to almost circular flat seeds of about 1.5 cm diameter. Seeds dark yellow to brown, when maturing under high-humidity conditions, dark brown. About 4,500 seeds per kg.

Observations in plant introduction nurseries showed that plant age and genotype seem to have an effect on the intensity of the silvery pubescence on the undersurface of leaflets. Matrangolo et al. (2018a) suggested that hot and sunny environments favor this characteristic.

Unlike the shrub, Yapacaní is a prostrate-climbing vigorously voluble herb with only slightly lignified stems and branches; leaflets are more elongated and completely lack the silvery pubescence on the undersurface.

[2]'Camaratuba' is almost exclusively used for *Cratylia mollis* Mart. ex Benth., a species endemic to the Brazilian northeastern region (*Caatinga* biome) with potential for semi-arid environments (Sousa and Oliveira 1996).

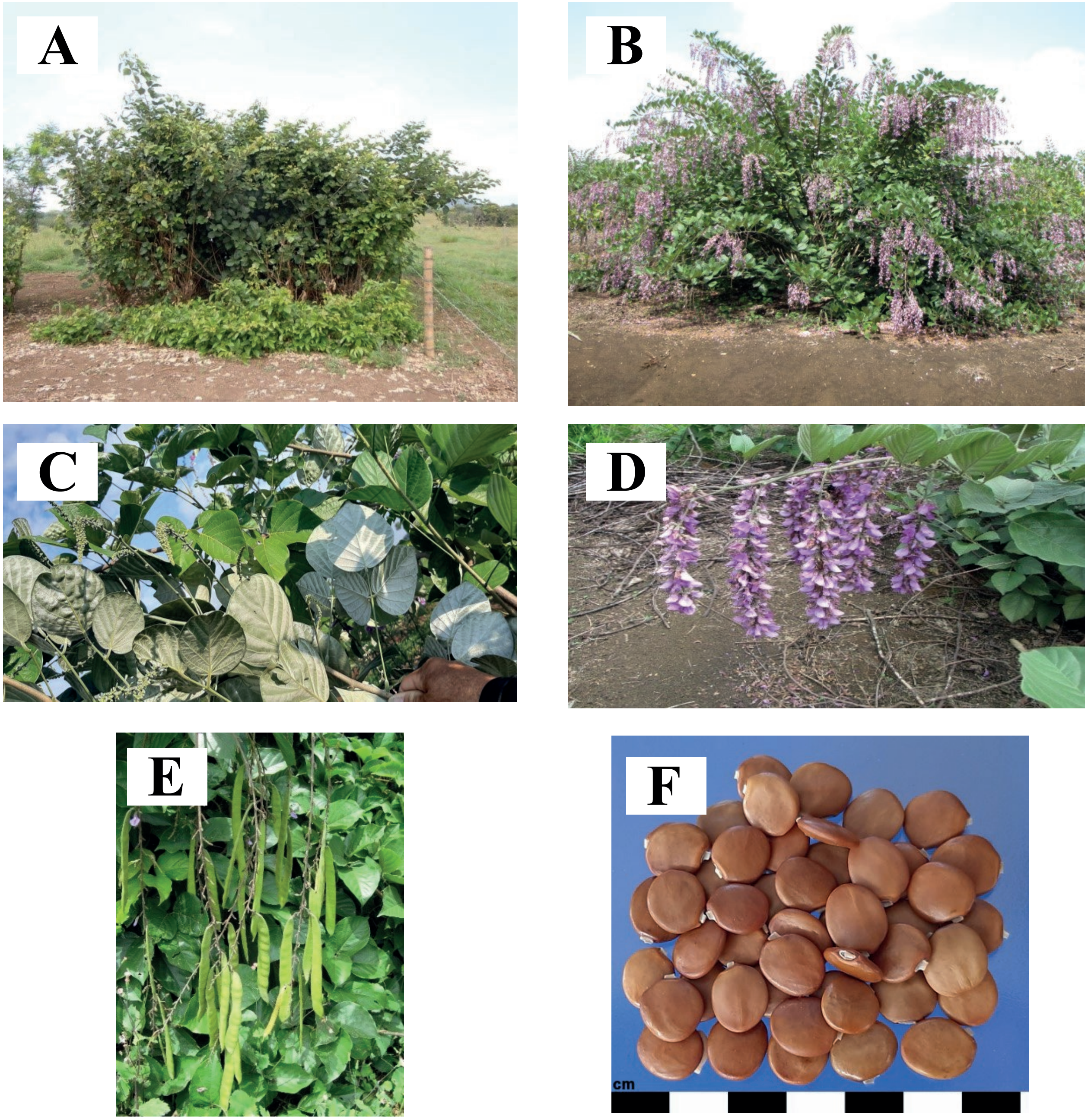

Figure 1. Morphology of *Cratylia argentea*. (A) Erect shrub morphotype vs. prostrate-climbing Yapacaní morphotype (Photograph: R. Schultze-Kraft); (B) Habit of flowering shrub morphotype (Photograph: A. Ciprián, CIAT); (C) Leaflet underside with silvery pubescense vs. upperside without (Photograph A. Ciprián, CIAT); (D) Flowering branch (Photograph: A. Ciprián, CIAT); (E) Fruiting branch (Photograph: A. Ciprián, CIAT); (F) Ripe seeds (Photograph: A. Ciprián, CIAT).

Biogeography

According to a comprehensive study of botanical specimens, *C. argentea* has the widest geographical distribution of the 7 *Cratylia* species (Queiroz and Coradin 1996): It extends from NE Brazil to Bolivia and Peru, south of the Amazon River and east of the Andes, mainly within longitudes 38–77° W and latitudes 07–18° S. The species occurs generally at low elevations (200–800 masl), mainly in open tree and shrub savanna habitats, but has also been found in transition zones to seasonal forest and semi-arid vegetation. Environments where occurrence of cratylia has been recorded are characterized with total rainfall ranges between 1,200 and 3,000 mm/year, a marked dry season of 4–6 months (i.e. <50 mm rainfall/month), often in combination with fire events (Figure 2), where the shrub type is fire tolerant (Figure 2C).

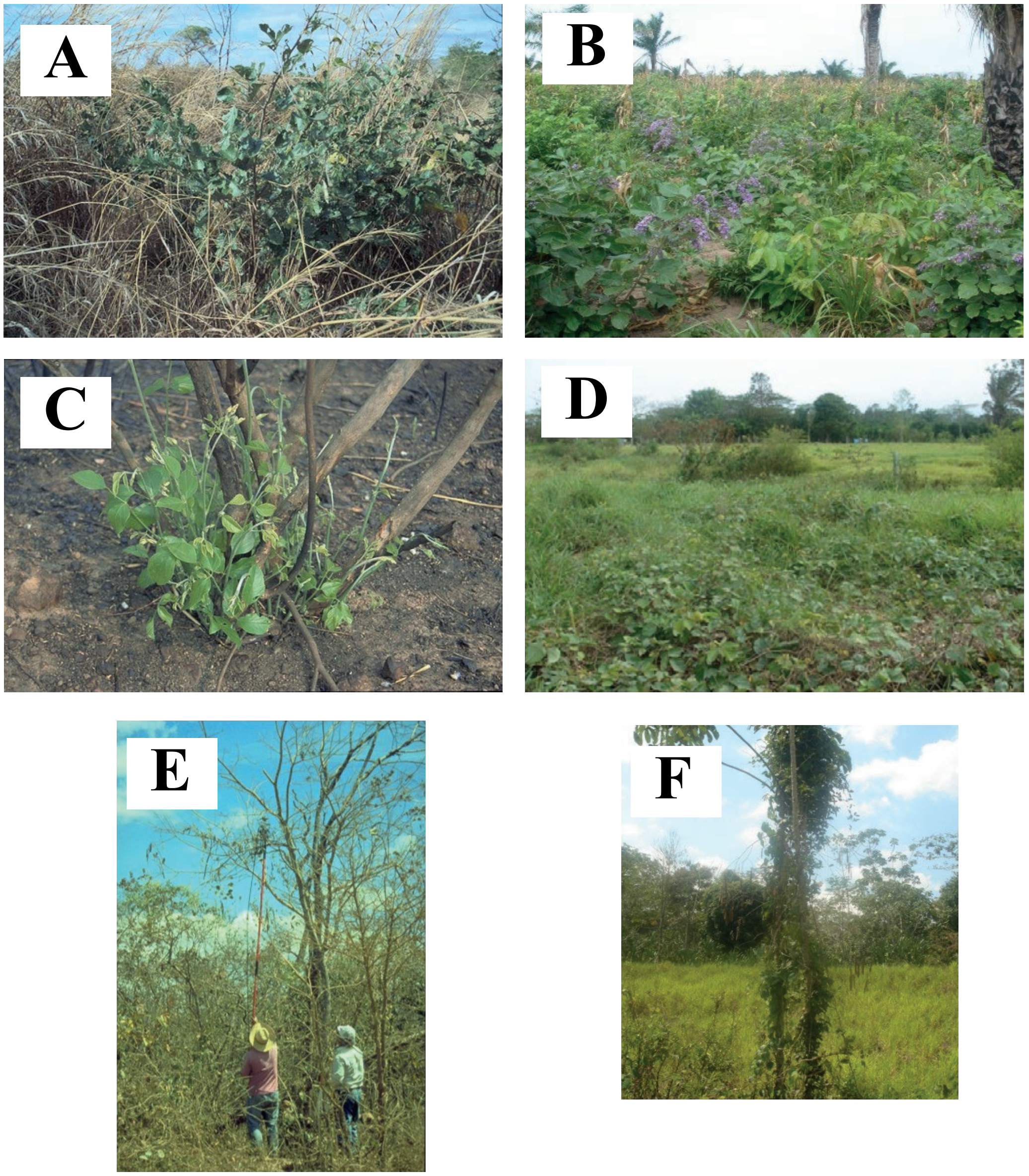

Figure 2. *Cratylia argentea* in its native habitat. (A) Young shrub morphotype, spontaneously growing in a dry Hyparrhenia rufa pasture, Goiás, Brazil (Photograph: R. Schultze-Kraft); (B) Shrub morphotype as part of fallow vegetation in a former maize field, Santa Cruz, Bolivia (Photograph: R. Schultze-Kraft); (C) Regrowth of shrub morphotype after savanna fire in Mato Grosso, Brazil (Photograph: R. Schultze-Kraft); (D) Yapacaní morphotype: Prostrate growth habit, Yapacaní area, Santa Cruz, Bolivia (Photographs: R. Schultze-Kraft); (E) Collecting seed of a shrub morphotype that became a voluble liana in Cerrado vegetation, Goiás, Brazil (Photograph: R. Schultze-Kraft); (F) Yapacaní morphotype climbing when there is a trellis tree (Cecropia sp.), Yapacaní area, Santa Cruz, Bolivia (Photographs: R. Schultze-Kraft).

Within this overall geographic distribution, live material of the Yapacaní morphotype is so far only known from central Bolivia, where it has been found in the western part of Ichilo province, Santa Cruz department, and in the east of adjoining Carrasco province, Cochabamba department (Schultze-Kraft et al. 2006). Unlike the shrub morphotype, the Yapacaní morphotype occurs on soils that are less well-drained.

Genetic resources

Cratylia was one of the legumes with very few germplasm samples collected during the early Brazilian plant exploration activities in the 1960s and 1970s, all of which aimed at a broad spectrum of native legume species with expected forage potential. Those cratylia collections were made in the states of Bahia, Goiás, Maranhão, Minas Gerais, Piauí, São Paulo and Tocantins (Hymowitz 1971; Costa et al. 1978; Rocha et al. 1979; Shock et al. 1979; Sobrinho and Nunes 1996). The evaluation work of José Marcelino Sobrinho in the late 1970s at EMGOPA (Empresa Goiana de Pesquisa Agropecuária) revealed the adaptation of the species to the Cerrado biome (Sobrinho and Nunes 1996) and led to increased interest by other institutions to broaden its germplasm base. Subsequently, new material was collected mainly during joint expeditions conducted by EMBRAPA-CENARGEN and CIAT in the 1980s in Mato Grosso, Goiás and southern Pará, and in the 1990s by Embrapa Recursos Genéticos e Biotecnologia and Embrapa Cerrados, also in cooperation with CIAT, in Goiás, Mato Grosso, Minas Gerais and Tocantins (Queiroz and Coradin 1996; Pizarro et al. 1997). More recently, collections were made in the states of Acre, Ceará, Goiás, Maranhão, Pará and Tocantins (Brasileiro et al. 2018). Based on plant exploration and land-use studies in the Terra Ronca State Park in northeastern Goiás, Mattar et al. (2020) suggested that the State Park be considered a potential *in-situ* conservation area for cratylia populations.

Before 2006, cratylia germplasm had not been collected outside Brazil, except for accession CIAT 22397, collected by E. A. Pizarro in the municipality of Yapacaní, Santa Cruz department, Bolivia in 1995. Since this was the only sample of a prostrate-voluble *C. argentea* morphotype, it triggered interest in further exploring species diversity in Bolivia. Subsequently, several Yapacaní morphotype populations were identified in the Santa Cruz and Cochabamba departments, along with 2 shrub morphotype populations in Santa Cruz (Schultze-Kraft et al. 2006).

A total inventory of *ex-situ* conserved cratylia germplasm is not available. Based mainly on figures presented by Queiroz and Coradin (1996), Pizarro et al. (1997) and Mattar (2018), there might be a total of 100–120 different accessions in the various Brazilian genebanks. The 50 accessions currently registered in the CIAT genebank (bit.ly/3WKEiUG) are duplicates of material conserved at Embrapa Recursos Genéticos e Biotecnologia, Brasília, Brazil. Areas for future collections were prioritized by Queiroz and Coradin (1996). Passport data on the origin of cratylia germplasm using a consolidated inventory will show to what extent these areas should be adjusted.

Genetics and reproductive biology

A chromosome number of 2n=22 was reported for *C. argentea* by Queiroz (1991) and confirmed by Vargas et al. (2007). Based on a preliminary study with a plant population at Embrapa Cerrados, Planaltina, Federal District, Brazil, Queiroz et al. (1997) suggested a mixed mating system of both allogamy and autogamy. Bystricky et al. (2010), however, found that at the CIAT Research Station, Palmira, Colombia, Veranera is largely self-incompatible, pollination being dependent on large insects, mainly the bee species *Xylocopa frontalis* and *Centris* spp. (both, Anthophoridae). A further pollination study conducted with both the Yapacaní and shrub morphotypes at the CIAT Experimental Station at Quilichao, Colombia showed that the Yapacaní morphotype is self-incompatible and that there is pollen flow between the 2 morphotypes (Rivera Hernández 2012).

The occurrence of a few white-flowered plants in otherwise lilac-flowered populations was observed in a site in the species' native habitat in Mato Grosso (Pizarro et al. 1997), in on-farm evaluation of Veraniega in Costa Rica (Mesén Villalobos and Sánchez Ledezma 2008) and in an evaluation plot at CIAT Quilichao (A. Ciprián, pers. comm. 2017). This indicates segregation following natural crosspollination.

Genetic variability

Owing to self-incompatibility as the prevailing breeding mechanism, molecular marker studies revealed more variability within an accession (defined as a sampled population registered in a genebank) than among accessions. Those studies were: (a) the genetic characterization of 47 *C. argentea* accessions in comparison with *C. mollis* using random amplified polymorphic DNA (RAPD) by Andersson et al. (2007); (b) the comparison of 11 *C. argentea* accessions by sequences from internal transcribed spacers (ITS/5.8S) of nuclear ribosomal DNA (Galdino et al. 2010); and (c) the molecular characterization with inter simple sequence repeats (ISSR) markers of 13 accessions from a Brazilian *C. argentea* population (Luz et al. 2015). Andersson et al. (2007) found that the only Yapacaní morphotype accession tested was genetically almost as distant from all shrub morphotype accessions as *C. argentea* from *C. mollis* at the species level. H. G. Suárez Baron (unpublished) conducted a genetic analysis with 11 Yapacaní morphotype accessions, 6 shrub morphotype accessions and 2 *C. mollis* accessions, using both RAPD and ITS molecular markers because of potential taxonomic implications. That study revealed a marked genetic differentiation between the Yapacaní and shrub morphotypes which, however, was not considered large enough – in comparison with the genetic distance between *C. argentea* and *C. mollis* – to suggest that the Yapacaní morphotype might be described as a new *Cratylia* taxon at species level. In both the genetic similarity assessment with RAPD markers and the phylogenetic analysis of ITS/5.8S sequences, significant differences between the Brazilian shrub morphotype accessions and the 2 Bolivian shrub morphotype accessions were detected (H. G. Suárez Baron, unpublished).

Regional research: Overview of species adaptation, evaluation and cultivar development

Information summarizing results from research in tropical America during 1978–1995, with emphasis on *C. argentea*, was presented at an international workshop on the genus *Cratylia* held in Planaltina, Brazil in 1995. The workshop proceedings (Pizarro and Coradin 1996) dealt with biogeography of the genus (Queiroz and Coradin 1996), species evaluation in Brazil (Xavier and Carvalho 1996; Pizarro et al. 1996; Sobrinho and Nunes 1996; Sousa and Oliveira 1996), Colombia (Maass 1996) and Central America and Mexico (Argel 1996) and feed quality and utilization (Lascano 1996). This state-of-the-art document was followed by a literature review (Argel and Lascano 1998) and technical bulletins with focus on Costa Rica (Argel et al. 2001) and Colombia (Lascano et al. 2002; Rincón Castillo et al. 2007). The following paragraphs provide an overview of studies of species adaptation, germplasm evaluation and cultivar development in the respective countries during the past 4 decades. The sequence of country presentation in this overview follows an approximately chronological order in which adaptation and evaluation studies were conducted in the respective countries within regions.

South America

Brazil. The cratylia accession IRI 2496 was mentioned as one of the 6 most promising native legumes that originated from the early (1962–1967) Instituto de Pesquisas IRI collections (Shock et al. 1979). This accession was subsequently "widely distributed with occasional success" in Brazil. There is no recent information on whether this accession is still in production.

Work in the late 1970s and early 1980s at EMGOPA was reported by Sobrinho and Nunes (1996), who highlighted promising results of a genotype from São Domingos, Goiás, on an infertile Oxisol (*Latossolo Vermelho-Amarelo*, LVA) of the Cerrado biome that prevails in that state. Under its accession number CIAT 18516, this genotype was widely tested outside Brazil and subsequently selected as 1 of 2 accessions used to develop Veraniega and Veranera.

Almost simultaneously, research on agronomy and feed value was conducted in the *Zona da Mata* region in the southeast of Minas Gerais state (Xavier et al. 1995; Xavier and Carvalho 1996; Xavier et al. 2003), which led to registration, in 2016, of a line developed from accession CNPGL-28 (origin: Jaíba, Minas Gerais) for release by EMBRAPA Gado de Leite as cultivar 'BRS Ceci' (Cook et al. 2020). Productivity studies were independently initiated in the *Central* region of Minas Gerais in 2010 (Miranda et al. 2011). A summary of the research in that region with focus on phenological and ecological aspects of the species was presented by Matrangolo et al. (2018a).

In the *Cerrado* biome of Central-West Brazil, research on shrub legumes during 5 years in the 1990s at Planaltina, revealed the high potential of the 11-accession collection of cratylia available at that time (Pizarro et al. 1996). Although this triggered further collecting activities (Pizarro et al. 1997), there are no published reports on subsequent germplasm evaluations and cultivar development in the region.

Colombia. Summarizing the evaluations of the cratylia collection available in the second half of the 1980s, Maass (1996) reported that all 11 accessions were well adapted to the acid, infertile soils and the climate of the various sites where the collection was tested. Performance at elevations >1,200 masl was poor. There was no major morphological variation among accessions. CIAT 18668 was considered to be particularly promising.

As a result of this and subsequent research (Corpoica 2002), the Corporación Colombiana de Investigación Agropecuaria (Corpoica, now Agrosavia), released Veranera in November 2002, following the Costa Rican approach of creating a physical mixture of 2 very similar accessions, CIAT 18668 and CIAT 18516. The release bulletin (Lascano et al. 2002) summarizes cratylia research results and presents recommendations for establishment and utilization of the legume.

Andersson et al. (2006) reported variation among 38 accessions at CIAT-Quilichao for phenology, dry matter (DM) production and nutritional quality. Subsequently and at the same site, Peters et al. (2009) compared cratylia germplasm from Bolivia, including 11 Yapacaní and 2 shrub morphotype accessions, with Brazilian shrub accessions. While the Yapacaní morphotype accessions produced considerably less DM than the shrub accessions in both the wet and dry season, there were no yield differences between the 2 Bolivian and the 4 Brazilian shrub morphotype accessions evaluated.

Most R&D activities with Veranera concentrated on the Andean piedmont region (high rainfall with a short dry season) in the Orinoco River basin (Piedemonte Llanero, Meta department) with the focus on dual-purpose cattle farms with acid, infertile soils (Plazas and Lascano 2005; Rincón Castillo et al. 2007). More recently, new shrub germplasm evaluation was conducted at 2 Agrosavia experimental stations in the well-drained Altillanura region (Taluma and Carimagua) with acid, infertile soils and >2.200 mm rainfall/year and a production-limiting dry season of 2–4 months. Cratylia outperformed *Desmodium velutinum*, *Flemingia macrophylla* (flemingia) and *Leucaena diversifolia* germplasm in terms of vigor and forage production (Corpoica 2017). CIAT 22389, the outstanding cratylia accession, was selected for subsequent animal production studies.

In a test of 5 forage tree/shrub species in the acid-soil, high-rainfall region of the Andean piedmont in the Amazon River basin in Piedemonte Amazónico, Caquetá department, where Maass (1996) had reported good adaptation of the species, cratylia (no accession or cultivar mentioned) presented the highest DM production (Suárez et al. 2008). Recently, the species was reported to be present in 32 farms that form part of a silvopastoral project in that region (Parra Celis et al. 2021).

To further assess adaptation to mid-altitude hillside sites, Parra and Gómez-Carabalí (2000) tested a varying number of shrub and tree species and accessions on low-fertility soils at 3 locations in the Cauca and Valle del Cauca departments. Cratylia was outstanding in terms of dry matter production at elevations up to 1,175 masl; accessions mentioned are CIAT 18597, CIAT 18668 and CIAT 18676. Poor growth of cratylia was reported from 1,650 masl in the Antioquia department (Vargas Zapata et al. 2017).

Peru. Published cratylia studies in Peru concentrate on 2 sites in the humid tropics with a 3-month minimum rainfall season and acid, infertile soils: Pucallpa (Ucayali department) and Tarapoto (San Martín department). At the former, in a comparison of 2 cratylia accessions with 5 other shrub legume species considered adapted to acid soils (*Cajanus cajan*, *Codariocalyx gyroides*, *D. velutinum*, flemingia and *Tadehagi triquetrum*), accession CIAT 18957 presented the highest DM production in a 12-wk regrowth cut during the minimum rainfall season (CIAT 1990). Recent work (Medina Dávila 2021), where cratylia was compared with *Erythrina berteroana* and *Leucaena leucocephala* (leucaena), confirmed the good adaptation of cratylia (no cultivar or accession mentioned).

At Tarapoto, accession CIAT 18516 was compared with 3 herbaceous legumes (*Arachis pintoi*, *Centrosema macrocarpum* and *Desmodium ovalifolium*) (Rojas Reátegui 2002). Establishment of cratylia was slow but its DM yields in 12-weekly cuts in both the maximum and minimum rainfall seasons were higher than those of the 3 non-shrub species. More recently, a development project report revealed no advantage of cratylia (no cultivar or accession mentioned) in comparison with leucaena and the non-legume species *Morus alba* and *Moringa oleifera* (Ibazeta Valdivieso et al. 2018).

Venezuela. Evaluating the 10-accession set of cratylia available for research in the second half of the 1990s in El Tigre, Anzoátegui state, Rodríguez and Guevara (2002) found no major differences among accessions for DM production and feed value. Cratylia proved to be well adapted to the sandy, low-fertility soil of the savannas in dry-subhumid eastern Venezuela and was officially recommended for use in the region (Rodríguez et al. 1999; Navarro Díaz et al. 2004), particularly as protein banks (Guevara et al. 2013). Seed distributed to farmers as 'Cratylia' was a mixture of unknown accessions (I. Rodríguez, pers. comm., July 2023).

Bolivia. Based on evaluations at 3 sites in Cochabamba department, cratylia is recommended for use as protein bank for acid soils in the humid tropics of Bolivia (CIF 2009; Gutiérrez 2010). Smallholder-produced seed of Veranera is marketed in the country (E. A. Pizarro, pers. comm., August 2023).

Central America and Caribbean

Costa Rica. An evaluation of 11 accessions of cratylia was carried out by Argel (1996) at Atenas, with fertile soils and a 5–6-month dry season and San Isidro, with acid infertile soils high in Al and a 3–4 month dry season. In terms of DM production, results showed little variability among accessions, including CIAT 18516. This accession was additionally tested at a high-rainfall site in Los Diamantes, Guápiles, where cratylia was first introduced in 1988. Subsequent research led to the release of Veraniega in 2001, a physical 50:50 mixture of accessions CIAT 18516 and CIAT 18668 that had proven to be very similar. The objective of the mixture was to broaden the genetic base of the cultivar. The release bulletin (Argel et al. 2001) summarizes research results and presents recommendations for establishment and utilization of the legume.

Guatemala. According to the only published information available, CIAT 18516 did not grow satisfactorily on a very low-P site at El Subín, Petén (Argel 1996).

Honduras. Although results of adaptation and evaluation studies are not published, based on the performance of cratylia in regions with a pronounced dry season, its use was officially recommended by Dicta (2002).

Caribbean. In a 3-legume shrub comparison in the south of Puerto Rico, establishment growth of cratylia (no accession mentioned) was very slow and DM production at 134 days after transplanting of seedlings considerably lower than for *Calliandra calothyrsus* (calliandra) and leucaena (Crespo et al. 2011). In the northeast of Dominican Republic, cratylia (no accession mentioned) outperformed, in terms of DM production, *Morus alba* (Frías and Valerio 2013).

Mexico. Most of the species' adaptation and evaluation studies were carried out in the state of Veracruz. Based on unpublished work by J. F. Enríquez Quiroz, Argel (1996) reported good performance of accession CIAT 18516 on an acid, infertile soil in the municipality of Isla. In evaluations of accessions CIAT 18516, 18666, 18668 and 18676 in Atzalan (Castillo-Gallegos et al. 2013) and Tlapacoyan (Valles-de la Mora et al. 2014), no major differences among accessions were reported for DM production or forage quality. These experiences in Veracruz were summarized by Valles-de la Mora et al. (2017). The only published evaluation outside Veracruz is a study of 10 legume species in Chetumal, Quintana Roo, where cratylia (no cultivar or accession mentioned), along with *Crotalaria juncea*, showed the highest DM production over this 2-year study (Sosa Rubio et al. 2008).

Africa

Information from research in Africa is essentially limited to the report of a French sponsored network RABAOC-AFRNET (1995) report, according to which accession CIAT 18516 was included in germplasm sets for 2-yr multilocational tests at 18 sites in 9 countries in West and Central Africa (Benin, Central African Republic, Cameroon, Côte d´Ivoire, Ghana, Guinea, Nigeria, Senegal and Togo), along with 5 other shrub legumes (*Cajanus*, *Codariocalyx*, *D. velutinum*, flemingia and leucaena) and a number of herbaceous legumes and grasses. The report does not provide a clear picture on the overall adaptation and agronomic performance of cratylia, which was affected by plant establishment/seed quality problems that prevented inclusion of the species in a combined multilocational analysis. In the few cases where plants were established, remarkable drought tolerance was noted. In Ghana, Barnes (1998) evaluated 13 woody legume species, among them cratylia, which performed poorly. Similarly, cratylia did not stand out among several other woody legume species tested in mid-altitude sites of eastern DR Congo (Dieudonné 2020).

Southeast Asia and China

Within the CIAT-ACIAR Forages for Smallholders Project, cratylia was tested in the 1990s in several SE Asian countries. According to W. Stür (pers. comm., March 2023), the species performed poorly, due to plant establishment problems in combination with low seed quality. Poor performance of cratylia within a forage tree collection (mainly *Leucaena* spp.) tested in a fertile-soil, high-rainfall environment was reported from the Philippines (Gabunada and Stür 1999). Similarly, cratylia performed poorly in a legume comparison trial at 2 sites in Laos (Stür et al. 2010). In Danzhou, Hainan province, China, cratylia was susceptible to low temperatures, which coincide with flowering of the plants and affect seed production (Tang Jun, pers. comm., Sept. 2023).

Ecological adaptation

Soil

Information on soils, to which cratylia is adapted, refers mainly to germplasm collecting sites. In synthesis, soils are well drained, acid (pH 4–7) and of low to medium fertility, values of P ranging 1–60 ppm, Ca+Mg 1–14 meq/100 g, and K 36–480 ppm (Pizarro et al. 1997; Mattar 2018). The considerable variation in soil data, mainly the high values, is probably due to some collections being made in soil fertility-disturbed vegetation, e.g., at roadsides. Field trials have demonstrated that cratylia is adapted over a wide fertility range. However, cratylia is not adapted to poorly drained or seasonally flooded soils nor to soils with a layer that hampers penetration of the taproot (Argel et al. 2001). Gama et al. (2009) reported good growth of cratylia on a Quartzpisamment soil with 90% sand in Mato Grosso do Sul, Brazil.

The above information refers to the cratylia shrub morphotype collected in Brazil. The Yapacaní morphotype (Bolivia) was found on less well-drained soils of medium to high fertility (Schultze-Kraft et al. 2006).

Perdomo (1991) documented differential soil adaptation by comparing the performance of 23 shrub and tree legume species on 2 contrasting soils in a field experiment in southwest Colombia, on a fertile Vertisol with pH 7.7 and 84.6 ppm P at CIAT-Palmira and on an infertile Ultisol with pH 4.0, 5.3 ppm P and 90.8% Al saturation at CIAT-Quilichao. DM production of cratylia accession CIAT 18516 on the Ultisol was only 32% less than that on the Vertisol, while leucaena and *Gliricidia sepium* (gliricidia) produced >99% less DM than on the Vertisol, showing adaptation of cratylia to high Al saturation. Xavier et al. (1998) reported that liming improved growth of cratylia in pot experiments conducted on an infertile Oxisol (LVA) in Minas Gerais, but at the optimum lime dose (1.5 t lime/ha to achieve 90% of maximum DM yield), soil pH was still <5 and Al saturation, 26%. Adaptation of CIAT 18516 to an acid, infertile Oxisol with pH 5.0 and 2.0 ppm P on a farm in the Eastern Plains (*Altillanura*) compared to growth on a Mollisol (formerly classified as Vertisol) at CIAT-Palmira was confirmed in an experiment on growth and chemical composition of 5 shrub legumes (Tiemann et al. 2009).

Climate

Rainfall data at locations where cratylia germplasm was collected and where it was evaluated have been determined based on map coordinates and long-term averages from nearby sites. The annual rainfall range for the Brazilian shrub morphotype is 1,230–2,240 mm, the distribution being monomodal with a dry season of 2–5 months, while the Yapacaní morphotype is from somewhat more humid environments (about 2,700 mm/ yr with 2 dry months). The altitudinal range of collection sites is 100–810 masl. As germplasm evaluation studies in Colombia have shown (Maass 1996; Parra and Gómez-Carabalí 2000), cratylia does not grow well at elevations above 1,200 masl. According to information from Brazil (Sobrinho and Nunes 1996) and China (Tang Jun, pers. comm., Sept. 2023), the species is intolerant of low temperatures.

The drought tolerance of well-established cratylia plants and dry season leaf retention were reported by Argel (1996), which Pizarro et al. (1996) suggested was due to a deep-reaching root system. For 4.5-yr-old plants (CIAT 18516 and 18675), the major root concentration was at 1.3–1.8 m depth. Dry season leaf retention is supported by yield trials (see following sections), in which the dry season portion of cratylia accounted for up to 40% of total annual production.

Agronomy

Establishment and plant growth

Under suitable conditions, healthy cratylia seeds germinate readily. Sanabria et al. (2004) found that seed scarification is not necessary. Initial growth is slow, as first shown by Xavier et al. (1990). This drawback was confirmed, regardless of edaphoclimatic conditions (Mesén Villalobos and Sánchez Ledezma 2008; Gutiérrez 2010; Crespo et al. 2011; Aquino et al. 2020). The general conclusion is that sowing or transplanting must be combined with weed control and sufficient time (7–12 months) allowed until the first cut or grazing. Matrangolo et al. (2018b) suggested that allocation of energy resources to the formation of its root system might be responsible for the slow initial growth of cratylia.

Aquino et al. (2020) evaluated the effects of direct seeding or transplanting of 4-mo old seedlings on establishment of cratylia. After an initial advantage of the transplanted seedlings, 10 months later there was no difference in plant height, regardless of method; labor made up to 86% of the total establishment costs. Similarly, transplants (no age mentioned) had a slight advantage over direct seeding for time to reach 1 m plant height at CIAT-Quilichao (Rosero Alpala et al. 2010).

Optimum plant density for highest cratylia forage production per unit area was found to be: 20,000 plants/ha in Veracruz, Mexico (Enríquez Quiroz et al. 2003); 40,000 plants/ha in Nicaragua (Pasquier Flores and Rojas Vallecillo 2006; Reyes Sánchez et al. 2007); and 111,111 plants/ha in the Andean piedmont region in Colombia (Corpoica 2002). Such large differences are probably due to environmental conditions (soil, climate).

Fertilizer application and rhizobiology

Phosphorous (P) was reported as the nutrient which limited growth of cratylia shoots and roots, affecting also physiological conditions of rhizobium nodules in a pot experiment using an infertile Oxisol (*Latossolo Vermelho-Escuro*, LVE) in Minas Gerais (Purcino and Lynd 1984). From a series of pot experiments on an LVA in the *Zona da Mata* region of Minas Gerais, P fertilizer application and liming improved growth of cratylia (Xavier et al. 1996; 1997; 1998). In particular, liming increased the efficiency of P application. The critical internal P concentration, at which 80% of maximum DM yield was obtained, was 0.14%.

Positive effects of fertilizer application with Ca, N and Mg on biomass production were reported from a field experiment on an infertile, sandy Oxisol in the savanna of eastern Venezuela (Navarro Díaz et al. 2002), although field research in Colombia on 2 contrasting soils did not show clear responses to P, K, Ca, Mg and S fertilizer application (Tiemann et al. 2009).

In field studies in the *Zona da Mata* region of Minas Gerais, Xavier and Carvalho (1996) observed active nodulation in cratylia with native cowpea type rhizobia. Oliveira et al. (1998), however, did not find any superior shoot and root production in a pot experiment with a Minas Gerais LVA where they tested the effect of inoculation with 17 different rhizobium strains, presumably due to the competition and effectiveness of the native cowpea strain. At CIAT-Quilicho, speed of cratylia establishment was not improved when seeds were inoculated with rhizobium (Rosero Alpala et al. 2010). In an inoculation test with 2 *Rhizobium* and 4 *Bradyrhizobium* strains on a sand/vermiculite substrate in the greenhouse, only 1 inoculum, CR52 (BR10257), led to nodulation and subsequent increased plant height after 85 days (Mattar et al. 2018). Among a total of 25 strains, Calazans et al. (2016) identified the same inoculum, CR52, along with CR42, as particularly successful. Argel et al. (2001) recommended inoculation with *Bradyrhizobium* CIAT 3561 or 3564 in Costa Rica.

Crop management

This section focuses on cratylia management for optimization of forage production in cut-and-carry systems, the use most evaluated by researchers. Diversity of options for plant age at first cut, cutting frequency and cutting height is documented in the report on early evaluation trials conducted in Colombia (Maass 1996).

Plant age at first cut. This is the time when plants can be considered established. There are objective criteria to determine when the plant is well established, although some authors chose a particular plant height (1 m; Rosero Alpala et al. 2010) or a particular plant age such as 7 months (Rodríguez and Guevara 2002; Gutiérrez 2010) or 12 months (Lobo and Acuña 2004) as criterion. There was no effect on DM production at 4, 6 and 8 months of the first cut after planting (Argel et al. 2001).

Cutting frequency. Cutting frequency has been a major subject of interest to researchers (Table 1). In summary, there is a tendency for considering 90 days as the suitable overall cutting frequency. The resulting range of cutting intervals recommended in the literature reflects the variation of environmental conditions and subsequent plant growth at the respective study sites. Findings reported should also be interpreted considering pertinent experimental details.

Cutting height. Studies to determine optimum cutting height reported varying results. In Minas Gerais, Xavier et al. (1990) found no yield difference when comparing 20 cm with 40 cm height. Santana and Medina (2005), testing 30, 60 and 90 cm in Colombia, reported that cutting height did not affect edible DM yield. Similarly, in Venezuela there was no yield difference after cutting at 50 or 70 cm (Lugo-Soto et al. 2009). In contrast, Lobo and Acuña (2004) found in Costa Rica that harvesting at 90 cm height led to higher DM yields in comparison with 30 and 60 cm, and in Nicaragua DM production was higher after cutting at 60 cm in comparison with 20 and 40 cm (Pasquier Flores and Rojas Vallecillo 2006). Again, environmental conditions affecting plant growth and production are suggested to be responsible for reported variations.

Appropriate management might be different if the objective is to maximize dry season production, when forage availability is generally limited. Based on their research in Goiás and Tocantins, Sobrinho and Nunes (1996) suggested that cutting during the 4–5-month dry season of the central Brazilian *Cerrado* stimulates regrowth of plants and leads to green leaves persisting until the start of the subsequent rainy season. For the Puntarenas province, Costa Rica, Lobo and Acuña (2004) recommend a standardization cut at the end of the rainy season to optimize dry season forage production.

Based on observations in cratylia's habitats (Figures 2C and 2D) and under managed conditions (Figure 3), cutting well established plants as close as possible to the ground will activate growing points at the soil surface level that will lead to an increased number of basal regrowth branches during the dry season. To the best of our knowledge, research in this regard has not been conducted, although several researchers have reported the number of sprouting branches in response to cutting (Maass 1996; Rodríguez and Guevara 2002; Lobo and Acuña 2004; Andersson et al. 2006).

In the Andean piedmont of the Colombian eastern plains, Plazas and Lascano (2005) found that in those cases where plants are not cut but browsed, a standardization cut should be performed after browsing to optimize forage production for the next use. Regrowth of edible leaf DM was only 29% of the whole plant as compared with 54% when plants were subjected to a standardization cut at 20 cm height.

Dry matter production

There is a considerable range of DM production reported in the literature (Table 2). This reflects the diversity of environmental conditions and trial arrangements, particularly planting density, at the study sites. In conclusion, DM yields of 10–20 t/ha/year can be obtained, with up to 40% of dry season yield. In the only trial where several Yapacaní morphotype accessions were tested, its productivity was much lower than that of the shrub morphotypes (Peters et al. 2009).

Seed production and seed quality

Daylength reduction is involved in the induction of flowering of cratylia (Andersson et al. 2006), as well as reduced water availability, since some authors report that flowering starts at the end of the rainy/onset of the dry season (Rincón Castillo et al. 2007; Matrangolo et al. 2018a; Pardo-Barbosa et al. 2021). As is characteristic of undomesticated species, flowering and seed setting are asynchronous and despite a previous standardization cut extend over several months after the end of the rainy season (Argel et al. 2001). Consequently, seed (pod) harvesting is a continuing manual operation during part of the dry season. First-year seed production is reported to be lower than in subsequent years (Matrangolo et al. 2018a; Pardo-Barbosa et al. 2021). Mesén Villalobos and Sánchez Ledezma (2008) found that seed yields

Table 1. Overview of cutting frequency of *Cratylia argentea* for maximization of dry matter production for selected countries and regions.

Country, region/site	Study	Results, observations	Reference
Colombia, Antioquia (Bajo Cauca)	Optimum frequency (and 3 cutting heights)	90 days better than 45 or 60 days	Santana and Medina (2005)
Costa Rica, Puntarenas (Esparza)	Optimum frequency (and 3 cutting heights)	90 days better than 60 days (but somewhat lower quality)	Lobo and Acuña (2004)
Costa Rica, San José (Upala)	Optimum frequency in rainy and dry season	75 days better than 60 days; no season effect	López-Herrera and Briceño-Arguedas (2016)
Honduras, Comayagua	Optimum frequency	80 days better than 40 or 60 days	Dicta (2002)
Mexico, Veracruz (Isla)	Optimum frequency	120 days better than 60 or 90 days	Enríquez Quiroz et al. (2003)
Mexico, Veracruz (Tlapacoyan)	Optimum frequency in in 3 seasons (wet, winter and dry; 4 accessions)	6, 9, 12 and 15 weeks tested; overall no statistical differences	Valles-de la Mora et al. (2014)
Nicaragua, Managua	Optimum frequency (and 3 cutting heights)	16 weeks better than 8 or 12 weeks	Reyes Sánchez et al. (2007)
Peru, Ucayali (Pucallpa)	Optimum regrowth age in rainy and dry season	30 days better than 10, 20 or 40 days; no difference between rainy and dry season	Medina Dávila (2021)
Venezuela, Barinas (Pedraza)	Optimum frequency (and 2 cutting heights)	90 days better than 30 or 60 days	Lugo-Soto et al. (2009)

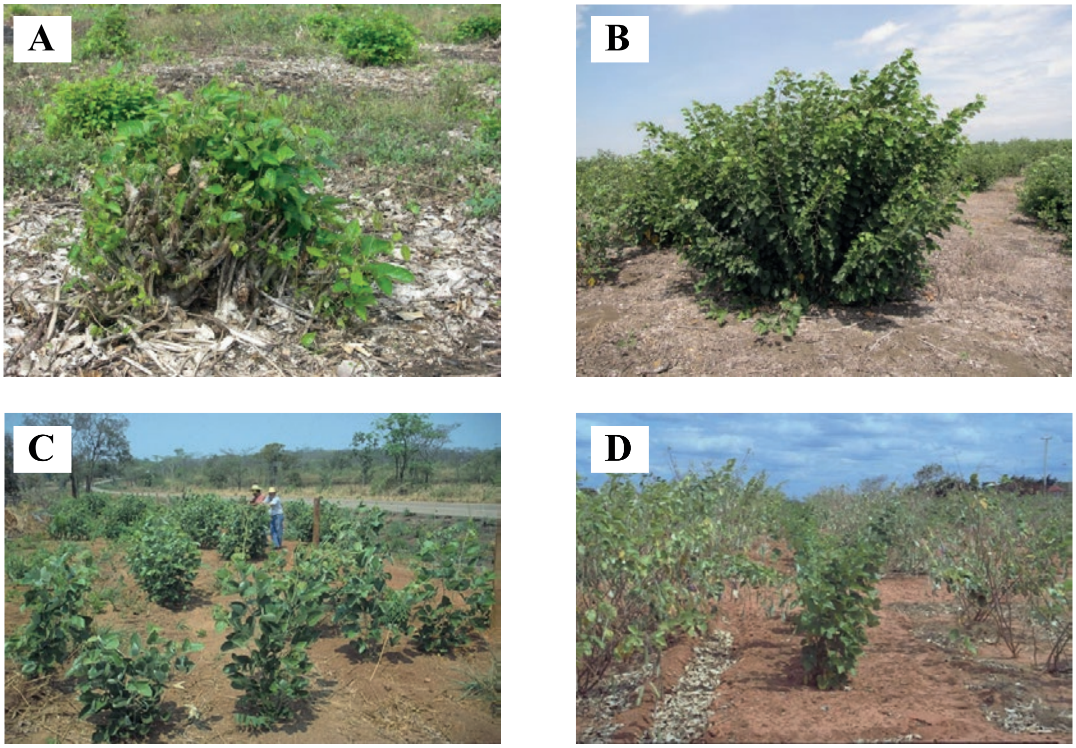

Figure 3. Management of *Cratylia argentea*. (A) Initial regrowth from basal buds after cutting of 7-yr old plants, CIAT-Quilichao, Colombia (Photograph: R. Schultze-Kraft); (B) Approx. 9-mo regrowth from basal buds, CIAT-Quilichao, Colombia (Photograph: A. Ciprián, CIAT); (C) Dry-season regrowth of shrub morphotype from below-ground buds after vegetation cutting and soil surface scraping by a bulldozer in Mato Grosso, Brazil (Photograph: R. Schultze-Kraft); (D) Dry season performance of 20-mo old plants in Anzoátegui, Venezuela: lateral rows are uncut, but still retaining leaves; central row is 4-mo old dry season regrowth. (Photograph: R. Schultze-Kraft)

(kg/ha) increased from 120 in year 1 to a peak of 2,450 in year 4 and then dropped to 830 in year 7 during a 7-yr on-farm study in San José Province, Costa Rica, showing the dynamics of seed production and the high yields that can be obtained.

The seed production potential of cratylia is high (Table 3), but yields are influenced by environment, planting density and management. Two guideline publications with a focus on agronomy, phenology, crop management and harvest to post-harvest management in Colombia offer comprehensive information and recommendations for artisanal seed production (Argel et al. 2003; Pardo-Barbosa et al. 2021), while overviews of seed production aspects in Brazil were provided by Ramos et al. (2003) and Matrangolo et al. (2018a).

When seed production of forage plants is difficult, vegetative propagation is often seen as an alternative. Pizarro et al. (1996) reported that for cratylia only 1% of vegetative-propagation trials using cuttings were successful, whereas experiences of Matrangolo et al. (2018a) with cuttings and tissue culture were positive. Tissue culture of cratylia was also successful in China (Li Zhiying et al. 2007).

Declining seed viability of cratylia is a major issue for dissemination. If seed longevity is to be ensured in the tropics, seeds must be stored under low temperature and low relative humidity (Table 4). In Cochabamba city, Bolivia (2,560 masl elevation and 16 °C mean temperature), storage under ambient conditions did not affect seed quality, while in the humid tropical lowlands of Cochabamba department, seed viability declined within <1 year (Gutiérrez 2010). Ramos et al. (2003) considered cratylia seeds to be orthodox, i.e., their desiccation does not affect their viability. However, Montoya Bárcenas et al. (2009) found that a seed moisture content <8% reduces germination, suggesting some recalcitrant behavior.

Biotic constraints

To date, no serious biotic constraints have been reported for cratylia. Among pests, leaf cutting ants, mainly *Atta* species, were registered in Brazil (Sobrinho and Nunes

Table 2. Overview of selected dry matter yields of *Cratylia argentea* reported for different countries and locations within countries.

Country, region/site	Study objective	Yield mean/range[1,2]	Observations	Reference
Bolivia, Cochabamba (humid low-land tropics)	Forage production potential at 3 locations (farms)	10.7	Veranera; mean of 3 locations; 7 mo after sowing; 10,000 plants/ha; leaf:stem (L/S) ratio: 2.34	CIF (2009)
Brazil, Minas Gerais (Zona da Mata)	Forage production potential	14.3	Accession CNPGL-119; 6-mo regrowth; 13,000 plants/ha	Xavier et al. (1990)
Brazil, Federal District	Forage production potential of 11 accessions	0.5–2.1	12-mo regrowth; L/S ratio: 1.4–3.1; 2,500 plants/ha	Pizarro et al. (1996)
Brazil, Minas Gerais (Central)	Phytomass production potential	Green matter: 72.5	Cumulative yield of 14 months (4 cuts with 3–4-mo interval); 73% leaf; 20,000 plants/ha	Matrangolo et al. (2013)
Brazil, Minas Gerais (Central)	General information on cratylia based on regional research experiences	39 (leaf DM)	Cumulative yield of 18 cuts in a total of 56 months; 6,300–7,500 plants/ha	Matrangolo et al. (2018a)
Colombia, Cauca (CIAT-Quilichao)	Forage production potential within the early cratylia collection	85–272 g DM/plant	Single-row evaluations; range of 11 accessions; means of two 3-mo regrowth cuts	Maass (1996)
Colombia, Antioquia (Bajo Cauca)	Forage production as influenced by cutting management	2.6 (digestible DM)	9-mo cumulative yield; mean of best cutting management; 10,000 pl/ha	Santana and Medina (2005)
Colombia, Meta (Andean piedmont)	On-farm evaluation of forage potential in wet and dry season	Wet: 3.34 Dry: 0.59	Veranera; 1-yr yield, means of 10 farms; 10,000 plants/ha; L/S ratio wet season: 1.9; dry season: 1.1	Plazas and Lascano (2005)
Colombia, Cauca (CIAT-Quilichao)	Forage production of a 38-accession collection in wet and dry season	g DM/plant Wet: 190–382 Dry: 124–262	Single rows; accession ranges, means of 2 cuts each in wet and dry season; 8-week regrowth	Andersson et al. (2006)
Colombia, Caquetá (Amazon piedmont)	Forage production potential in 2 topographies, rolling hills (R) and flat (F)	g DM/plant R: 3,078 F: 883	Total of four 3-month yields; L/S ratio: 1.8 (R) and 1.4 (F)	Suárez et al. (2008)
Colombia, Cauca (CIAT-Quilichao)	Forage production of 11 Yapacaní and 6 shrub morphotype accessions in wet and dry season	g DM/plant Yapacaní Wet: 99; Dry: 75 Shrub Wet: 246; Dry: 284	Means of accessions and three 8-week regrowth cuts in each season	Peters et al. (2009)
Colombia, Meta (Andean piedmont)	Forage production of 5 selected accessions	14.6	80-day yields; mean of accessions; 64% leaf; 10,000 plants/ha	Corpoica (2017)
Colombia, Casanare (Yopal)	Forage production on degraded soil	7.86	Total of five 45-day interval cuts; mean L/S ratio 2.91; 10,000 plants/ha	Navas Panadero et al. (2020)

Continue

Country, region/site	Study objective	Yield mean/range[1,2]	Observations	Reference
Costa Rica, Alajuela (Atenas)	Forage production of an 11-accession collection in wet and dry season	Edible DM (g/plant) Wet: 110–190	Edible DM (leaf and thin stems); single rows; accession ranges, means of five 8-wk and four 12-wk cuts in wet and dry season, respectively	Argel (1996)
Costa Rica, Alajuela (Atenas)	Forage production of CIAT 18516 as affected by planting density	3.7	Yield per cut; 8-week regrowth rainy season, 12-week regrowth dry season; 20,000 plants/ha	Argel et al. (2001)
Costa Rica, Puntarenas (Esparza)	Forage production of Veraniega as influenced by cutting management	7.4	Mean of eight 90-d regrowth cuts at 90 cm height; 28% of total yield in dry season; 20,000 plants/ha	Lobo and Acuña (2004)
Costa Rica, San José (Upala)	Forage production of Veraniega as influenced by season and regrowth age	g DM/plant Wet: 272 Dry: 241	90-day cutting interval	López-Herrera and Briceño-Arguedas (2016)
Mexico, Veracruz (Isla)	Forage production as influenced by cutting management	11.3	Yield per year (three 120-d regrowth cuts); 61% leaf; 20,000 plants/ha	Enríquez Quiroz et al. (2003)
Mexico, Veracruz (Tlapacoyan)	Forage production of 4 accessions as influenced by cutting frequency and season	8.0	Mean of accessions and cutting frequencies; yield per year; seasonal contribution: wet, 33%; winter, 22%; dry, 45%; 10,000 plants/ha	Valles-de la Mora et al. (2014)
Nicaragua, Managua	Forage production of accession CIAT 18668 as influenced by planting density and cutting height	18.1	Yield per year; 33% of total yield in dry season; 60 cm cutting height; 40,000 plants/ha	Pasquier Flores and Rojas Vallecillo (2006)
Nicaragua, Managua	Forage production of Veranera as influenced by planting density and cutting interval	18.2	Yield per year; 69% edible forage; 25–35% of total yield in dry season; 16-wk cutting interval; 40,000 plants/ha	Reyes Sánchez et al. (2007)
Peru, San Martín (Tarapoto)	Forage production of accession CIAT 18516 in wet and dry season	Wet: 5.6 Dry: 4.7	Yield of 12-week regrowth; planting density not provided	Rojas Reátegui (2002)
Venezuela. Anzoátegui (El Tigre)	Forage production of a 10-accession collection in wet and dry season	Wet: 1.94 Dry: 0.76	Yields per cut; leaf only; collection mean of 2 (wet season) and 1 (dry season) 8-wk regrowth cuts/ year (2 years); 20,000 plants/ha	Rodríguez and Guevara (2002)
Venezuela, Barinas (Pedraza)	Forage production as influenced by cutting management	g DM/plant 107.3	90-day yield; mean of 2 cutting heights; 5,102 plants/ha	Lugo-Soto et al. (2009)

[1]All yield data are in t DM/ha if not indicated otherwise; [2]Calculation of per-hectare yields based on per-plant measurements (if planting density data were available).

Table 3. Overview of seed production of *Cratylia argentea* reported for different countries and locations within countries.

Country, region/site	Variety/accession	Plant density (plants /ha)	Mean/range (kg/ha)[1]	Observations	Reference
Costa Rica, Alajuela (Atenas)	Veraniega	10,000	500–700	Plants 3 years old; harvests during 2–3 months	Argel et al. (2001)
Colombia, Cauca (CIAT-Quilichao)	CIAT 18516 CIAT 18668	1,600	596	Mean of 2 accessions: 2 harvests in 1 year	Maass (1996)
Colombia, Meta (Andean piedmont)	Veranera	6,666	313	Mean of 7 farms	Plazas and Lascano (2005)
Colombia, Meta (Andean piedmont)	Veranera	2,500	250	Plants >2 years old	Rincón Castillo et al. (2007)
Colombia, Cauca (CIAT-Quilichao)	CIAT 18516 CIAT 18668	1,600	372	Mean of 2 accessions: 2 harvests in 1 year	Lascano et al. (2002)
Colombia, Cauca (CIAT-Quilichao)	Collection of 38 accessions		g/plant Mean: 179 Range: 13–757	1 harvest period; 14 months old plants in single-row plots	Andersson et al. (2006)
Colombia, Meta (Altillanura and Andean piedmont)	3 accessions	5,000	623–816	Mean yields at 3 sites; 1 harvest period	Corpoica (2017)
Brazil, Minas Gerais (Central)	Unidentified accession	12,000	1,409	1 year old plants; harvest during 1 month (October)	Miranda et al. (2011)
Brazil, Minas Gerais (Central)	Unidentified accession		g/plant Mean: 530 Range: 20–2,460	12 plants >3-yr old; harvest during 1 month (October)	Matrangolo et al. (2018a)
Costa Rica, San José	Veraniega	10,000	Year 1: 120 Year 2: 600 Year 3: 2,020 Year 4: 2,450 Year 5: 1,890 Year 6: 1,360 Year 7: 830	7-yr study; daily seed harvests during 2 months	Mesén Villalobos and Sánchez Ledezma (2008)
Honduras, Comayagua	Unidentified accession	10,000	800		Dicta (2002)

[1]Calculation of per-hectare yields based on per-plant measurements (if planting density data were available).

Table 4. Overview of germination of *Cratylia argentea* seeds following storage under ambient (A) and controlled (C) storage conditions.

Country, region	Germination at harvest	Germination after storage		Observations	Reference
		A	C		
Costa Rica, Alajuela (Atenas)	80%	50%		24 months storage; A: 24 °C, 70% RH[1]	Argel et al. (2001)
Brazil, Federal District	90%	33%	91%	Mean of 2 accessions (CIAT 18516 and CIAT 18668); 24 months storage; C: 5–10 °C, 5–10% RH	Ramos et al. (2003)
Brazil, Minas Gerais (Central)	84%	50% and <10%	84%	16 and 18–26 months storage, respectively; C: refrigerator	Matrangolo et al. (2018a)

[1]RH – relative humidity.

1996; Matrangolo et al. 2018b), Colombia (Lascano et al. 2002) and Venezuela (Navarro Díaz et al. 2004); plants, however, recover readily. In Colombia, establishment can be affected by beetle larvae of the Melolonthidae family (Maass 1996). In seed production plots in Brazil, the wasp, *Podagrion* sp. (Hymenoptera: Torymidae) and bruchids have been reported as insect pests (Matrangolo et al. 2018a) and in Colombia the bean pod borer, *Maruca testulalis* (Pardo-Barbosa et al. 2021). At the experimental station level, Andersson et al. (2006) recorded a nematode problem at CIAT-Quilichao, considering it of minor, site-specific importance.

Regarding diseases, Mesén Villalobos and Sánchez Ledezma (2008) registered 3% plant loss in the fifth year in a 7-yr experiment in Costa Rica due to stem diseases, possibly caused by fungi of the genera *Nectria*, *Phytophthora* and *Graphium*; they also observed *Penicillium* and *Aspergillus* species on cratylia seeds possibly related to poor storage conditions. In Colombia, the fungi *Phoma* and *Cladosporium* have been associated with the occasional occurrence of empty pods (Pardo-Barbosa et al. 2021).

Multipurpose uses

Several authors have suggested that cratylia, being an N-fixing legume, has potentially other uses in addition to providing forage for livestock, i.e., particularly for reclamation of degraded soils, as mulch and green manure in mixed production systems, and/or providing fuel wood (Xavier et al. 1995; Matrangolo et al. 2013, 2018a).

Soil improvement

In Colombia, Parra and Gómez-Carabalí (2000) reported from a medium-elevation site (Corpopalo, Santander de Quilichao, Cauca; 1,075 masl) that, after 16 weeks, cratylia presented a faster litter degradation and N release than *Codariocalyx* and flemingia. In contrast, Cobo et al. (2002) found at higher elevation (Pescador, Cauca department; 1,500 masl) that decomposition and nutrient release of 6-months old cratylia foliage were slow. Also, in Colombia (Casanare department), Navas Panadero et al. (2020) showed that, after 14 months of a cratylia protein bank established on an Entisol soil (considered "degraded" after 2 years of intensive experimental applications of pesticides), soil organic matter (SOM), soil organic carbon and soil macrofauna had increased. In the Central Pacific region of Costa Rica, Lobo and Acuña (2004) observed that SOM under a pure stand of cratylia increased in 3 years from 3.1% to 4.1%.

In the *Central* region of Minas Gerais, Marques et al. (2014) concluded from a soil restoration study that cratylia has potential for revegetating gully-eroded sites. In revegetation pot studies using soil contaminated with toxic iron ore sludge after the 2015 Mariana dam disaster in Minas Gerais, outstanding performance of cratylia, along with *Sophora tomentosa*, was reported among the 5 legume species tested (Costa et al. 2018).

Integrated production systems

The potential of cratylia for integrated crop/tree-livestock production systems has been suggested by several authors (Navarro Díaz et al. 2004; Matrangolo et al. 2016; Valles-de la Mora et al. 2014) and documented from studies conducted in Brazil and Colombia. For the *Central* region of Minas Gerais, Miranda et al. (2011) and Gomes et al. (2015) showed the potential of cratylia as green manure in alley-cropping systems. From the same region, Matrangolo et al. (2018a) reported that in a total of 18 cuts in 56 months, cratylia leaf biomass applied as green manure to the soil contributed (kg/ha): 1,337 N; 97.7 P; 715.4 K; 672.4 Ca; 134.9 Mg; and 84 S. From a 2.5-year agro-silvo-pastoral trial conducted in Mato Grosso do Sul, Gama et al. (2014) concluded that cratylia was less suitable than leucaena for a silvopastoral system in association with Massai grass (*Megathyrsus maximus*, formerly *Panicum maximum*). In the Andean piedmont region of Colombia, farmers established cratylia protein banks via intercropping with maize or vegetables to reduce the weeding costs for planting the legume (Plazas and Lascano 2005).

Ecological aspects

From a several-year survey of the fauna visiting native cratylia in central Minas Gerais, Matrangolo et al. (2018b) concluded that, mainly due to the large number of potentially beneficial arthropods, cratylia should be considered a "biodiversity island" in the region. The study emphasized arthropods diversity on cratylia, where bees accounted for 15.5%, biological control agents for 24%, and phytophagous insects feeding on green plants for 60.5% of the arthropods present. The potential agroecological implications of these observations were discussed by Matrangolo et al. (2018a, 2019).

Strengths and weaknesses

Strengths and weaknesses of cratylia based on the review of the literature cited are:

Strengths

- Adaptation to acid, infertile soils with high levels of aluminum
- Adaptation to low-phosphorus soils but responsive to fertilizer application
- Rhizobium promiscuity
- Tolerance of drought
- Tolerance of fire
- Absence of major biotic constraints
- Vigorous regrowth after cutting
- High DM yield potential
- High seed production potential
- Multi-use potential (forage, soil improvement, fuel wood)
- Suitability for integrated production systems

Weaknesses

- Labor requirements for establishment and forage harvest
- Slow establishment
- Rapidly declining seed quality
- Need of manual seed harvest over an extended period

Research suggestions

The proceedings of the Cratylia workshop held in July 1995 in Brasília concluded with research recommendations on (1) taxonomy, biogeography and genetic resources and (2) agronomic evaluation (Pizarro and Coradin 1996). Many of the suggested studies were carried out during the past 30 years, but some recommendations remain, and new research needs were identified in the meantime. Among the range of topics that result from this review and require research actions, we consider the following as priority:

Genetic resources. A consolidated inventory of germplasm accessions along with their passport data and information on actual availability of viable seed is required as a basis for further collecting. Available genetic diversity of cratylia needs to be increased by collecting germplasm in areas so far neglected (such as Peru and Bolivia) as well as in areas of higher elevations and higher latitudes (for exploration of potential adaptation to low temperatures).

Genetics. Studies are needed to clarify the self-incompatibility of cratylia and possible environmental influences on the breeding system, as well as to determine possible genetic shift within an accession as a consequence of repeated multiplication cycles. Such studies are important to optimize seed multiplication protocols in genebanks where the original genetic purity of an accession is conserved or for consideration of bulking seeds of mixed accessions for use.

Adaptation. Research in Sub-Saharan Africa and Southeast Asia in locations with low fertility soils and well-defined dry seasons to clarify why cratylia performed poorly in those few cases where the species was included in evaluation trials. Multilocational trials for cut and carry systems using high-quality seed could be considered once agro-ecological niches have been identified.

Agronomy. While overcoming the drawback of slow establishment should receive the highest research attention though screening the whole range of available genetic resources for speed of early plant growth, including Yapacaní morphotype accessions, which could lead to subsequent breeding opportunities for this trait, other areas include:

- Rhizobiological research to quantify the N fixation potential of cratylia with cowpea rhizobia and continue the search for more effective *Rhizobium*/*Bradyrhizobium* strains.

- Studies to further clarify the need for liming of this acid soil-adapted legume as well as its responsiveness to fertilizer.

- Cutting management studies to activate regrowth meristems at soil surface level for optimizing dry season regrowth and production.

Utilization. Studies on the use of cratylia for purposes other than the provision of forage are scarce and merit research attention, including its potential for soil improvement and role in production systems where forage/livestock is integrated with crops and/or trees (agropastoral, silvopastoral systems).

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(Note of the editors: All hyperlinks were verified 16 May 2024).

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Review paper

Cratylia argentea – review of a tropical shrub legume: Quality and utilization[1]

Cratylia argentea- *revision de una leguminosa tropical arbustiva: Calidad y utilización*

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Abstract

A review synthesizing the research on the quality and use of *Cratylia argentea* forage to create incentives for its use in animal production systems in the tropics is presented. The species has been extensively evaluated, mainly in tropical America, to develop it as a shrub legume for infertile, acid soils as an alternative to *Leucaena leucocephala* and *Gliricidia sepium* that are not adapted to these soils. This review includes a synthesis and discussion of research findings with *C. argentea* forage on (1) nutritive value, including secondary compounds, (2) alternative uses in animal production systems, and (3) live weight gain and milk production. The strength of the species is its drought tolerance and high protein content that results in increased milk yield and liveweight gain when grazed in association with grasses, particularly in the dry season. Supplementation of fresh or ensiled cratylia to grazing animals usually results in increased carrying capacity of the pasture and milk yield for cows of medium to high genetic potential. Its deficiency is the low acceptability of fresh forage by animals with no previous experience and high demand for labor when used in cut and carry systems. The issue of low adoption is addressed and suggestions for future research are presented.

Keywords: Adoption, grazing, intake, milk yield and liveweight gain, protein and digestibility, secondary compounds, silage.

Resumen

Se presenta una revisión que resume las investigaciones sobre la calidad y utilización de *Cratylia argentea* con el objetivo de contribuir a crear incentivos para su uso en sistemas de producción animal del trópico. La especie ha sido ampliamente evaluada, principalmente en América tropical, con el objetivo de desarrollarla como una leguminosa arbustiva para suelos ácidos de baja fertilidad como alternativa a las especies *Leucaena leucocephala* y *Gliricidia sepium* que no están adaptadas a esos suelos. Esta revisión incluye una síntesis y discusión de resultados de las investigaciones con *C. argentea* sobre: (1) valor nutritivo, incluyendo compuestos secundarios, (2) usos alternativos en sistemas de producción animal, y (3) aumento de peso vivo y producción de leche. La fortaleza de la especie es su tolerancia a la sequía y su alto contenido de proteína que resulta en aumentos de la producción de leche y peso vivo cuando se pastorea en asociación con gramíneas, particularmente en la estación seca. La suplementación de *C. argentea* fresca o ensilada a animales de pastoreo resulta normalmente en aumentos de la capacidad de carga del potrero y producción de leche con vacas de potencial genético medio a alto. Sus limitaciones son la baja aceptabilidad del forraje fresco por parte de animales que no la han consumido previamente y la alta demanda de mano de obra cuando se utiliza en sistemas de corte y acarreo. Se discute el problema de la baja adopción de *C. argentea* y se presentan sugerencias para futuras investigaciones.

Palabras clave: Adopción, compuestos secundarios, consumo, ensilaje, pastoreo, proteína y digestilidad, producción de leche y ganancia de peso.

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[1]This review article is dedicated to the memory of Dr. Jorge Ramos de Otero, Brazilian pioneer in research on tropical forage plants in the 1940s and 1950s, and the first to recognize the potential of *Cratylia argentea*.

Introduction

One of the factors that limits milk and meat production in the tropics is availability and quality of forage grasses in the dry season, which varies in duration between 2 and 6 months, depending on the location. To solve this problem, producers have the alternative of using shrub legumes as a source of protein to supplement low-quality grasses. Some well-known shrub and woody legume species (*Leucaena leucocephala*, *Gliricidia sepium*), which have been extensively researched as sources of forage for ruminants, are marginally adapted to the acid infertile soils that prevail in some areas with prolonged dry seasons and where small and medium-sized producers rely on livestock for livelihoods. This has led to a marked interest in selection of shrub legumes adapted to these ecosystems. In Brazil, Otero (1952) first highlighted the potential of *Cratylia argentea* (Desv.) owing to its adaptation to acid soils, drought tolerance and high protein concentration. This potential was realized through extensive research on agronomy and management from 1978-1995 (Pizarro and Coradin 1996), although adoption has been limited. In this paper we summarize and analyze information on forage quality and utilization of *C. argentea* in production systems from research conducted throughout the tropics. We also briefly discuss the issue of low adoption of *C. argentea* and offer some suggestions on future research needs.

Feed value

Of the many parameters measured in forages to assess their feed value, this review focuses on protein (CP), digestibility, minerals, and intake, which affect animal performance. Secondary compounds like condensed tannins (CT) and lectins in cratylia are also discussed. In most cases the plant part used in evaluation trials with animals is not specified and the material fed is referred to as cratylia forage, composed of leaf and fine edible stems.

Crude protein and digestibility

Crude protein and digestibility, as a proxy of energy, are quality parameters that are key in defining the feed value of a forage legume. Values reported for cratylia in comparison with other legume species are affected by accession, season, soil fertility, plant density and cutting management (Table 1). Where possible, we differentiate between species known to be adapted to acid soils (cratylia, *D. velutinum*, calliandra and flemingia) and those not adapted (*Cratylia mollis*, gliricidia, leucaena, and *Erythrina fusca*). The leaf protein concentration from different studies falls mostly in the range of 15–20%, values that are similar to those of other woody legumes, including leucaena, gliricidia, flemingia and calliandra (Perdomo 1991; Lascano 1996; Flores et al. 1998; Yi Kexian et al. 1998; Suárez Salazar et al. 2008; Peters et al. 2009; Zhou Hanlin et al. 2011). Soil fertility can affect protein concentration of cratylia, possibly related to a dilution effect due to differences in plant growth (Tiemann et al. 2009a).

Cratylia can be classified as having moderate digestibility (range 45–55%), associated with high fiber concentration (Lascano 1996; Andersson et al. 2006), but not with CT (Lascano 1996; Yi Kexian et al. 1998; Stürm et al. 2007). Fiber (NDF) values in cratylia range from 40 to 60% and as with digestibility are affected by accession, season and soil fertility (Fässler and Lascano 1995; Hess et al. 2004; Andersson et al. 2006; Tiemann et al. 2009a; Álvarez Carrillo et al. 2022).

Variability in crude protein and digestibility among accessions of cratylia was found in few studies (Lascano 1996; Andersson et al. 2006; Peters et al. 2009; Castillo-Gallegos et al. 2013). However, the extent to which variability affects intake and animal performance is not known and may not be significant. These results suggest that plant attributes, including leafiness, regrowth capacity, forage and seed yield, and environmental conditions, including soil fertility and length of dry season, may be more important than forage quality parameters in the selection of cratylia accessions for a given location.

Planting density does not affect quality of cratylia (Table 1) and forage maturity only has small effects on protein concentration and digestibility, similar to most tropical legumes in comparison with grasses (Franco et al. 1998; Santana and Medina 2005; Pasquier Flores and Rojas Vallecillo 2006; Reyes Sánchez et al. 2007; Lugo-Soto et al. 2009).

Table 1. Overview of crude protein (CP) and in vitro dry matter digestibility (IVDMD) values of *Cratylia argentea* in comparison with other shrub legumes as affected by season, soil fertility and management.

Country, region/site	Study	Values	Reference
Brazil, Mato Grosso do Sul (Campo Grande)	Quality of shrub legumes in wet and dry season (selection)	*C. argentea* Wet: CP 20.9%: IVDMD 48.0% Dry: CP 20.3%; IVDMD 47.9% *G. sepium* Wet: CP 20.3%; IVDMD 49.1% Dry: CP 20.9%; IVDMD 48.1% *L. leucocephala* Wet: CP 19.9%; IVDMD 44.2% Dry: CP 20.0%; IVDMD 44.7%	Gama et al. (2009)
China, Hainan (Danzhou)	Quality of shrub legumes adapted and not adapted to acid soils (selection)	*C. argentea* CP 18.4%; IVDMD 66.2% F. macrophylla CP 14.2%; IVDMD 43.0% *L. leucocephala* CP 18.2%; IVDMD 60.7%	Zhou Hanlin et al. (2011)
Colombia, Cauca (CIAT-Quilichao, Q) and Meta (Carimagua, C)	Quality comparison among 10 cratylia accessions at 2 acid-soil sites	Means: Q: CP 24.2%; IVDMD 58.4% C: CP 18.6%; IVDMD 52.7%	Lascano (1996)
Colombia, Cauca (CIAT-Quilichao)	Comparison of the quality of cratylia with 2 shrub legumes adapted to acid soils	*C. argentea* CP 21.1%; IVDMD 48.4% *D. velutinum* CP 20.8%; IVDMD 55.4% *F. macrophylla* CP 17.9%; IVDMD 22.9%	Yi Kexian et al. (1998)
Colombia, Antioquia (Bajo Cauca)	Effect of cutting frequency and height on quality of cratylia	Range of both effects: CP 19.1–21.0 Digestibility in situ: 58.9–68.6% Ranges: Wet: CP 18.4–22.2% Dry: CP 20.4–23.7% Wet: IVDMD 58.9–69.0% Dry: IVDMD 62.0–68.3%	Santana and Medina (2005)
Colombia, Cauca (CIAT-Quilichao)	Quality comparison among 38 cratylia accessions in wet and dry season	*C. argentea* F: CP 15.0%; IVDMD 26.7% R: CP 17.8%; IVDMD 35.3% *G. sepium* F: CP 18.2%; IVDMD 43.3% R: CP 22.4%; IVDMD 46.94% *Erythrina fusca* F: CP 15.8; IVDMD 21.6% R: CP 16.8; IVDMD 26.9%	Andersson et al. (2006)
Colombia, Caquetá (Amazon piedmont)	Quality of cratylia in comparison with other tree legumes in 2 topographies [flat (F) and rolling hills (R)]	*C. argentea* CP 17.7%; IVDMD 56.1% *Piptocoma discolor* CP 13.1%; IVDMD 55.6%	Suárez Salazar et al. (2008)

Continue

Country, region/site	Study	Values	Reference
Colombia, Caquetá (Amazon piedmont)	Quality of cratylia in comparison with a native non-timber species consumed by cattle in secondary forest	*C. argentea* (range) Wet: CP 22.5–28.6%; IVDMD 55–71% Dry: CP 24.7–30.8%; IVDMD 65–71% *C. mollis* (mean) Wet: CP 20.1%; IVDMD 63% Dry: CP 20.1%; IVDMD 59%	Álvarez Carrillo et al. (2022)
Colombia, Cauca (CIAT-Quilichao)	Quality of 8-wk old cratylia forage in wet and dry season; 11 'Yapacaní' and 6 shrub morphotype accessions, and 2 *C. mollis* accessions	*C. argentea* (range) Wet: CP 22.5–28.6%; IVDMD 55–71% Dry: CP 24.7–30.8%; IVDMD 65–71% *C. mollis* (mean) Wet: CP 20.1%; IVDMD 63% Dry: CP 20.1%; IVDMD 59%	Peters et al. (2009)
Colombia, Valle (CIAT-Palmira) and Meta ('Altillanura')	Protein of cratylia grown in fertile (Mollisol) and acid infertile (Oxisol) soil, in wet and dry season	Mollisol: Wet: CP 18.2% Dry: CP 16.9% Oxisol: Wet: CP 26.8% Dry: CP 26.9%	Tiemann et al. (2009a)
Costa Rica, Cartago, (Turrialba)	Quality of shrub legumes adapted and not adapted to acid soils (selection)	*C. argentea* CP 23.8%; IVDMD 51.5% *C. calothyrsus* CP 30.3%; IVDMD 34.0% *L. leucocephala* CP 24.5%; IVDMD 51.1%	Flores et al. (1998)
Costa Rica, Cartago (Turrialba)	Effect of regrowth age on quality of cratylia	Range of regrowth effect: CP 20.8–22.8%; IVDMD 51.9–53.4%	Franco et al. (1998)
Mexico, Veracruz (Atzalan)	Comparison among 4 cratylia accessions	Means: CP 19.1% (SE 0.7) In situ rate of degradation 0.0488/h (SE 0.019)	Castillo-Gallegos et al. (2013)
Nicaragua, Managua	Effect of plant density and cutting height on quality of cratylia CIAT 18668	Range of density effect: CP 20.1–21.1%; IVDMD 57.9–59.3% Range of height effect: CP 19.1–22.6%; IVDMD 56.6–60.8%	Pasquier Flores and Rojas Vallecillo (2006)
Nicaragua, Managua	Effect of plant density and cutting frequency on quality of cratylia cutlivar Veranera (means of 2 years)	Range of density effect: CP 18.6–20.8% IVDMD 54.8–59.6% Range of frequency effect: CP 18.5–21.9% IVDMD 54.7–60.5%	Reyes Sánchez et al. (2007)
Venezuela, Barinas (Pedraza)	Effect of regrowth age on protein of cratylia	Range of regrowth effect: CP 18.4–21.9%	Lugo-Soto et al. (2009)

Minerals

Phosphorus (P) is the most limiting mineral in tropical grasses and the most expensive to supplement. In acid-soil savannas of eastern Venezuela, the level of P in cratylia averaged 0.34% and 0.19% in the wet and dry season, respectively (Rodríguez and Guevara 2002), while for the rainforest biome in Pucallpa, Peru, Medina Dávila (2021) reported no difference between seasons (average 0.34%). In a well-drained site of the eastern plains of Colombia, P concentration in cratylia was on average 0.19% across seasons and fertilizer treatments (Tiemann et al. 2009a). Results summarized by Corpoica (2017) showed that P levels in cratylia for 3 accessions evaluated also in the eastern plains of Colombia ranged from 0.17 to 0.28% (Taluma experimental station) and 0.12–0.19% (Carimagua experimental station). In the Amazon piedmont of Colombia (Caquetá department), a region that lacks a pronounced dry season, P averaged 0.33% (Suarez Salazar et al. 2008). For plants growing on an infertile Inceptisol at a hillside site in Cauca, Colombia, Cobo et al. (2002) reported 0.15% P concentration in cratylia. Considering the results of Little (1980) that 0.12% P in the forage of a tropical legume (*Stylosanthes humilis*) can sustain adequate growth of cattle, it is inferred that P concentrations in cratylia grown in different locations with contrasting soil fertility are adequate to sustain animal growth.

Other minerals measured in cratylia forage grown on both fertile and infertile soils are in the range of: Mg 0.1–0.7%; K 1.7–3.5%; S 0.16–0.41% and Ca 0.43–1.63% (Medina Dávila 2021; Cobo et al. 2002; Corpoica 2017). These values are in agreement with those of tropical legumes in general (Harricharan et al. 1988). Concentrations of micronutrients in cratylia are reported by Gomes et al. (2015) and Corpoica (2017). These results indicate that mineral concentrations in cratylia are similar to other tropical legumes and can sustain livestock requirements in different locations when grown on soils of contrasting fertility.

Acceptability and voluntary intake

Among the factors known to influence voluntary intake by ruminant animals are those dependent on plant attributes (plant part, chemical composition, secondary compounds), season, and those related to the animal (species, age, size, physiological state). In this section we review studies aimed at defining how acceptability/intake of cratylia compares with other shrub legumes when fed fresh, wilted or sun dried at different maturity stages (Table 2).

Acceptability/intake of shrub legumes seems to be less affected by animal species than by plant species, which in turn is related to quality factors such as digestibility and CT. This was shown by the study of Yi Kexian et al. (1998) where both sheep and goats consumed more cratylia and *D. velutinum* than flemingia, which has high levels of CT and low digestibility (Perdomo 1991; Pereira et al. 2018). In other studies, intake of cratylia in mixture with grasses was similar to intake recorded for leucaena but higher than intake of calliandra (Rodríguez et al. 2015) or *Codariocalyx* (Celis et al. 2004).

Acceptability of cratylia measured as short-term intake was low with immature (3-mo regrowth) forage fed fresh to sheep, but increased by twofold when the forage was wilted (48 h) or sun dried, regardless of age or previous experience of animals (Raaflaub and Lascano 1995). Ibrahim et al. (2001) reported a 32% increase in intake of cratylia (4-mo regrowth) when the forage was wilted under shade for 16 h and fed to crossbred heifers. The higher intake of wilted or dried immature cratylia forage can be the result of increased DM concentration or partial or complete loss of volatile compounds during wilting or drying. However, greater acceptability of dried forage could also be associated with previous experience of animals. Raaflaub and Lascano (1995) found that differences in intake rate between fresh and dried cratylia forage were greater when animals had been previously exposed to the legume. A similar observation was made in the Zona da Mata region of Minas Gerais, where grazing cows only consumed cratylia in the rainy season after being subjected to a period of adaptation (Xavier et al. 1995). Wilting fresh legume forage, however, does not always contribute to increased forage intake. For example, Palmer and Schlink (1992) found that intake of calliandra was 59% higher when fed fresh than wilted. The difference was attributed to the negative effect of CT on intake of wilted calliandra, which does not seem to be the case with cratylia with undetectable levels of CT, as will be discussed below. The role of other secondary compounds like lectins, possibly present in cratylia, on intake of fresh, wilted and dried forage is not known.

Table 2. Overview of intake of *Cratylia argentea* fed to small ruminants and cattle in different forms and levels.

Country, region/site	Study	Results[1,2]	Reference
Brazil, Minas Gerais (Zona da Mata)	Intake of cratylia fed to sheep housed in metabolism crates and offered leaf + stem of 2-mo regrowth	Intake (g DM/kg $BW^{0.75}$/day)[3] 46.0	Aroeira and Xavier (1991)
Brazil, Pará, (Belém)	Effect of incremental levels of inclusion of cratylia on DM intake by sheep fed *Urochloa humidicola* and housed in metabolism crates	Intake of DM/day (% of BW) 25% cratylia: 1.76b 50% cratylia: 1.96a 75% cratylia: 1.89ab 100% cratylia: 1.31c	Santos (2007)
Colombia, Cauca (CIAT-Quilichao)	Effect of plant maturity (immature vs. mature) and forage processing on short-term intake of cratylia forage offered to confined sheep	Intake (g DM/h/animal) Immature Fresh: 84b Wilted (24 h): 157a Wilted (48 h): 183a Sun-dried: 160a Mature Fresh: 291 Wilted: 376 Sun-dried: 359	Raaflaub and Lascano (1995)
Colombia, Cauca (CIAT-Quilichao)	Short-term (½ hour AM and ½ hour PM) intake by confined sheep and goats housed in metabolism crates, of fresh forage (6–8 mo regrowth) of cratylia in comparison with 2 other shrub legumes	Intake (g DM/kg $BW^{0.75}$/day)[3] *C. argentea* Goats: 4.12; sheep: 3.81; mean: 3.97a *D. velutinum* Goats: 4.21; sheep: 2.99; mean: 3.60a *F. macrophylla* Goats: 3.08; sheep: 2.09; mean: 3.06b	Yi Kexian et al. (1998)
Colombia, Valle (Corpoica-Palmira)	Intake of cratylia by sheep housed in metabolism crates, in comparison with 2 other woody species	Intake (g DM/kg BW/day) *C. argentea*: 16.3b *C. gyroides*: 16.8b *Malvaviscus arboreus*: 23.2a	Celis et al. (2004)
Colombia, Cauca (CIAT-Quilichao)	Effect of level and frequency of feeding cratylia (AM only vs. AM and PM) on intake by confined sheep	Intake (g DM/kg BW/day) Feeding AM: 0.5% BW: 2.0c 1.0% BW: 3.1b Feeding AM and PM: 0.5% BW: 2.0c 1.0% BW: 3.6a	Quiñonez et al. (2004)
Costa Rica, Puntarenas (San Miguel de Barranca)	Effect of wilting of cratylia and addition of molasses on intake by heifers after 4 hours of confinement	Intake (g DM/100 kg BW/day) Without molasses: Fresh: 280 Wilted: 370 With molasses: Fresh: 400 Wilted: 430	Ibrahim et al. (2001)
Puerto Rico, Mayagüez	Intake of sun-dried cratylia by confined sheep in comparison with 2 legumes offered in a 50:50 hay mixture with guinea grass	Intake (grass + legume) (g DM/animal/day) *C. argentea*: 1,210a *C. calothyrsus*: 802b *L. leucocephala*: 1,214a	Rodríguez et al. (2015)

[1]Results followed by different letters differ significantly ($P<0.05$).
[2]Units for intake vary by experiment.
[3]Metabolic weight.

The effects of level and frequency of feeding cratylia to sheep in metabolism crates were evaluated by Quiñonez et al. (2004), who showed that frequency of feeding at a low level (0.5% of body weight, BW) had no effect on intake of cratylia. However, when a higher level (1% of BW) of cratylia was offered, more frequent feeding (AM + PM) resulted in greater intake than feeding only once a day. The level or frequency of feeding cratylia had no effect on digestibility, while N retention was greater when sheep were given forage-based supplements at the higher level and twice a day (Quiñonez et al. 2004).

Results from reviewed studies suggest that, in cut-and-carry systems, the need for wilting or drying immature forage of cratylia would not impose a major constraint to its utilization. However, under grazing use of cratylia as a protein bank or in association with a grass would require that animals, particularly in the wet season, be previously exposed to cratylia to ensure that it is well consumed. Results also showed that frequency and level of supplementation affect intake of cratylia when offered as a supplement in a cut-and-carry system.

Secondary compounds

A major secondary compound in some temperate and tropical legumes are CT, which in cratylia forage are absent or occur only at very low levels (Perdomo 1991; Celis et al. 2004; Stürm et al. 2007) when measured with the Butanol-HCl assay that separates extractable and bound CT (Terrill et al. 1992). Nevertheless, in some studies cratylia has been included as a tannin-rich legume, mainly to evaluate its effect on reducing enteric methane production or controlling gastrointestinal parasites.

Condensed tannins and rumen fermentation. In Brazil, in a study to evaluate the effect of 10 tannin-rich tropical legumes, including cratylia, on suppressing in vitro methane production, Fagundes et al. (2020) found that among the 5 shrub legumes tested only leucaena significantly suppressed rumen methanogenesis. Other studies confirm that shrub legumes high in CT like flemingia suppress methane production as compared to cratylia (Tiemann et al. 2009b; Aragadvay-Yungan et al. 2021). Hess et al. (2004) reported that cratylia can improve body protein retention but does not suppress absolute enteric methane release in vitro or in vivo.

When studying the effect of CT on in vitro ruminal fermentation of various low-tannin and high-tannin legumes, Stürm et al. (2007) found that CT concentrations measured with the Butanol-HCl assay in 4 different shrub legumes ranged from nil in cratylia to 260 g/kg DM in calliandra while fermentation parameters (in vitro DM digestibility, gas production, concentration of volatile fatty acids) were higher in cratylia than in the other legumes. The addition of CT-inactivating polyethylene glycol (PEG) (Decandia et al. 2000) had no effect in rumen fermentation parameters with cratylia in contrast to what was observed with the tanniniferous legumes, calliandra, flemingia and leucaena, evaluated in the study. Similarly, Fagundes et al. (2020) confirmed that cratylia did not suppress in vitro methane production as was the case with leucaena.

Condensed tannins and gastrointestinal parasites. As CT-containing legumes are known to have potential in controlling gastrointestinal (GI) nematodes in ruminants, von Son-de Fernex et al. (2012) carried out an in vitro study with 5 tropical legumes including 3 cratylia accessions (*C. argentea* cultivar 'Veranera' (Veranera), CIAT 22386 and the 'Yapacaní' morphotype CIAT 22397 (Yapacaní) to assess their effect on the GI nematode, *Haemonchus contortus*. Results showed differences among cratylia accessions regarding larval exsheathment and larval migration inhibition that were attributed to CT. The activity of cratylia extracts on parasites was blocked after addition of PEG, which is considered proof of prevention of tannins/phenolic compounds binding to proteins (Decandia et al. 2000).

In Brazil, Silva et al. (2018) carried out an in vivo trial with sheep to assess the effect of feeding cratylia on GI parasites. Crossbred lambs were fed cratylia, cratylia + grass (*Urochloa* species) or grass only. Animals fed cratylia had a lower average number of eggs per gram of feces, the average count being 10 times lower than that in the control. The authors concluded that both protein and tannin consumption from cratylia in a protein bank may have influenced the host's ability to control endoparasites.

The positive response of cratylia in controlling GI parasites suggests that secondary compounds with CT-type properties are present in this legume but are not detected with the Butanol-HCl assay. CTs are heterogeneous phenolic compounds with different monomer composition and molecular weights. Most plant CTs (anthocyanins) are composed of cyanidin, delphinidin, and pelargonidin monomer units (Mueller-Harvey 2006). Studies to define the antioxidant and biological activity of monomer units in CT showed that delphinidin had the strongest activity followed by cyanidin and pelargonidin (Quijada et al. 2015; Koss-Mikołajczyk and Bartoszek 2023). In Brazil, Pereira et al. (2018) characterized CT in tropical forage legumes and found that only pelargonidin was present in cratylia. Thus, future studies should assess the role of pelargonidin in parasite control.

Lectins and gastrointestinal parasites. Early studies reported the presence of a lectin in seeds of cratylia (Moreira et al. 1984; Oliveira et al. 2004). An in vitro study showed that cratylia extracts obtained from pods/ground seeds had the potential to control young stages of GI nematodes (Silva et al. 2017). Lectins are plant secondary metabolites, which bind carbohydrates and have been reported to control GI parasites through disrupting the development of parasitic larvae. This property was shown in vitro with plant extracts of gliricidia and leucaena (Ríos-de Alvarez et al. 2012). Including PEG and fetuin, which are CT and lectin inhibitors, respectively, partially reversed the anthelmintic activity of extracts of the 2 legumes. In this study, however, fetuin was more potent than PEG in inhibiting the anti-larval effects of extracts of gliricidia than of leucaena, suggesting that in the former the anthelmintic activity could be mainly due to lectins and not CT. We postulate that this could also be the case with cratylia and suggest that plant extracts of cratylia accessions should be screened for type of lectins present, and in vitro anthelmintic properties need to be validated through in vivo studies.

Utilization in livestock production systems

Tropical pastures are characterized by marked seasonal fluctuations in quantity and quality of forage biomass. In grasses, a reduction in protein concentration and digestibility, and an increase in the cell wall component are common during the dry season, causing decreased intake and weight loss or reduced milk yield. Under these circumstances, supplementation with a drought-tolerant shrub legume like cratylia is an option.

Consequently, cratylia, as a high protein forage legume, is frequently used in protein banks (pure stands) for cut-and-carry or grazing with controlled access or in association with grasses for direct grazing. It is recommended for use as a fresh or ensiled forage/feed supplement for cattle and small ruminants, poultry and swine or for strategic feeding mainly during periods of forage scarcity, mostly in dry seasons, but in the humid tropics also during periods of excessive rains. A concrete example of strategic use of a cratylia protein bank in the subhumid tropics was the suggestion to cut forage for conservation as silage in the rainy season and feed as fresh forage in the dry season (Lobo and Acuña 2004) (Figure 1).

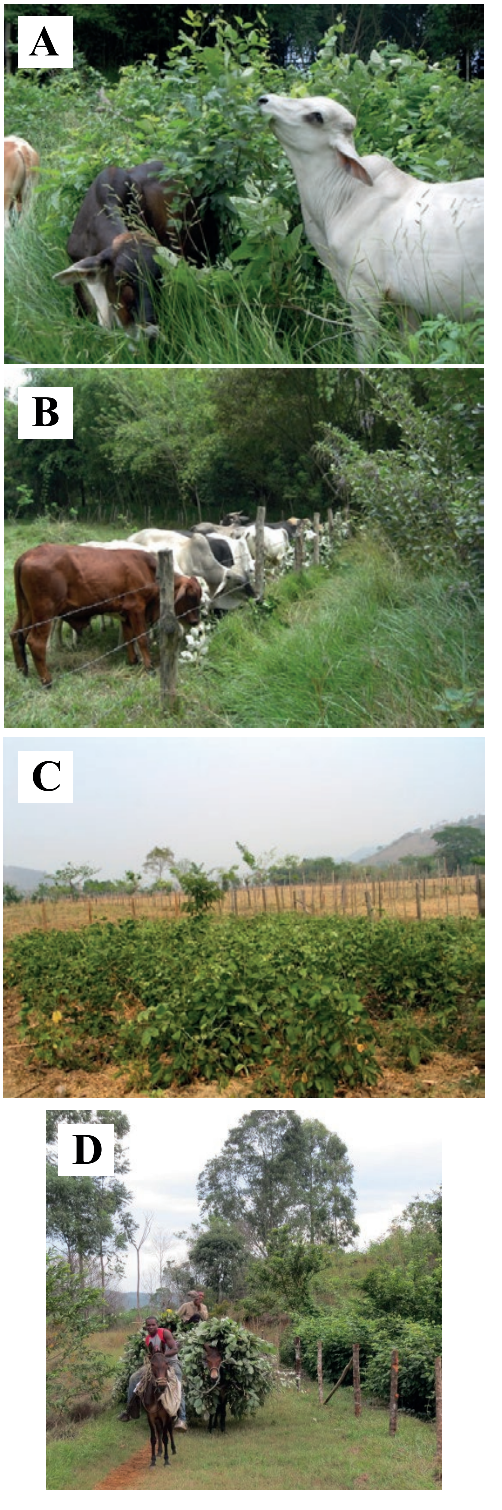

Figure 1. Utilization of *Cratylia argentea*. (A) Steers browsing cratylia in a *Urochloa humidicola* pasture, Valle del Cauca, Colombia (Photograph: R. Schultze-Kraft); (B) Steers in a *U. humidicola* pasture feeding on cut cratylia branches, Valle del Cauca, Colombia (Photograph. R. Schultze-Kraft); (C) Young protein bank in dry season, Danlí, El Paraíso, Honduras (Photograph: R. Schultze Kraft); (D) Cut-and-carry, Patía, Cauca, Colombia (Photograph: B. Hincapié, CIAT).

Silage production and utilization for milking cows

Results of research on silage production and on-station and on-farm trials conducted to evaluate cratylia as a protein supplement for cattle, small ruminants, and other animal species, for forage intake, milk yield and liveweight gain are presented. Use of silage for dry season feeding and as an alternative to replace concentrates or crop by-products is considered an alternative for dual-purpose cattle production systems. However, it is recognized that ensiling legumes presents difficulties due to their high buffering capacity and low concentration of water-soluble carbohydrates (WSC). In a study in Colombia, Correa Pinzón and Niño-Mariño Mariño (2010) found that the protein concentration in cratylia silage (15.8%) was lower than that of fresh forage (19.3%) or cratylia hay (19.2%), possibly related to proteolysis known to occur in silage stored at high temperatures (Aloba et al. 2022).

Lactic acid bacteria inoculation together with addition of a fermentable carbohydrate source has proven useful for promoting favorable fermentation in forage species including tropical legumes (Oliveira et al. 2017). This was confirmed for cratylia in a laboratory study with 10 legume species, where Heinritz et al. (2012) found a low concentration of WSC (34.8 g/kg DM), similar to that of other shrub legumes like flemingia and *L. diversifolia*. After addition of sucrose (20 g/kg of fresh forage) to the material being ensiled and inoculation with a *Lactobacillus* strain, cratylia and the other legumes could be ensiled satisfactorily. The inoculation with *Lactobacillus* in combination with WSC reduced protein losses by ammonia-N formation through rapid acidification. Similarly, Jiménez et al. (2004) obtained satisfactory lactic acid fermentation with the addition of 10% molasses to chopped cratylia, resulting in good quality silage. They also found that adding 25% chopped sugarcane as an alternative source of WSC was adequate to prevent alcoholic fermentation.

Another role of cratylia is to improve the quality of grass silage. By adding 30–45% of cratylia, López Monroy (2014) raised the protein concentration of Napier grass [*Cenchrus purpureus* (formerly *Pennisetum purpureum*)]/sugarcane silage from 5.0 to 8.8–10.8%. Romero and González (2004) found that a 3-month regrowth of cratylia resulted in good quality silage when mixed in a proportion of 65% sugarcane and 35% cratylia.

Utilization of cratylia silage as a supplement has been evaluated on station and on farm in dual-purpose cattle systems, mainly in Central America. Resulting milk yields vary depending on the milking potential of cows. In Nicaragua, Sánchez and Ledin (2006) supplemented medium-producing (7–9 kg/day) milking cows that were fed sorghum silage and found that, when adding 2 or 3 kg of molasses-sprayed fresh cratylia to the silage, DM intake increased by 18 and 32%, respectively. While milk production increased on average by 59% with the addition of cratylia, the concentrations of milk fat, total solids, protein, and organoleptic characteristics (smell, taste, and color) were not different among diets. In contrast, Laguna-Gámez (2018) found no effect on milk yield when ensiled cratylia was added to a Taiwan grass (*Cenchrus purpureus*) diet of low-producing (4 kg/day) cows in Nicaragua, but milk fat increased from 3.6 to 4.0%.

In trials in Costa Rica, Argel et al. (2000) on farm and Romero and González (2004) on station reported that ensiled cratylia successfully replaced concentrate and chicken manure as a protein supplement fed to milking cows. Although feeding cratylia silage had no effect on milk yield, milk fat concentration was increased. At farm level, the benefit:cost ratio of feeding ensiled cratylia was lower than when feeding fresh cratylia, due to high labor costs (Argel et al. 2000). However, an advantage of ensiling cratylia is that forage produced in the wet season can be conserved for dry season feeding.

In general, results reviewed indicate that cratylia can enhance quality of grass silage, economically replace concentrates and, when ensiled and supplemented in cow diets, has variable results on milk yield and composition.

Supplementation and intake

In view of the generally low protein concentration in tropical grasses, particularly during the dry season, and subsequent low forage intake by animals, several studies assessed the effect of supplementing low-quality grass diets with high protein cratylia on forage intake by ruminant animals (Table 3).

Supplementing cratylia to sheep fed a low-quality grass diet showed that total DM intake was not affected when cratylia was offered alone or in mixture with flemingia, a high-tannin shrub legume (Fässler and Lascano 1995). However, urinary N loss was reduced with increased intake of the legume mixture, suggesting less rumen ammonia losses due to protection by CT in flemingia. Other results show that supplementation of low-quality grasses with cratylia in different proportions significantly increased total DM intake, protein intake, NH_4-N in the rumen, flow of total and bacterial N to the duodenum, and apparent absorption of N in the lower gastrointestinal tract, resulting in increased protein retention (Wilson and Lascano 1997; Hess et al. 2004; González-Arcia et al. 2018). In contrast, including cratylia to replace a high-quality grass like *Cynodon dactylon* cultivar 'Tifton 85' in finishing lamb diets did not influence weight gain, dry matter intake, dry matter digestibility, feed efficiency and nitrogen balance (Teixeira et al. 2023).

In most studies reviewed, supplementation with cratylia resulted in substituting the basal grass diet (Fässler and Lascano 1995; Wilson and Lascano 1997; González-Arcia et al. 2018) and decreased – or had no effect on – digestibility of the total diet due to high concentration of indigestible fiber.

Animal production – ruminants

This section summarizes results of studies carried out to measure milk yield (Table 4) and liveweight gain (Table 5) of cattle supplemented with cratylia, either in pens or under grazing.

Milk production. Milk production in most tropical regions is characterized by low yields due to poor quality and low availability of grasses in pastures, particularly in the dry season. In addition, cows used in dual-purpose production systems (milk and meat) have generally low genetic potential with limited response to increased quality of the pasture and supplementation with forage legumes (Lascano and Ávila 1993).

In an on-farm study carried out in Nicaragua, milk yield was quantified with cows supplemented with cratylia (5 kg) + sugarcane (15 kg) offered after milking. Although results were not statistically different due to large variation between animals, a trend was observed where cows supplemented produced 22% and 32% more milk than un-supplemented cows, in the wet and dry seasons, respectively (Morales Lara and Herrera Maradiaga 2009).

Table 3. Overview of intake of *Cratylia argentea* fed to small ruminants and cattle in different forms and levels.

Country, region/site	Study	Results[1,2]	Reference
Colombia, Cauca (CIAT-Quilichao)	Intake by sheep fed a low-quality grass (*U. humidicola* cultivar 'Llanero' with CP 5.1%) supplemented with cratylia (51%), cratylia (37%) + flemingia (10%) or cratylia (26%) + flemingia (19%)	Intake (g DM/animal/day) Grass alone: 457 Grass + cratylia: 476 Grass + cratylia + low flemingia: 510 Grass + cratylia + high flemingia 511	Fässler and Lascano (1995)
Colombia, Cauca (CIAT-Quilichao)	Intake by sheep fed a low-quality grass hay (*U. humidicola* cultivar 'Llanero' with CP 6.9%) supplemented with incremental additions of cratylia	Intake (g DM/kg BW/day) Grass alone: 21.6c Grass + 10% cratylia: 23.5ab Grass + 20% cratylia: 24.7a Grass + 40% cratylia: 25.5a	Wilson and Lascano (1997)
Colombia, Cauca (CIAT-Quilichao)	Intake by sheep fed a low-quality grass (*U. humidicola* cultivar 'Llanero' with CP 3.9%) supplemented with different levels of cratylia (+ concentrate)	Intake (g DM/kg $BW^{0.75}$/day)[3] Grass alone: 70.0 Grass + 33% cratylia: 74.1 Grass + 66% cratylia: 76.8	Hess et al. (2004)
Mexico, Veracruz (Atzalan)	Intake by bullocks fed a low-quality grass (*U. arrecta* with CP 6.2%) supplemented with incremental additions of cratylia	Intake (g DM/kg $BW^{0.75}$/day)[3] Grass alone: 113.7 Grass + 15% cratylia: 124.4 Grass + 30% cratylia: 145.0 Grass + 45% cratylia: 149.4	González-Arcia et al. (2018)
Brazil, Minas Gerais (Central)	Intake by lambs supplemented with different levels of cratylia hay to replace hay (*Cynodon dactylon* cultivar 'Tifton 85' with CP 18%)	Intake (kg DM/animal/day) Grass alone: 1.4 20% cratylia: 1.4 40% cratylia: 1.3 100% cratylia: 1.5	Teixeira et al. (2023)

[1]Results followed by different letters differ significantly ($P<0.05$).
[2]Units for intake vary by experiment.
[3]Metabolic weight.

Table 4. Overview of supplementation with *Cratylia argentea*: Effect on milk yield in different utilization systems.

Country, region/site	Study	Results[1,2]	Reference
Colombia, Cauca (CIAT-Quilichao)	Controlled access of cows grazing *Urochloa decumbens* to a protein bank of immature or mature cratylia	Immature cratylia: Grass only: 10.0 Grass + legume: 9.8 Mature cratylia: Grass only: 10.5 Grass + legume: 10.4	Aparicio et al. (2002)
Colombia, Cauca (CIAT-Quilichao)	Cows supplemented with cratylia (1.5% of BW) in a cut-and-carry system or with access to a *U. decumbens* - cratylia association (dry season)	Grass only (control): 6.1b Supplemented: Cut-and-carry: 6.7b Direct grazing: 7.5a	Lascano et al. (2004)
Costa Rica, Puntarenas (San Miguel de Barranca)	Effect of feeding cratylia (1 kg DM/100 kg BW) to cows grazing *Hyparrhenia rufa* supplemented with molasses (0.5 kg/cow) in the wet season	Without cratylia: 5.9 With cratylia: 5.8	Franco Valencia (1997)
Costa Rica, Alajuela (Atenas)	Milk yield of cows fed cratylia (6 kg) ensiled or fresh, supplementing a basic diet of 12 kg sugarcane + 0.6 kg rice polishing	Basic diet + ensiled cratylia: 5.1b Basic diet + fresh cratylia: 5.5a Basic diet + chicken manure: 5.3a,b	Lobo and Acuña (2004)
Nicaragua, Managua	Milk yield resulting from incremental levels of cratylia to cows in confinement fed with sorghum silage	Without cratylia: 3.7 With cratylia (2 kg DM/d): 4.9 With cratylia (3 kg DM/d): 5.4	Sánchez and Ledin (2006)
Nicaragua, Región Autónoma del Atlántico Sur (Nueva Guinea)	Milk yield of cows supplemented with a 75:25 mixture of sugarcane and cratylia during the dry and wet seasons	Dry season: Control: 4.4 Supplemented: 5.8 Wet season: Control: 3.7 Supplemented: 4.5	Morales Lara and Herrera Maradiaga (2009)

[1]Results followed by different letters differ significantly ($P<0.05$); [2]kg/cow/day.

When cows grazed the low-quality grass, *Hyparrhenia rufa*, in the Pacific region of Costa Rica, supplementation during the dry season with fresh cratylia, and molasses, did not affect milk yield, but increased milk solids (Franco Valencia 1997). Also in Costa Rica, Ibrahim et al. (2004) reported that supplementing cratylia to cows grazing the same low-quality grass in the dry season replaced chicken manure and improved profitability per liter of milk produced.

One alternative for the utilization of shrub legumes is to allow milking cows to have controlled access to pure stands (protein banks). In Colombia, crossbred Zebu × Holstein cows grazing *U. decumbens* had access to an immature or a mature cratylia stand for 2 hours after milking (Aparicio et al. 2002). Although there was no difference in milk yield between the 2 groups, concentration of milk urea-N (MUN) was higher in cows with access to the immature (18.7 mg/dL) and mature (14.9 mg/dL) cratylia protein banks relative to the control (10.9 mg/dL). According to Jonker et al. (1998), these differences in MUN suggest an energy-to-protein imbalance in the rumen fermentation process of cows with access to the protein bank. At the same location, milk yield of cows was 23% higher in a period of low rainfall when cows had access to a *U. decumbens* pasture associated with cratylia as compared with the grass alone, or when cratylia was offered in a cut-and-carry system. No differences in milk yield were observed among treatments in the wet season (Lascano et al. 2004).

Milk yield response of supplementation with cratylia in cut-and-carry systems is variable and, as indicated previously, dependent on the genetic potential of cows (Lascano and Ávila 1993). However, the utility of cratylia as a supplement in tropical milking systems cannot be limited to increases in milk yield as shown in a study in the Andean piedmont of Colombia (Plazas and Lascano 2005). There, a total of 6.5 ha cratylia were established in 9 representative farms to supplement cows with fresh legume forage in the milking parlor. Milk yield per cow did not increase with the supplemented cratylia relative to no supplementation (6.4 vs. 6.8 kg/cow/day). However, other benefits of cratylia not contemplated by researchers were observed: (a) feeding cows with cratylia in the wetter part of the rainy season, when grazing in the pastures was limited due to excess rainfall and high soil moisture; (b) partial replacement of expensive commercial concentrates in the dry and wet seasons; and (c) improvement of body condition of cows for better reproduction.

For the same Andean piedmont region, an ex-ante simulation study on the benefits of using cratylia in form of cut-and-carry showed that cost of producing milk was reduced by 13, 7 and 11% when fed fresh alone, with the addition of molasses or in combination with Napier grass, respectively (Holmann et al. 2002). Utilizing cratylia under grazing in association with grass (2,500 plants cratylia/ha re-established every 5 years) resulted in the greatest cost reduction (19%) in milk production. It had an additional benefit of freeing 18–25% of land under pastures for other uses, indicating that when livestock numbers remain unchanged, there was an increase in carrying capacity of the farm with the introduction of cratylia.

Liveweight gain. In a dual-purpose cattle system in Colombia, pre-weaned calves in a 7-month period gained 16% more weight on a grass pasture (*Urochloa* hybrid cultivar 'Mulato') in association with cratylia than those grazing the grass alone but supplemented with a mixture of chicken manure + corn bran + sugarcane (Benavides-Calvache et al. 2010). The authors only indicate that cratylia was browsed but did not report on acceptance or frequency of browsing.

In the humid tropics of Mexico, daily weight gain of F1 Holstein × Zebu heifers was measured in 3 periods in pastures of *U. brizantha* cultivar 'Toledo' alone or in association with cratylia. Heifers on the pasture with cratylia gained on average 53% more weight than those on the grass alone pasture (Valles-de la Mora et al. 2017).

In the Andean piedmont of Colombia, Rincón (2005) evaluated a fattening system of steers that combined grazing and feeding a mixture of cratylia with sugarcane in confinement (3 PM to 8 AM of the following day). Results showed that LWG of both Zebu steers and cross-bred steers were very low, possibly due to low intake of the supplement by animals in partial confinement.

Table 5. Overview of supplementation with *Cratylia argentea*: Effect on liveweight gain (LWG).

Country, region/site	Study	Results[1]	Reference
Colombia, Meta (Andean piedmont)	Performance of Zebu and cross-bred steers grazing *U. decumbens* vs. grazing from 8 AM to 3 PM and supplemented in a corral from 3 PM to 8 AM with sugarcane (5 kg/steer) + cratylia (3 kg/steer)	LWG (g/animal/day) Control (grazing without supplementation): Zebu: 522 Cross-bred: 637 Limited grazing with supplementation: Zebu: 78 Cross-bred: 125	Rincón (2005)
Colombia, Meta (Andean piedmont)	Supplementation of Zebu and cross-bred steers grazing *U. decumbens* with sugarcane (5 kg/steer) + cratylia (3 kg/steer)	LWG (kg/ha) Control (without supplementation): Zebu: 498 Crossbred: 630 With supplementation: Zebu: 1,239 Crossbred: 1,171	Rincón (2005)
Colombia, Meta (Andean piedmont)	Supplementation of heifers grazing *U. decumbens* + *U. brizantha* cultivar 'Toledo' with cratylia (30%) + sugar cane (70%) silage or grazing only grass	LWG (g/animal/day) Grazing: 603 Grazing + silage supplement: 765	Corpoica (2017)
Colombia, Caldas (Anserma)	LWG of pre-weaned calves grazing *Urochloa* hybrid cultivar 'Mulato'; comparison of a conventional supplement with cratylia	LWG (kg/calf/7 months) Conventional supplement: 59.1 Cratylia: 68.7	Benavides-Calvache et al. (2010)
Mexico, Veracruz (Atzalan)	LWG of heifers grazing an association of *U. brizantha* cultivar 'Toledo' and cratylia	LWG (g/animal/day; average of 3 periods) Control (grass only): 400 Grass + cratylia: 610	Valles-de la Mora et al. (2017)

[1]Units for live weight gain vary by experiment.

In a second experiment, steers grazed only *U. decumbens* grass or were supplemented in the pasture with the same mixture of cratylia and sugarcane fed to confined animals (Rincón 2005). Daily LWG of steers did not differ between animals supplemented in the pasture with sugarcane + cratylia (660 g) and those not supplemented (618 g). In this study the advantage of supplementing cratylia with sugarcane was in terms of carrying capacity, which was 2.5 times greater in the pasture where animals were supplemented (2 animals/ha vs. 5 animals/ha). The economic analysis performed indicated that supplementation of grazing animals with cratylia + sugarcane resulted in twice the profitability as compared to no supplementation, even though animals substituted the less expensive grass in the pasture with the cratylia + sugarcane supplement.

In a third experiment in the same region, heifers grazing an *Urochloa*-based pasture were supplemented with cratylia/sugar cane silage silage and gained 27% more weight than those not supplemented. A major advantage of supplementation with cratylia/sugarcane silage was that carrying capacity of the pastures was increased from 1.4 animals/ha to 2.8 animals/ha (Corpoica 2017).

Results reported from Mexico and Colombia confirm that associations of cratylia with grasses are an economic alternative resulting in increased liveweight gain and milk yield. Results from the Andean piedmont of Colombia indicate that a major advantage of supplementing cratylia + sugarcane to grazing animals is in increasing carrying capacity of the pasture, which has significant economic implications. In addition, results suggest that fattening systems with confined animals should ensure adequate intake of the cratylia + sugarcane supplement.

Animal production – non-ruminants

Smallholder production systems aim at achieving economic impact by using forage legumes as alternatives to replace concentrate in poultry, swine and rabbit diets.

Poultry. In Puebla, Mexico, González-Martínez (2016) found that mature sun-dried, ground cratylia leaves (15.8% CP concentration) did not improve LWG of broilers raised in a backyard system, regardless of their proportion in a mixture with maize (5, 10 or 15%). In a study with penned broilers in Colombia, Silva Higuera et al. (2013) replaced protein in a balanced diet that contained animal protein (meat meal) with increasing levels of cratylia (0, 5, 10 and 15%). Results showed that LWG of animals was negatively affected (-10 to -20%) at all substitution levels. However, the authors conclude that a 5% inclusion of cratylia can be recommended given that feed conversion was similar to the control (2.8 vs. 3.2). From these few studies it can be inferred that cratylia forage may not be the preferred option to replace protein in the diet of growing broilers even at low levels, possibly related both to low protein quality in terms of essential amino acids and to high fiber concentration.

Swine. Pig rearing is a common smallholder livelihood activity in many tropical regions. However, in these systems poorly balanced pig diets, particularly low protein concentration, is a major cause of low growth rates and poor reproductive performance. The alternative of feeding pigs in smallholder systems with legumes is an option not as well researched in tropical America as it is in Southeast Asia (Stür et al. 2010). In Colombia, Sarria and Martens (2013) compared silages of 3 legumes (cratylia, *Clitoria ternatea* or *Centrosema brasilianum*) and a grass silage (*Urochloa* hybrid cultivar 'Mulato II') offered ad lib to growing pigs as supplements of a balanced diet. Intake of cratylia or *Clitoria ternatea* silages was 17% higher than grass silage and similar to a balanced diet with commercial concentrate. It was concluded that cratylia silage could be offered up to 500 g/kg of diet DM as a supplement to a commercial concentrate despite its high fiber concentration. Future studies should evaluate the substitution effect of cratylia fed fresh and ensiled in LWG of growing pigs.

Rabbits. For adequate growth, rabbits require diets with fiber, which, in traditional commercial systems, is supplied by alfalfa meal given its nutritional attributes. Câmara (2017) evaluated the feasibility of replacing alfalfa by cratylia leaf meal in Brazil. When feeding rabbits with either a balanced concentrate ration with 42% alfalfa or the concentrate ration where 20% cratylia leaves replaced alfalfa, the diet influenced neither intake nor LWG.

Strengths and weaknesses

Strengths and weaknesses of cratylia as livestock feed are:

Strengths

- High leaf+ fine stem protein concentration
- Increased milk yield of cows of medium to high genetic potential when associated with grasses
- Improved liveweight gain when associated with grasses
- Increased livestock carrying capacity of pastures when offered as a supplement
- Replacement of concentrates when offered fresh or as silage to milking cows
- Anthelmintic property when offered to sheep
- Absence or low concentrations of condensed tannins
- Suitability for cut-and-carry, grazing, silage, leaf meal
- Suitability for integrated agropastoral production systems

Weaknesses

- Labor requirements for forage harvest in cut and carry systems
- Low intake of fresh forage by animals not accustomed to the legume

Technology adoption

Lack of data on the actual use of cratylia through area planted, number of users or quantities of seed sold, impedes assessing the adoption and impact of this legume. Based on literature consulted and personal information obtained, we conclude that within the 20 years after the release of cratylia cultivars (in Costa Rica and Colombia), and in spite of promising on-farm experimental results the rate of adoption has probably been low.

Slow establishment and high labor requirements probably play a significant role in low adoption, along with lack of access to commercial quality seed at affordable prices. Low cratylia adoption is also the result of the technology being developed with a focus on tropical America. In this region, cattle production, regardless of farm size, is based traditionally on grasses with less management requirements than legumes. It is only now that, within the discussions related to sustainable intensification and environmental impact of agriculture, incentives and pressure may be starting to build to support the use of legumes (Schultze-Kraft et al. 2018). The potential of cratylia should be considered in regions with long dry seasons and acid, infertile soils where well-known shrub/tree legumes such as leucaena are not adapted.

Another explanation for the slow adoption of cratylia, could be that with the changes in research and development strategies in major research centers during past years, there are a lack of whom Shelton et al. (2005) called “champions” - motivated individuals, who interact with farmers and institutions and explore and promote the use of a new technology through participatory research.

Research suggestions

Although many of the suggested studies raised at the 1995 workshop (Pizarro and Coradin 1996) were carried out during the past 30 years, some have not yet been addressed and new research needs have been identified with the following considered as priority:

Feed value. Further evaluation of feeding mixtures of cratylia with other acid-soil adapted but high-CT legumes such as flemingia and calliandra for cattle should be done to improve overall feed intake, reduce enteric CH_4 production and N losses in urine. Existing interest could be pursued on deploying cratylia to control gastrointestinal parasites in ruminants to respond to the growing resistance of parasites to anthelmintic drugs and the control obtained by feeding legumes with CT and lectins. Even though seed extracts and forage from cratylia controlled parasites in sheep, the question remains if this control is associated with CT since only traces are measured using recommended chemical assays. Thus, accessions of cratylia should be screened for the monomer units that form the chemical structure of CT and for other secondary compounds like lectins.

Utilization in livestock production systems. Priority should be given to grazing management studies with cratylia as a protein bank and in agropastoral systems in association with grasses, because in many regions direct grazing of cratylia may be the preferred use of the legume by farmers, owing to labor costs involved in cut-and-carry systems. Future studies should also explore the use of cratylia as a feed resource in swine production in smallholder systems.

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(Note of the editors: All hyperlinks were verified 23 May 2024).

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Artículo Científico

Mejora del crecimiento de gramíneas asociadas a *Leucaena leucocephala* co-inoculada con un hongo micorrízico arbuscular y un aislado de rizobio

Growth improvement of grasses associated with Leucaena leucocephala *co-inoculated with an arbuscular mycorrhizal fungi and a rhizobia isolate*

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Resumen

El objetivo de este trabajo fue evaluar el efecto de la asociación de *Leucaena leucocephala*, y su co-inoculación con una cepa del hongo micorrízico arbuscular (HMA) *Claroideoglomus claroideum* y un aislado local de rizobio, sobre el comportamiento de las gramíneas asociadas (*Bouteloua gracilis*, *Bouteloua curtipendula* y *Setaria macrostachya*). Se estudiaron las estructuras micorrízicas y la nodulación. Se realizaron tres experimentos independientes, uno por cada gramínea, en asociación con *L. leucocephala* co-inoculada y sin inocular, o sola (como testigo). Los pastos asociados con *L. leucocephala* co-inoculada produjeron mayor cantidad de tallos que aquellos asociados con *L. leucocephala* sin inocular. *B. gracilis* y *B. curtipendula* acumularon mayor biomasa cuando se asoció con *L. leucocephala* co-inoculada. Las concentraciones de clorofilas *a*, *b* y totales en *S. macrostachya* y la de clorofila *b* en *B. gracilis* se vieron favorecidas por la asociación con *L. leucocephala*. La co-inoculación promovió el desarrollo de estructuras micorrízicas en la rizósfera y el número de nódulos en raíces de *L. leucocephala*, aunque el porcentaje de nódulos efectivos no reflejó diferencias entre tratamientos. En conclusión, la asociación de gramíneas con *L. leucocephala* y su inoculación con HMA y aislados de rizobios locales no solo promueve el desarrollo de estructuras micorrízicas y la nodulación, sino también aumenta el crecimiento y el contenido de pigmentos fotosintéticos en las gramíneas asociadas.

Palabras clave: Asociaciones leguminosas-gramíneas de clima semiárido, *Claroideoglomus claroideum*, bacterias fijadoras de nitrógeno, nodulación, estructuras micorrízicas, clorofilas.

Abstract

The objective of this study was to assess the effect of the association of *Leucaena leucocephala*, and its co-inoculation with a strain of the arbuscular mycorrhizal fungus (AMF) *Claroideoglomus claroideum* and a local isolate of rhizobium, on the performance of associated grasses (*Bouteloua gracilis*, *Bouteloua curtipendula* and *Setaria macrostachya*). The mycorrhizal structures and nodulation were also studied. Three independent experiments, one for each grass species, were grown in association with *L. leucocephala* co-inoculated and non-inoculated, or alone (control treatment). Grasses associated with co-inoculated *L. leucocephala* produced a greater number of stems than those associated with non- inoculated *L. leucocephala*. *B. gracilis* and *B. curtipendula* grown with co-inoculated *L. leucocephala*

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accumulated higher biomass. The concentration of chlorophylls *a*, *b* and total chlorophylls in *S. macrostachya* were favored by the association with *L. leucocephala*; whereas in *B. gracilis* such effect was only observed for chlorophyll *b*. Co-inoculation promoted the development of mycorrhizal structures in the rhizosphere and the number of nodules in roots of *L. leucocephala*, although the percentage of effective nodules did not reflect differences due to treatments. In conclusion, the association of grasses with *L. leucocephala* and its inoculation with AMF and local rhizobium isolates not only promotes the development of mycorrhizal structures and nodulation, but also increases growth and the content of photosynthetic pigments in the associated grasses.

Keywords: Mixtures of legumes and semiarid grasses, *Claroideoglomus claroideum*, mycorrhizal structures, nitrogen fixing bacteria, nodulation, chlorophylls.

Introducción

La dieta base para la producción bovina en condiciones tropicales, especialmente en la región latinoamericana, se compone principalmente de pastos y otras fuentes forrajeras (Aguilar et al. 2019; Urbina-Cruz et al. 2019), pero para lograr la rentabilidad en este tipo de sistemas es necesario obtener niveles de producción forrajera que garanticen cubrir las demandas nutricionales de los animales. En las áreas ganaderas del trópico predominan los pastos naturales e introducidos, en su mayoría gramíneas; sin embargo, se ha demostrado la importancia de promover en estas áreas el uso de leguminosas, principalmente las arbóreas como *L. leucocephala*, ya que permite al animal seleccionar una dieta más variada y de mejor calidad (Peniche-González et al. 2014; Ramírez-Avilés et al. 2019). Respuestas similares se han reportado en condiciones de zona templada (Ford et al. 2019).

La búsqueda de alternativas que reduzcan las aplicaciones de altas dosis de fertilizantes químicos y enmiendas orgánicas para aumentar la productividad de los pastos está siendo un tema clave de investigación, por el impacto negativo del uso excesivo de fertilizantes químicos en la contaminación de suelos y aguas subterráneas (Rodríguez-Eugenio et al. 2019). En este contexto, uno de los recursos biológicos que puede contribuir a mejorar los sistemas de producción ganadera basados en el uso de pasturas asociadas es el manejo eficiente de los microorganismos rizosféricos, aplicados en forma de inoculantes (González et al. 2017).

La fijación biológica de nitrógeno a través de la simbiosis rizobio-leguminosa tiene implicaciones económicas y ambientales directas, debido a la disminución en el uso de fertilizantes nitrogenados (Martínez-Viera y Dibut 2012), ya que en algunos casos la fijación simbiótica es capaz de abastecer hasta el 90% de las necesidades de nitrógeno de las plantas (López-Alcócer et al. 2020). Al establecer asociaciones entre ambos grupos de plantas, es posible incrementar la producción de biomasa y mejorar el contenido nutricional de la pradera (Guerra-Guzmán et al. 2021), constituyendo una alternativa para la sustitución de fertilizantes nitrogenados y la mejora de la dieta de los animales (Santos et al. 2011).

La aplicación de inoculantes a base de rizobios estimula la capacidad de fijación de nitrógeno atmosférico en las leguminosas y, en el caso de los cultivos forrajeros, puede contribuir significativamente a incrementar su potencial productivo y a mejorar el balance de este nutriente en los pastizales (Carvalho y Pires 2008; Guzmán y Montero 2021). Por otro lado, los hongos micorrízicos arbusculares (HMA) habitan de forma natural en la rizosfera en simbiosis con las plantas forrajeras y desempeñan un papel clave en la mejora de la capacidad de absorción de nutrientes y agua (Tao Zhang et al. 2012; Quiñones–Aguilar et al. 2019). En aquellos casos donde las comunidades residentes de HMA no son capaces de establecer una asociación efectiva con los pastos, la introducción de cepas eficientes ha ayudado a promover el crecimiento (González et al. 2015; Ojeda-Quintana et al. 2020).

Algunos estudios muestran que la inoculación con HMA no solo favorece el crecimiento de las plantas inoculadas, sino también de las demás plantas asociadas a ellas (Tajini et al. 2012). En asociaciones de gramíneas con leguminosas co-inoculadas con HMA y rizobios, las gramíneas también pueden ser colonizadas por los HMA inoculados a la leguminosa, y así incrementar su capacidad para absorber nutrientes a través de las hifas del hongo, incluyendo el nitrógeno liberado por la descomposición de los nódulos de las leguminosas asociadas (Crespo-Flores 2016).

La asociación de gramíneas con leguminosas y su inoculación con HMA y aislados locales de rizobios puede contribuir a incrementar el crecimiento de las gramíneas (Crespo-Flores 2016) y favorecer la producción de pigmentos fotosintéticos en algunas especies de gramíneas asociadas, además de promover el desarrollo de estructuras micorrízicas y la nodulación.

Teniendo en cuenta trabajos previos, este estudio se realizó para evaluar, en condiciones de invernadero, el efecto de la co-inoculación de *Leucaena leucocephala* con *Claroideoglomus claroideum* y el aislado R3 de rizobio sobre las estructuras micorrízicas, la concentración de pigmentos fotosintéticos, el crecimiento y la producción de biomasa de las gramíneas *Bouteloua gracilis*, *Bouteloua curtipendula* y *Setaria macrostachya* que crecían solas y en asociación con *Leucaena leucocephala*.

Materiales y Métodos

Condiciones experimentales

En la Facultad de Agronomía y Veterinaria de la Universidad Autónoma de San Luis Potosí (México), se realizaron tres experimentos en condiciones semicontroladas, Para el crecimiento de las plantas se utilizó un sustrato compuesto por una mezcla de suelo procedente de una zona agrícola cercana al sitio experimental y arena de río en proporción 1:1 v:v, con el cual se llenaron bolsas de plástico de 35 × 35 cm de ancho y largo para un volumen total de 5 kg de suelo. Antes del llenado de las bolsas se tomaron 10 muestras para el análisis químico del sustrato preparado, los resultados obtenidos fueron los siguientes: 35 (SE±: 0.07), 66.3 (SE±: 0.06), 3300 (SE±: 2.36) y 540 (SE±: 0.47) mg/kg para P, K, Ca y Mg respectivamente; 1.92% de materia orgánica (MO) y un pH=6.9. Los métodos utilizados para determinar estos valores fueron los siguientes: pH (H_2O) por potenciometría (proporción 1: 2.5, suelo: agua) (NC ISO 10390 1999), materia orgánica por el método de Walkley and Black (NC 51 1999), fósforo (P) asimilable por el método de extracción con H_2SO_4 0.05 mol/L, Ca y Mg por complexometría y Na y K por fotometría de llama (NC 51 1999).

De acuerdo con los valores del análisis químico, el sustrato presentó bajas concentraciones de K y MO, altos valores de P asimilable, Ca y Mg, un porcentaje aceptable de Na y un pH cercano a la neutralidad (NC 52 1999). El sustrato presentó un promedio de 140 esporas de HMA en una muestra de 50 g. Durante todo el periodo experimental (17 de septiembre de 2020 al 04 de junio de 2021) se registró una temperatura media de 20.62 °C y 50.43% de humedad relativa, medidos con un registrador de temperatura HOBO Onset U23-001A colocado junto a las plantas usadas en el experimento.

Diseño experimental

El estudio consistió en tres experimentos independientes con cada una de las siguientes especies de gramíneas: *Bouteloua gracilis* (Kunth) Griffiths (Navajita), *Bouteloua curtipendula* (Michx.) Torr. (Banderita) y *Setaria macrostachya* Kunth (Tempranero). En cada experimento se evaluaron tres tratamientos: (1) gramínea sola; (2) gramínea asociada con *Leucaena leucocephala* (Lam.) de Wit (leucaena, guaje) sin inocular; y (3) gramínea asociada con *L. leucocephala* co-inoculada con una cepa de HMA y un aislado de rizobio.

Los tratamientos se distribuyeron según un diseño completamente al aleatorizado con cuatro repeticiones. La unidad experimental estuvo constituida por las bolsas de 35.0 × 35.0 cm de ancho y largo, respectivamente, las cuales contenían tres plantas, en el tratamiento de gramínea no asociada, y tres plantas de gramínea más una de *L. leucocephala*, en los tratamientos donde se asociaron las especies de ambas familias.

Inoculantes empleados

El inoculante de HMA [*Claroideoglomus claroideum* (Schenck & Sm.) Walker & Schüßler] utilizado en los experimentos fue aislado de una parcela en una zona agrícola productora de maní (*Arachis hypogaea*) en Ciudad Fernández, SLP, México (22° 00'47.36" N y 100° 21'14.66" W). El inoculante se preparó a partir de esporas extraídas de inóculos previamente multiplicados sobre un sustrato arcilloso esterilizado previamente en autoclave a 120 °C, durante una hora por tres días consecutivos. La especie *Sorghum vulgare* se usó como cultivo trampa.

El aislado de rizobio utilizado en los experimentos fue obtenido de muestras de raíces de *L. leucocephala* recolectadas en un área ubicada en la localidad de Tocoy del municipio de San Antonio, San Luis Potosí (21° 38'19.0"N 98° 52'15.0"W) (Crespo-Flores 2021). El cultivo de células de rizobio se preparó en medio líquido Levadura-Manitol-Agar (LMA) a 28 °C y en condiciones de agitación, durante 24-30 horas (Vincent 1970).

Ambas cepas inoculantes, identificadas como AMF2 y R3, en el caso del HMA y el rizobio respectivamente, fueron seleccionadas para su aplicación en este estudio, dado que en un estudio previo (Crespo-Flores et al. 2022) se demostró que presentaban una mayor efectividad en la promoción de estructuras micorrízicas, nodulación, crecimiento y producción de biomasa de plántulas de *L. leucocephala* y *Prosopis laevigata*.

Propagación de plantas y aplicación de inoculantes

Las plantas de gramíneas se propagaron por semillas. Las semillas se colocaron en bandejas de germinación de 200 cavidades con musgo de turbera ("peat moss") como sustrato. Previo a la germinación, las semillas se desinfectaron sumergiéndolas durante 10 minutos en una solución de hipoclorito de sodio al 10%; posteriormente se enjuagaron con agua destilada. Cuando las plántulas alcanzaron una altura entre 6 y 7 cm, se trasplantaron a las bolsas que contenían el sustrato previamente preparado.

Las plantas de *L. leucocephala* se propagaron por semilla. Las semillas se escarificaron en agua a 80 °C por dos minutos, luego se sumergieron en una solución de hipoclorito de sodio al 5% por tres minutos, seguidamente se colocaron en bandejas germinadoras con 200 cavidades que contenían turba como sustrato. Cuando las plántulas alcanzaron entre 5 y 8 cm de altura, se trasplantaron a las bolsas que contenían las gramíneas trasplantadas 30 días antes. Las plantas de *L. leucocephala* junto con las gramíneas se cultivaron durante 259 días (del 17 de septiembre de 2020 al 04 de junio de 2021). Durante ese período se aplicó la misma cantidad de agua a cada unidad experimental en días alternos o de acuerdo con las necesidades de las plantas.

La inoculación de HMA se realizó aplicando 0,5 ml de solución de Ringer (7.5 g de NaCl, 0.75 g de KCl, 0.1 g de $CaCl_2$ y 0.1 g de $NaHCO_3$ en 1 L de H_2O) que contenía 60 esporas extraídas del inóculo. En el caso del aislado de rizobio (R3), se aplicó 1 ml del inóculo al sustrato. Cada ml de inóculo contenía 10^8 CFU. Ambos inoculantes se aplicaron directamente alrededor de las raíces de las plántulas de *L. leucocephala*, al momento del trasplante.

Evaluación de las variables de crecimiento

El crecimiento de las gramíneas se evaluó en cuatro cortes, el primero a los 42 días después del trasplante (ddt) de *L. leucocephala*, y luego a los 176, 224 y 259 ddt, respectivamente. En cada corte se determinó el número de tallos y la masa seca (MS) por maceta de la parte aérea de las gramíneas. Al final del experimento se determinó de forma independiente la MS de las raíces para cada una de las gramíneas y de *L. leucocephala*. Para obtener la MS, las muestras se colocaron en la estufa a 70 °C hasta alcanzar peso constante. El peso de MS se registró en una balanza SCS Precisa LS320M, con precisión de 1 mg. La MS total acumulada se determinó sumando los cuatro cortes.

Evaluación de las variables fúngicas de los HMA y de la nodulación

La colonización de micorrizas se determinó al final del experimento en las raíces de las plantas previamente lavadas con agua corriente y secadas al aire. Para las determinaciones se pesaron aproximadamente 200 mg de raicillas, las cuales fueron secadas a 70 °C, y teñidas según la metodología descrita por Phillips y Hayman (1970). La frecuencia de colonización micorrízica, que expresa el grado de ocupación de las raíces por HMA, se evaluó por el método de los interceptos (Giovannetti y Mosse 1980). La densidad visual o intensidad de la colonización se estimó según Trouvelot et al. (1986). La cuantificación del número de esporas (esporas/50 g) se realizó a partir de muestras de 50 g de sustrato de las bolsas, extrayéndose dichas estructuras por tamizado húmedo y decantación y observación posterior al microscopio (Herrera et al. 1995).

El número de nódulos totales y su efectividad se evaluó según lo indicado en FAO (1985). Para ello, se extrajeron las raíces de *L. leucocephala* de la bolsa, separándolas del sustrato y lavándolas con agua corriente. Una vez limpias las raíces se cuantificaron los nódulos totales y se determinó su efectividad observando la coloración interna a través de un corte transversal del nódulo. Los nódulos que presentaron coloración de rojo a rosa fueron considerados como nódulos efectivos por presencia de leghemoglobina, mientras que los blancos fueron considerados como nódulos jóvenes (no efectivos).

Evaluación de la concentración de pigmentos fotosintéticos en los pastos

La concentración de pigmentos (clorofilas *a* y *b*, clorofilas totales y carotenoides) se evaluó en muestras frescas de hojas de las gramíneas. Para el análisis de pigmentos se seleccionó la cuarta hoja completamente expandida (Silva et al. 2001). El total de muestras se recolectó entre las 9:00 y 10:00 a.m. para evitar variaciones relacionadas al tiempo de muestreo. Para determinar la concentración de los pigmentos se tomaron 80 mg de cada muestra y se colocaron en frascos de vidrio color ámbar con 2 ml de N, N-dimetilformamida (Inskeep y Bloom 1985). Los frascos se cubrieron previamente con papel de aluminio para bloquear la translucidez y reducir la desnaturalización de los pigmentos, y luego se dejaron a 4 °C durante 72 h (Inskeep y Bloom 1985). Posteriormente, se registró la absorbancia a las longitudes de onda de 667, 645 y 480 nm, utilizando un espectrofotómetro (AGILENT 8453). Las concentraciones de clorofilas *a* y *b*, clorofilas totales y carotenoides se calcularon utilizando las fórmulas descritas por Minocha et al. (2009).

Análisis estadístico

El análisis de datos se realizó mediante el programa estadístico IBM SPSS Statistics 25 para Windows (SPSS 2017). Los datos se evaluaron mediante análisis de varianza de clasificación simple. Los análisis se realizaron por separado para cada experimento, con cada una de las tres especies de gramíneas asociadas, con o sin *L. leucocephala*. El mismo criterio se aplicó para el análisis de los efectos de tratamientos en las diferentes fechas de corte. En los casos en que hubo un efecto significativo de los tratamientos, se utilizó la prueba de comparación múltiple de Duncan para establecer las diferencias entre las medias; mientras que en el caso de comparaciones entre solo dos grupos de datos, se utilizó la prueba t de Student para dos grupos (Gómez y Gómez 1984).

Resultados

Biomasa aérea

El número de tallos de las gramíneas se vio afectado significativamente por los tratamientos (P <0.05). En el segundo, tercero y cuarto corte, se constató que *B. gracilis* y *B. curtipendula* presentaron mayor número de tallos creciendo solas o en asocio con *L. leucocephala* co-inoculada que cuando se asociaron con *L. leucocephala* sin inocular. En el caso de *S. macrostachya*, solo en el tercer y cuarto corte el número de tallos fue superior cuando creció en monocultivo o en asocio con *L. leucocephala* co-inoculada, con respecto a su asocio con *L. leucocephala* sin inocular (Figura 1).

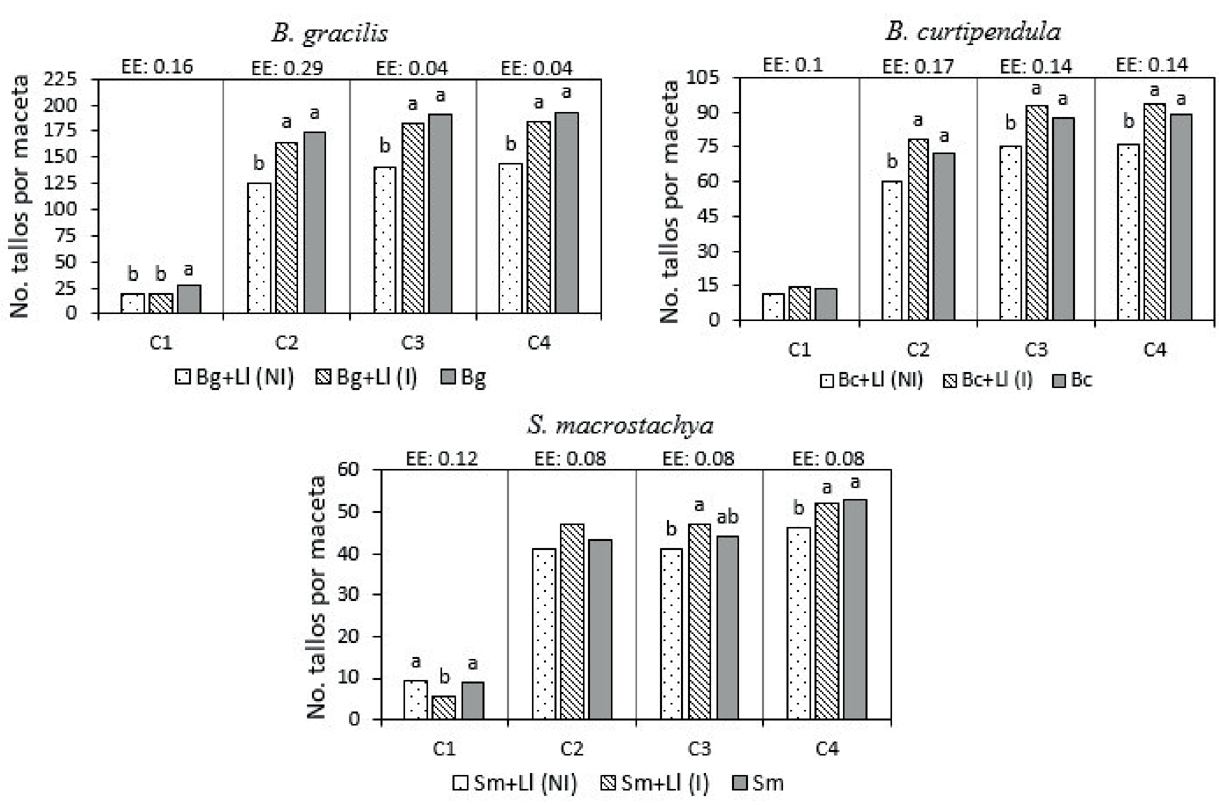

Figura 1. Efecto de la co-inoculación de *L. leucocephala* con *C. claroideum* y con el aislado de rizobio (R3) en el número de tallos de *B. gracilis* (Bg), *B. curtipendula* (Bc) y *S. macrostachya* (Sm). Donde: C1, C2, C3 y C4 representan cada corte. NI (no inoculado), I (inoculado), *L. leucocephala* (Ll). EE = error estándar; *n* = 4. [ab] Los valores con letras diferentes dentro de cada corte indican diferencias (P < 0.05) entre tratamientos, según la prueba de Duncan.

La producción de biomasa aérea de las gramíneas también mostró diferencias debidas a tratamientos (P<0.05), comportándose de manera similar al número de tallos, principalmente en *B. gracilis* y *B. curtipendula*. En todos los cortes, excepto en el primero, las gramíneas produjeron mayor cantidad de biomasa cuando se asociaron con *L. leucocephala* co-inoculada o cuando crecieron solas. En todos los casos, los pastos combinados con *L. leucocephala* sin inocular tuvieron la menor cantidad de biomasa. En el último corte, las plantas de *B. gracilis* y *B. curtipendula* sin asociar superaron los rendimientos de masa seca (MS) de las gramíneas asociadas a *L. leucocephala* co-inoculada, y estas, a su vez, siguieron siendo superiores a las asociadas con leucaena no inoculada (Figura 2).

Solo en *B. gracilis* y *B. curtipendula* se observaron diferencias (P<0.05) debidas a tratamientos en cuanto al acumulado de biomasa seca en los cuatro cortes, no así en el caso de *S. macrostachya* (Figura 3). Cuando cada una de las especies de gramíneas se asoció con *L. leucocephala*, los tratamientos de co-inoculación produjeron una mayor cantidad de biomasa aérea que aquellos sin inoculación. A su vez, las gramíneas que no se asociaron con *L. leucocephala* tuvieron una tendencia a producir mayor biomasa que las gramíneas asociadas con y sin inoculación, aunque solo en *B. gracilis* se detectó diferencia significativa (P<0.05) (Figure 3).

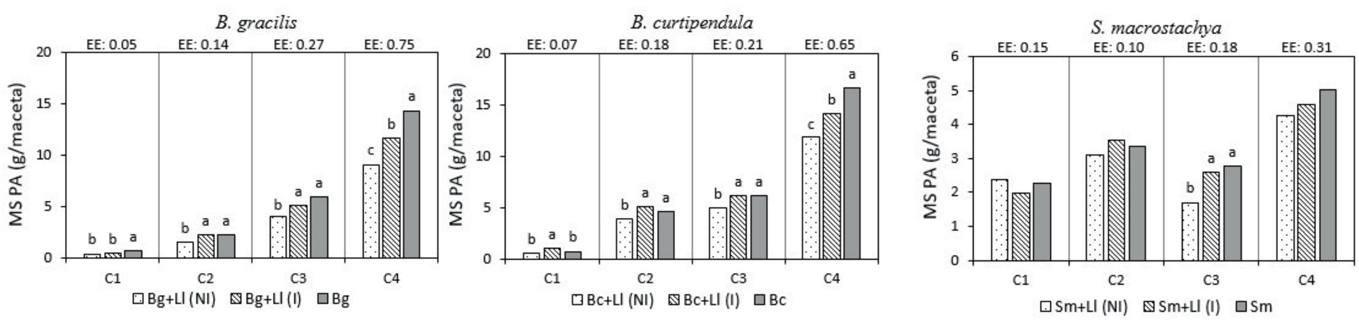

Figura 2. Efecto de la co-inoculación de *L. leucocephala* con *C. claroideum* y con el aislado de rizobio (R3) en la producción de biomasa aérea (MS PA) en cada corte de *B. gracilis* (Bg), *B. curtipendula* (Bc) y *S. macrostachya* (Sm). Donde: C1, C2, C3 y C4 representan cada corte. NI (no inoculado), I (inoculado), L. leucocephala (Ll). EE = error estándar; *n* = 4. [ab] Los valores con letras diferentes dentro de cada corte indican diferencias (P < 0.05) entre tratamientos, según la prueba de Duncan.

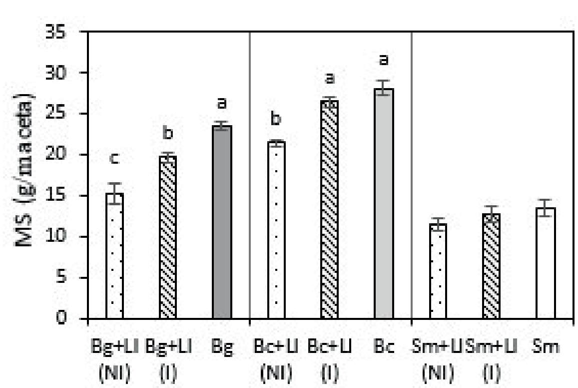

Figura 3. Efecto de la asociación con *L. leucocephala* y su co-inoculación con *C. claroideum* y el aislado de rizobio R3 sobre la producción de biomasa aérea de gramíneas (MS, g/maceta) acumulada en los cuatro cortes. Donde: *B. gracilis* (Bg), *B. curtipendula* (Bc), *S. macrostachya* (Sm), *L. leucocephala* (Ll). MS PA (Masa seca de la parte aérea de los pastos). NI (no inoculado), I (inoculado). Las barras (Ͱ) superpuestas representan el error estándar de las medias de tratamiento; *n* = 4. [abc] Los valores con letras diferentes en cada corte difieren (P < 0.05) según la prueba de Duncan.

Biomasa radicular

Los promedios de biomasa de las raíces de las gramíneas y de *L. leucocephala* no mostraron diferencias (P>0.05) debidas a tratamientos (Figuras 4A y 4B). Por otro lado, se observó que la masa seca de las raíces de *L. leucocephala* asociada a *S. macrostachya* alcanzó valores muy superiores con respecto a la leucaena asociada a las otras gramíneas, es decir una diferencia de entre 64 % y 68% respecto al asocio con *B. gracilis* y 70% a 72% respecto al asocio con *B. curtipendula*. En correspondencia con lo anterior, la Figura 4B muestra que la biomasa de raíces (g MS/maceta) de *S. macrostachya* fue menor a la de *B. curtipendula* y *B. gracilis*, en ese orden.

No se detectó diferencias en la biomasa total de las raíces (gramíneas + *L. leucocephala*) debidas a los tratamientos cuando las gramíneas asociadas fueron *B. gracilis* y *B. curtipendula*. En contraste, la asociación de *S. macrostachya* con *L. leucocephala* co-inoculada o sin inocular promovió hasta tres veces más producción de biomasa de raíces de cuando se consideraron ambas especies (Figura 4C).

Variables fúngicas y de nodulación

Los tratamientos estudiados generaron efectos significativos (P<0.001) sobre las variables que caracterizan las estructuras micorrízicas asociadas a la rizosfera de las especies de gramíneas y *L. leucocephala*. El mayor número de esporas se presentó en los tratamientos co-inoculados en cada asociación de gramíneas con *L. leucocephala*. También se encontraron esporas en el tratamiento de la asociación con *L. leucocephala* sin inocular, así como en las gramíneas no asociadas, obteniendo un mayor número en las asociaciones leguminosa-gramíneas que en las gramíneas solas (Figura 5A). Los indicadores de colonización micorrízica y densidad visual se comportaron de manera similar al número de esporas, donde los mayores porcentajes se alcanzaron en los tratamientos de asociación co-inoculada, seguidos de las asociaciones sin inocular y las gramíneas solas (Figura 5B y 5C).

El número de nódulos en las raíces de las plantas de *L. leucocephala* fue mayor (P<0.05) en las plantas co-inoculadas respecto a las no inoculadas, cuando se asociaron con *B. gracilis* y *S. macrostachya*

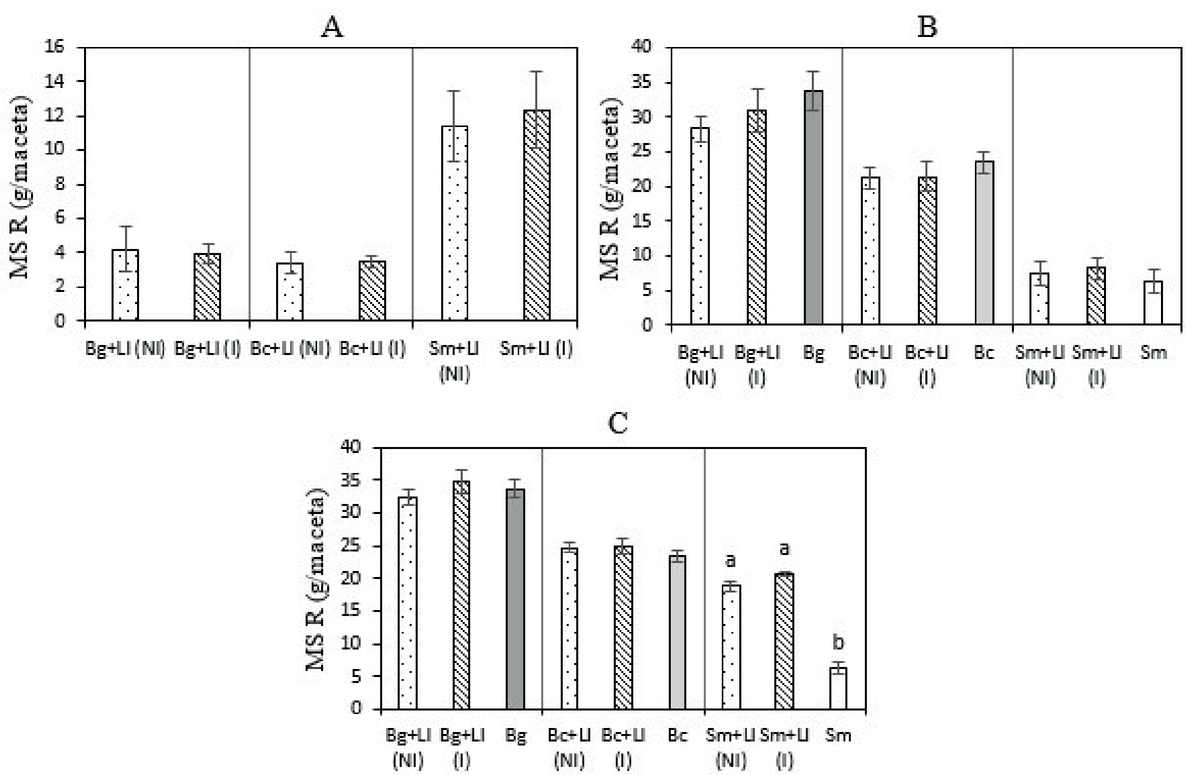

Figura 4. Efecto de la asociación con *L. leucocephala* y su co-inoculación con *C. claroideum* y el aislado de rizobio R3 sobre la producción total de biomasa radical (MS R, g/maceta) en *L. leucocephala* (A), en las gramíneas (B) y en gramíneas + *L. leucocephala* (C). Donde: *B. gracilis* (Bg), *B. curtipendula* (Bc), *S. macrostachya* (Sm), *L. leucocephala* (Ll). NI (no inoculado), I (inoculado). Las barras (Ⱶ) superpuestas representan el error estándar de las medias de tratamiento; *n* = 4. [ab] Los valores con letras diferentes en cada corte difieren (P < 0.05) según la prueba de Duncan.

(Figura 6A); en cambio, las plantas de *L. leucocephala* co-inoculadas asociadas con *B. curtipendula* no aumentaron significativamente el número de nódulos en comparación con las plantas sin inocular. Por otro lado, la efectividad de los nódulos no mostró diferencias (P>0.05) debidas a la inoculación, en el caso de los asocios con las tres especies de gramíneas evaluadas (Figura 6A y 6B).

Concentración de pigmentos fotosintéticos en las gramíneas

La concentración de pigmentos fotosintéticos en las hojas de las gramíneas mostró diferencias (P<0.05) entre tratamientos en al menos dos de las especies de gramíneas. La clorofila *b* fue más abundante cuando se asoció *B. gracilis* con *L. leucocephala* co-inoculada en comparación con el

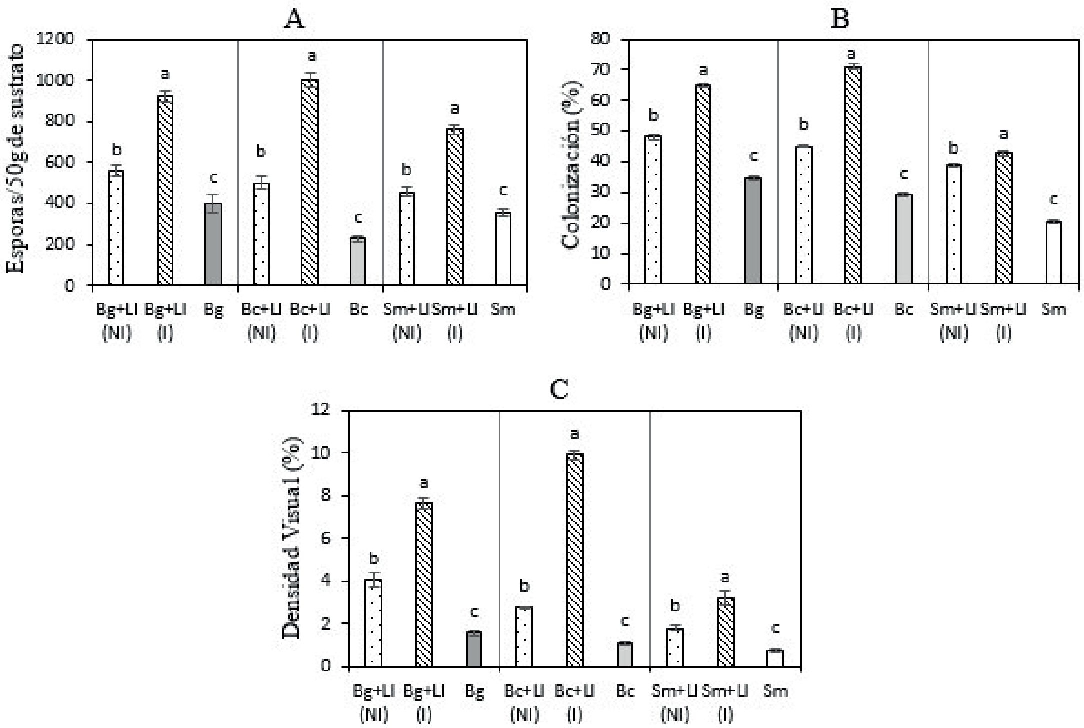

Figura 5. Efecto de la asociación con *L. leucocephala* y su co-inoculación con *C. claroideum* y el aislado R3 sobre el contenido de esporas de HMA (A) y los porcentajes de colonización (B) y densidad visual (C) en la rizosfera y raíces de cada especie de gramínea. Donde: *B. gracilis* (Bg), *B. curtipendula* (Bc), *S. macrostachya* (Sm) y *L. leucocephala* (Ll). NI (no inoculada), I (inoculada). Las barras (Ͱ) superpuestas representan el error estándar de las medias de tratamiento; *n* = 4. [abc] Los valores con letras diferentes en cada corte difieren (P < 0.05) según la prueba de Duncan.

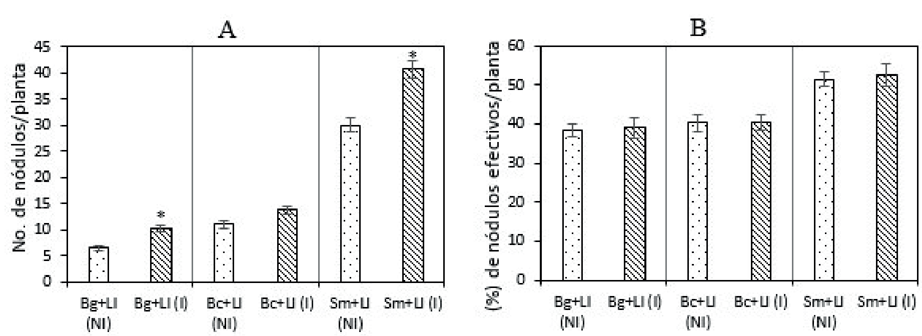

Figura 6. Efecto de la asociación con *L. leucocephala* y su co-inoculación con *C. claroideum* y el aislado R3 en el número de nódulos (A) y el porcentaje de nódulos efectivos (B) en *L. leucocephala* (Ll) asociada con cada especie de gramínea. Donde: *B. gracilis* (Bg), *B. curtipendula* (Bc), *S. macrostachya* (Sm). NI (no inoculado), I (inoculado). Las barras (Ͱ) superpuestas representan el error estándar de las medias de tratamiento; *n* = 4. *Diferencia significativa (P <0.05) según la prueba t de Student.

tratamiento de asociación sin inocular y solo pastos; sin embargo, eso no resultó en diferencias para clorofilas totales (clorofila *a* + clorofila *b*) ni carotenoides totales (Figura 7). Al asociar *S. macrostachya* con *L. leucocephala*, las plantas de la gramínea presentaron mayor concentración de clorofilas *a* y *b* en sus hojas en comparación con las que no se asociaron con la leguminosa, independientemente de la presencia o no de co-inoculación. En cambio, en el asocio con *B. curtipendula*, los tratamientos de inoculación o co-inoculación de *L. leucocephala* no afectaron (P>0.05) las concentraciones de pigmentos fotosintéticos en la gramínea (Figura 7).

Discusión

Evaluación del crecimiento de las gramíneas

La inoculación de *L. leucocephala* con rizobio y HMA favoreció el crecimiento de las tres especies de gramíneas procedentes de climas semiáridos, respecto al tratamiento con la leguminosa sin inocular (Figuras 1 y 2). Crespo-Flores (2016) obtuvo resultados similares en un ambiente cálido-húmedo, trabajando con *Brachiaria decumbens* asociada a *Stylosanthes guianensis* co-inoculado con dos aislamientos de rizobio y el hongo *Funneliformis mosseae*.

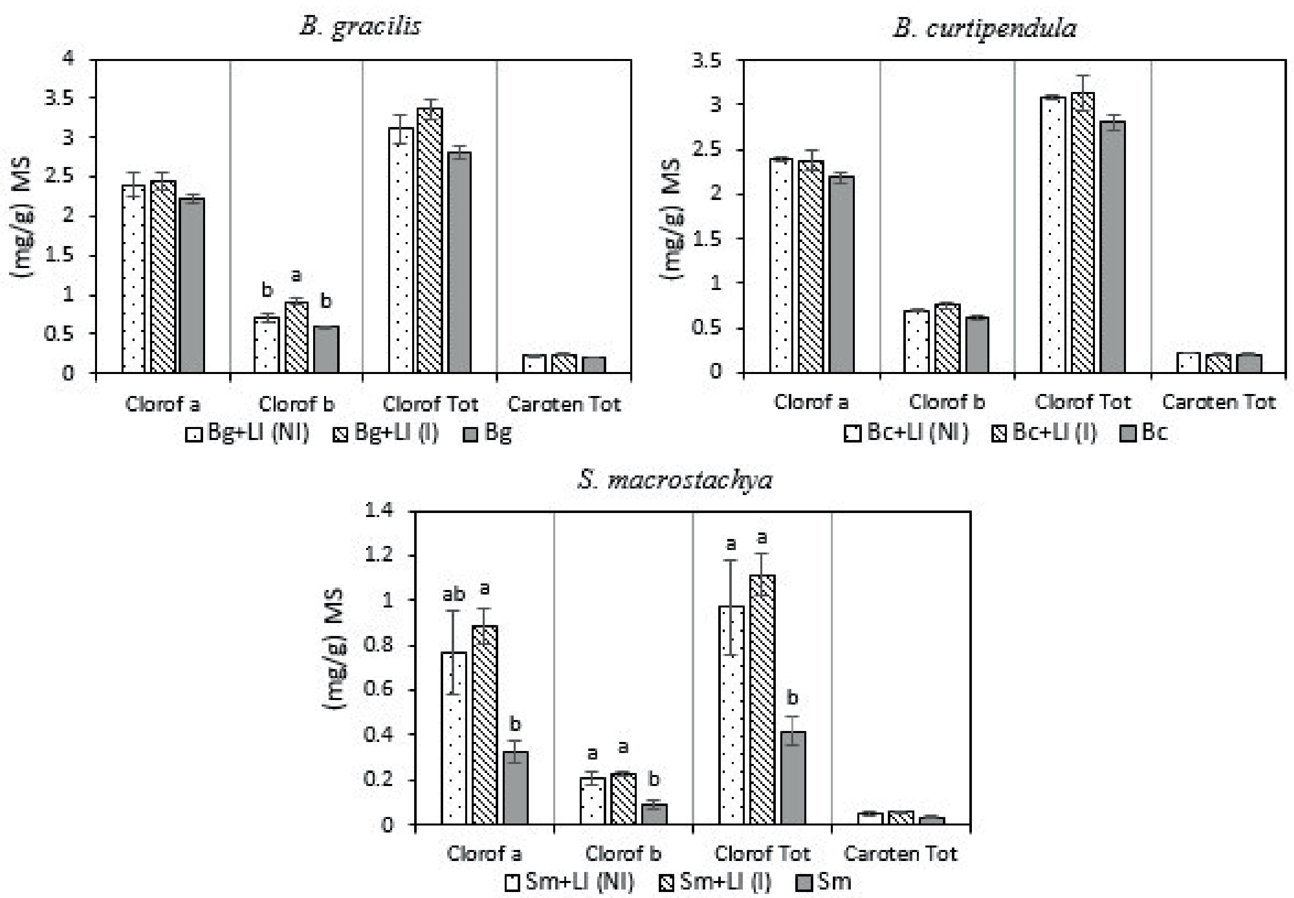

Figura 7. Efecto de la co-inoculación con *C. claroideum* y el aislado R3 en *L. leucocephala* (Ll) sobre la concentración de pigmentos fotosintéticos (Clorofila *a*, clorofila *b*, clorofilas y carotenoides totales) en *B. gracilis* (Bg), *B. curtipendula* (Bc) y *S. macrosthachya* (Sm). Donde: NI (no inoculado), I (inoculado). Las barras (Ⱶ) superpuestas representan el error estándar de las medias de tratamiento; $n = 4$. [ab] Los valores con letras diferentes en cada corte difieren ($P < 0.05$) según la prueba de Duncan.

Otros trabajos demuestran el beneficio que reciben algunas plantas al crecer junto a otras que han sido micorrizadas (Tajini et al. 2012). Al explorar el sustrato en busca de nutrientes, las hifas de la cepa del hongo *C. claroideum* pueden haber colonizado las raíces de las gramíneas y establecido una relación simbiótica con estas, y de esa manera contribuido a mejorar su nutrición y absorción de agua. Así, es probable que esta mejora en la nutrición trajera consigo un aumento en el crecimiento de las gramíneas asociadas.

Las gramíneas no asociadas produjeron un número de tallos y cantidad de biomasa similar a las gramíneas asociadas a *L. leucocephala* co-inoculada, e incluso, en el último corte, produjeron mayor cantidad de biomasa en *B. gracilis* y *B. curtipendula*. Este resultado contrasta con lo obtenido en otros estudios, donde se observó una mejora en el crecimiento de las gramíneas cuando se asociaban con otras leguminosas (Bolívar et al. 1999). En el caso de este trabajo, la diferencia podría deberse al tamaño reducido de las bolsas (35.0 × 35.0 cm), por el cual las gramíneas asociadas con *L. leucocephala* estuvieron sometidas a una mayor competencia por espacio y recursos (nutrientes, agua e incluso luz), con respecto a las gramíneas solas.

En los tratamientos de asociación se tuvo cuatro plantas por bolsa, tres de gramínea y una de *L. leucocephala*, a diferencia de solo tres plantas de gramíneas en los tratamientos sin asociación. Esto pudo haber representado una ventaja para el tratamiento de gramíneas no asociadas *versus* las asociadas, en cuanto a la disponibilidad de recursos en el mismo volumen de sustrato, y estos tendieron a volverse más limitante a medida aumentaba el volumen de las raíces (Figura 4). Además, en las gramíneas asociadas, la competencia por luz de estas con *L. leucocephala* debe haber sido también cada vez mayor hasta el momento en que las gramíneas alcanzaron un tamaño similar a la leguminosa; pero, la co-inoculación aplicada a *L. leucocephala* posiblemente les permitió a las gramíneas reducir las desventajas provocadas por la competencia, con respecto a las gramíneas que crecieron solas.

Los resultados indican que la co-inoculación de *L. leucocephala* con HMA y el aislado de rizobio estimuló la producción de biomasa en las tres especies de gramíneas (*B. gracilis*, *B. curtipendula* y *S. macrosthachya*) cultivadas en asociación. Esto demuestra que las gramíneas se vieron favorecidas por la colonización de la cepa de *C. clarouideum*, inoculada en *L. leucocephala*, lo cual se relaciona con los mayores porcentajes de colonización y densidad visual encontrados en sus raíces con respecto a los tratamientos sin inocular (Figuras 5B y 5C). Por otra parte, si bien se detectó diferencias en la efectividad de los nódulos en los tratamientos de inoculación respecto a los no inoculados, es posible que el nitrógeno que pudo estar presente en el sustrato haya sido transferido con mayor eficiencia a las raíces de los pastos gracias a la cepa de HMA inoculada. En este sentido, existen varios reportes sobre la contribución de la fijación biológica de nitrógeno (FBN) a la nutrición nitrogenada de las especies acompañantes (López-Alcócer et al. 2020; Zúñiga-Estrada et al. 2022), y el efecto sinérgico entre los HMA y los microorganismos que ejercen FBN (Harris et al. 2019; Delgado-Álvarez et al. 2023).

Variables fúngicas y de nodulación

En este estudio se comprobó que la presencia de *C. claroideum* aumentó los niveles de ocupación (% colonización y % de densidad visual) en las raíces de las plantas y el número de esporas en su rizosfera (Figura 5). Esto demostró que, bajo las condiciones de este estudio, la cepa inoculada fue más efectiva para colonizar las raíces de las plantas con respecto a las que estaban presentes en el sustrato. Por otra parte, la presencia de una cepa seleccionada de rizobio también puede haber favorecido la efectividad de la micorrización, teniendo en cuenta que la interacción entre ambos microorganismos en simbiosis con la planta aporta recursos que favorecen su funcionamiento. Esto corrobora lo encontrado en otros estudios que indican que la inoculación simple o combinada de cepas efectivas de HMA y rizobios incrementa las estructuras del hongo en las raíces y rizosfera de las plantas, tanto en las inoculadas (Tamayo-Aguilar et al. 2021) como las asociadas (Tajini y Drevon 2012).

En este sentido, la introducción de especies seleccionadas de HMA es una opción a considerar, especialmente en los casos en que los HMA residentes no produzcan los beneficios deseados, debido a su baja efectividad (Oliveira et al. 2014; González et al. 2016). Asimismo, en el caso de las leguminosas, se recomienda la inoculación combinada de cepas de HMA y rizobios, por la potenciación de los efectos que se producen en esta interacción tripartita, lo que repercute favorablemente en el rendimiento de la leguminosa (Martín et al. 2015).

El número de nódulos en raíces de *L. leucocephala* fue influenciado por la co-inoculación, sin embargo, no se observó diferencias entre tratamientos en el porcentaje de nódulos efectivos (Figura 6). Aparentemente, la presencia del aislado R3 en este experimento no tuvo el mismo éxito logrado en un experimento anterior, en el que se comprobó la efectividad de la inoculación simple y combinada de tres aislados de rizobio y dos cepas de HMA en *L. leucocephala* (Crespo-Flores et al. 2022). Esta situación pudo haber sido producto de la incidencia de algún otro factor, como el hecho que si bien la leucaena fue trasplantada y coinoculada en idénticas condiciones de sustrato y con la misma altura de las plantas que en el experimento antes citado (Crespo-Flores et al. 2022), en este ensayo el trasplante se realizó muy cerca de las gramíneas que ya tenían 30 días de plantadas.

Por otro lado, el mayor número de nódulos encontrados en los tratamientos co-inoculados puede deberse a que la cepa de HMA introducida también favoreció la simbiosis de *L. leucocephala* con los rizobios residentes en el sustrato, aunque los nódulos producidos por estos no mostraron un alto porcentaje de efectividad. Esto confirma lo planteado por varios autores (Rabie et al. 2005; Toro et al. 2008; Lara et al. 2019) sobre la interacción tripartita rizobio-leguminosa-HMA, en la que se favorece el desarrollo de cada organismo de forma individual y en su conjunto. Cabe anotar que algunos autores consideran que, si el mayor número de nódulos presentes en las raíces proviene de la colonización de la población alóctona del suelo, la tasa de fijación de N2 y el número de nódulos efectivos vendrán determinados por la efectividad de dicha población, la cual es generalmente baja (Lodeiro 2015).

Concentración de pigmentos fotosintéticos en los pastos

En el presente estudio se observó que las concentraciones de clorofila *a* y *b* en *S. macrostachya* estuvieron afectadas por los tratamientos. Aunque en las gramíneas asociadas con *L. leucocephala* co-inoculada hubo cierta tendencia a presentar mayores contenidos de estas clorofilas, la diferencia no fue significativa ($P<0.05$) con respecto a las gramíneas asociadas con *L. leucocephala* no inoculada. Sin embargo, la influencia de *L. leucocephala* se reflejó en las gramíneas asociadas con respecto a las que crecieron solas (Figura 7C). Esto último fue más evidente en de *S. macrostachya* asociada con *L. leucocephala*, lo que sugiere que esta leguminosa fue más efectiva en su simbiosis con rizobios cuando estuvo asociada a esa gramínea (Figura 6).

Otros estudios han reportado que la inoculación con HMA aumenta la concentración de pigmentos fotosintéticos en las hojas de algunas especies (Manjarrez-Martínez et al. 2005; Chiquito-Contreras et al. 2018). Sin embargo, en algunos cultivos como los pastos, la concentración de pigmentos fotosintéticos también puede variar según la edad del cultivo y de sus rebrotes, siendo insuficiente la influencia de la inoculación en algunas etapas (Díaz y Garza 2006).

Los resultados el presente estudio parecen indicar que la influencia de *L. leucocephala* sobre las concentraciones de clorofilas *a* y *b* en las gramíneas asociadas podría estar relacionada con la existencia de nitrógeno fijado en la leguminosa, lo que favorece en cierta medida el aporte de nitrógeno a las plantas asociadas, en este caso las gramíneas, ya sea por la proximidad de sus raíces o por su conexión a través de las hifas de los HMA (Tajini et al. 2012).

Lo anterior parece apoyar lo planteado por Casierra-Posada et al. (2012), quienes consideran que uno de los indicadores de la capacidad fotosintética de las plantas es la cantidad de clorofila en las hojas, lo cual incide en la eficiencia del proceso fotosintético. Por otro lado, Demotes et al. (2008) y Sánchez et al. (2018) sugieren que el contenido de clorofila también puede indicar el estado nutricional de la planta en términos de nitrógeno, el cual es un elemento crucial en la síntesis de proteínas fotosintéticas.

Se recomienda validar los resultados del presente estudio en experimentos de campo, para así obtener una mejor comprensión de las interacciones que ocurren entre especies de gramíneas, leguminosas y microorganismos rizosféricos en un ambiente natural; ya que en este estudio hubo un buen control de varios factores bióticos y abióticos, gracias a que las plantas se manejaron en bolsas, bajo condiciones de invernadero.

Conclusiones

La co-inoculación de *L. leucocephala* con *C. claroideum* y el aislado local de rizobio (R3) promueve el desarrollo de estructuras micorrízicas y un mayor número de nódulos en *L. leucocephala*, lo cual a su vez favorece el crecimiento de las gramíneas *B. gracilis*, *B. curtipendula* y *S. macrostachya*, asociadas con ella. La co-inoculación con estas cepas, permite que *B. gracilis* y *B. curtipendula* asociadas a

L. leucocephala reduzcan las desventajas provocadas por la competencia con respecto a las gramíneas cultivadas solas. El crecimiento conjunto de gramíneas y leguminosas promueve la producción de pigmentos fotosintéticos en las gramíneas, lo cual fue más evidente en el asocio de *S. macrostachya* y *L. leucocephala*.

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Artículo Científico

Frecuencia de corte en la producción de biomasa de materiales destacados de *Tithonia diversifolia* identificados en Cuba

Effect of cutting frequency on the biomass production of outstanding materials of Tithonia diversifolia *identified in Cuba*

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Resumen

Se estudió el efecto de la combinación de la frecuencia de corte y materiales destacados de *Tithonia diversifolia* colectados e identificados en Cuba sobre la producción de biomasa durante tres años. El experimento fue diseñado como parcelas divididas en bloques al azar, donde la parcela principal correspondió al factor frecuencia de corte (40, 60 y 80 días) y la sub-parcela al factor materiales destacados de *Tithonia diversifolia* (IcaCuba Oc-10, Oc-23, Oc-24 y Oc-25). Las parcelas no recibieron fertilización ni riego a lo largo del ensayo. En la estación poco lluviosa, a los 60 días se presentaron los valores más altos para número de tallos por plantón, número de hojas verdes por tallo, peso verde de hojas por planta y rendimiento de MS (t/ha). Se encontró diferencias ($P \leq 0.01$) entre los materiales para las variables número de hojas verdes por tallo, peso verde de tallos y de planta total, con valores superiores para Oc-23; pero el Oc-25 presentó el mayor porcentaje de hojas. La producción de forraje/ha fue muy semejante en los materiales Oc-10, Oc-23 y Oc-24. En el periodo lluvioso, las frecuencias de 60 y 80 días presentaron los valores más altos para la mayoría de las variables y el mayor rendimiento/ha se alcanzó con 80 días. Se detectaron diferencias ($P \leq 0.05$) entre los materiales destacados en el número de hojas verdes por tallo, porcentaje de hojas y rendimiento de MS. Se concluye que los 4 materiales destacados de tithonia presentan características adecuadas para la producción de biomasa bajo corte, en condiciones similares a las del estudio.

Palabras clave: Época del año, podas, porciones de planta, rendimiento de forraje.

Abstract

The effect of cutting frequency on biomass production of outstanding materials of *Tithonia diversifolia* collected and identified in Cuba was studied for three years. The experiment was designed as a split-plot in complete randomized blocks, with the cutting frequency (40, 60 and 80 days) as the main plot, and the outstanding *Tithonia diversifolia* materials (IcaCuba Oc-10, Oc-23, Oc-24 and Oc-25) as the subplots. Experimental plots were neither fertilized nor irrigated during the study. In the dry season, the higher values for the number of stems per seedling and green leaves per stem, green weight of leaves per seedling and DM yield (t/ha) were obtained at 60 days of regrowth. Differences ($P \leq 0.01$) among outstanding materials were obtained, with the highest values in the number of green leaves per stem, green weight of stems and the whole plant for Oc-23; however, Oc-25 had the highest % of leaves. Forage yield/ha was very similar for Oc-10, Oc-23 and Oc-24. In the rainy season, higher values for most of the variables were obtained for harvests at 60 and 80 days, but the highest yield/ha was achieved for the frequency of 80 days. Differences between materials ($P \leq 0.05$) were detected for the number of green leaves per stem, % of leaves and DM yield (t/ha). It was concluded that under conditions like the ones prevalent in the study, the 4 outstanding materials of tithonia produce adequate biomass for use in a cut and carry system.

Keywords: Forage yield, pruning, plant portions, season

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Introducción

Los sistemas ganaderos tradicionales requieren de una utilización más eficiente de los recursos alimenticios, entre los que se puede contar a las forrajeras arbustivas. Mahecha et al. (2002), Gallego et al. (2014) y Ruíz et al. (2014a) definen a la *Tithonia diversifolia* como una alternativa para mejorar las condiciones de manejo y optimizar la producción de los sistemas ganaderos en el trópico. Esta arbustiva presenta alta producción de biomasa, debido a su capacidad para aprovechar los nutrientes del suelo (Murgueitio 2022). La mayoría de los estudios con *T. diversifolia* han prestado más atención a la composición bromatológica (Riascos-Vallejos et al. 2020) que al crecimiento y desarrollo de esta forrajera (Ruíz et al. 2016).

La producción del follaje de tithonia bajo corte es bien conocida en muchos países de Latinoamérica y en otras zonas geográficas (Thijssen et al. 1998; Ríos 1999; Ríos 2002). Ruíz et al. (2012) informaron los primeros resultados de producción de follaje con tithonia en Cuba, y estos coincidieron con lo observado en otras regiones de Latinoamérica.

Murgueitio (2005 y 2022) refiere que los sistemas de corte y acarreo, así como los bancos forrajeros mixtos, son ideales para la conservación de suelos frágiles de laderas y en ecosistemas húmedos, áreas muy usadas en sistemas de producción campesina y de lechería. Mahecha y Rosales (2005) y Rivera et al. (2021) definen a *Tithonia diversifolia* como una especie con buena capacidad de producción de biomasa y rápida recuperación después del corte, según la densidad de siembra, suelos y estado vegetativo, por lo que se adapta a esos sistemas. Sin embargo, esta planta, ha mostrado amplia variedad fenotípica, la cual posibilita la identificación de genotipos destacados capaces de mejorar su productividad (Ruíz et al. 2013; Holguín et al. 2015; Ruíz et al. 2016; Rivera et al. 2019; Rivera et al. 2021; Alonzo Lazo et al. 2024).

Por ello, el objetivo del presente estudio fue evaluar la producción de biomasa en cuatro materiales destacados de *Tithonia diversifolia* colectados e identificados en Cuba, cuando fueron sometidos a diferentes frecuencias de corte.

Materiales y Métodos

La investigación se realizó en el Centro Experimental de Pastos y Forrajes "Miguel Sistachs Naya" del Instituto de Ciencia Animal (ICA), ubicado en el municipio de San José de las Lajas, actual provincia de Mayabeque, Cuba, situada a lo 23º55´ Norte y a los 82º00´ Oeste, a una altitud de 92 msnm. El tipo de suelo en el área experimental es Ferralítico Rojo Éutrico, de rápida desecación, arcilloso y profundo sobre calizas (Hernández et al. 2015).

Con relación a las condiciones climáticas prevalentes durante el período en que se realizó el ensayo (3 años), la precipitación media durante la estación lluviosa (mayo–octubre) fue menor a la media histórica (promedio de 15 años) tanto en volumen como en el número de días con lluvia, con una diferencia de 663.9 mm y 38 días, respectivamente; sólo en julio el nivel de precipitación superó a la media histórica, pero no así en cuanto al número de días con lluvia. En cuanto a la estación seca (noviembre–abril), en la etapa experimental la precipitación fue 170 mm menor que la media histórica, y el número de días con lluvia fue de 19 días menos. En diciembre no hubo precipitación y en los meses de noviembre, febrero, marzo y abril sólo hubo un día con lluvia. Por otro lado, en los tres años que duró el estudio, la temperatura media anual fue de 24.86 °C.

Para el establecimiento del ensayo, el suelo tuvo una preparación con aradura y dos pases de grada. La siembra se efectuó en junio, a inicios de la estación lluviosa, en surcos separados a 70 cm y con un distanciamiento de 50 cm entre estacas. Para el establecimiento se utilizaron estacas tomadas de la parte media del tallo, con edad de 80 días de rebrote, un diámetro de 2 cm y 50 cm de largo, y estas se plantaron sobre los surcos, a una profundidad de 10 cm.

Durante la fase de establecimiento el área se mantuvo limpia de malezas mediante azadón. El corte de uniformización previo al inicio el experimento se efectuó 120 días después de la siembra y a una altura de 15 cm, y a lo largo del ensayo la altura de corte fue de 10–15 cm (Ruíz et al. 2014b). Todos los cortes se efectuaron de acuerdo con lo recomendado por Ruíz et al. (2014b; 2020) para el uso de *Tithonia diversifolia*. A lo largo de todo el ensayo no se aplicó fertilizantes ni riego.

El experimento fue diseñado como parcelas divididas en bloques completos al azar, con cuatro réplicas, donde la parcela principal correspondió al factor frecuencias de corte (40, 60 y 80 días) y la sub-parcela al factor materiales destacados de *Tithonia diversifolia* (IcaCuba Oc-10, Oc-23, Oc-24 y Oc-25). La denominación de "materiales destacados" fue otorgada por la Dirección de Semillas y Recursos Fitogenéticos del MINAG de Cuba para el Registro de Variedades Comerciales, a los materiales bajo estudio que habían sido colectados, evaluados y seleccionados por el Instituto de Ciencia Animal (ICA) para ser utilizados en la zona centro-occidental del país. El área experimental total fue de 1,008 m^2. En cada réplica hubo una parcela principal (16.8 × 5.0 m) para cada frecuencia estudiada y dentro de la misma cuatro subparcelas (4.2 × 5.0 m) para los materiales destacados de tithonia, todas ubicadas aleatoriamente. En cada subparcela se tuvo siete surcos.

Si bien la investigación se desarrolló durante tres años consecutivos, en este artículo se reportan las medias obtenidas en ese período, dado que no se detectó interacción entre los años y los factores en estudio.

A lo largo del ensayo se empleó la metodología elaborada, aplicada y perfeccionada para estos fines por el Proyecto "*Tithonia diversifolia* arbusto de interés para la ganadería" del Programa Nacional de Ciencia e Innovación Tecnológica: Mejoramiento Vegetal y Recursos Fitogenéticos PNCT-015", el cual inició esta línea de investigación en el periodo 2006–2010 (Ruíz 2010).

Las mediciones se efectuaron en todos los cortes realizados a lo largo de la investigación, tomando 10 plantas localizadas en los cinco surcos centrales de cada subparcela. Para estimar el contenido de materia seca en las muestras de los componentes vegetales de los materiales de tithonia, éstas se colocaron en estufa de circulación de aire forzado a 60 °C hasta alcanzar peso constante.

Las variables analizadas fueron: número de tallos por plantón; número de hojas por tallo (verde, amarilla y seca); peso verde de hojas, tallo y biomasa aérea total (g/planta); peso de 10 hojas desarrolladas (g); contribución de las hojas a la biomasa aérea total (%); y rendimiento de biomasa área seca (t MS/ha).

A lo largo del ensayo, con una frecuencia mensual, se monitoreó también la presencia-ausencia de insectos, observando por cada material 10 plantas elegidas al azar, en las que se evaluaron los organismos asociados y el índice de plantas dañadas. En los diferentes materiales evaluados no se detectó afectaciones de plagas que influyeran en el buen desarrollo de las plantas.

La información analizada corresponde a los periodos poco lluvioso y lluvioso, así como para el total anual. En todos los casos se probó los supuestos de normalidad de los errores para las variables número de hojas verdes por tallo, número de tallos por plantón usando la dócima de Shapiro-Wilk (1965) y homogeneidad de varianza por la dócima de Levene (1960). Dichas variables cumplieron los supuestos de normalidad por lo que se realizó el análisis de varianza. Se utilizó la dócima de Duncan (1955), para la comparación de las medias en los casos en que las variables presentaron diferencias significativas. Para el procesamiento de la información se utilizó el software Infostat (2001). Los análisis se hicieron independientemente para cada periodo y para el total anual.

Resultados

Para todas las variables, excepto el peso verde total por planta, no se detectó significancia para la interacción frecuencia de corte × materiales destacados; por ello en los Cuadros 1 y 2 se presentan los resultados para los efectos simples de esos factores durante el período poco lluvioso, y en los Cuadros 3 y 4 los del período lluvioso. Los datos del peso verde por planta, en función de la edad de rebrote × el genotipo de tithonia, se muestran en el Cuadro 5, porque solo para ese variable fue significativa la interacción, y solo para los cortes efectuados en el período lluvioso.

Estación poco lluviosa

La producción de biomasa de Tithonia manejada bajo corte fue menor en la estación poco lluviosa (Cuadro 1) con respecto a la observada en el período de mayor precipitación (Cuadro 3), lo cual era de esperar dado que la escasez de lluvias es un factor limitante para la producción de forraje (Navale et al. 2022). Sin embargo, en el caso de este estudio la escasez de lluvias fue más crítica que en años anteriores, pues durante el período en que se desarrolló el estudio las condiciones de precipitación fueron menores en 170 mm y 19 días de lluvia con relación a la media histórica; además, que no se aplicó riego a lo largo del período experimental.

En el Cuadro 1 se observa que la frecuencia de corte afectó significativamente todas las variables, pero el nivel de significancia más bajo (P=0.05) correspondió al peso verde de hoja por planta. La frecuencia de 60 días presentó los mejores indicadores para la mayoría de las variables evaluadas, como el número de tallos por plantón, número de hojas verdes por tallo, peso verde de hojas y rendimiento de biomasa. Si bien con la frecuencia de 80 días se obtuvo el mayor peso de 10 hojas, por tener estas un mayor tamaño, esto no se tradujo en mayor producción de biomasa por hectárea, pues con esa frecuencia de corte se detectó un menor número de tallos por plantón, número de hojas verdes por tallo, y contribución porcentual de hojas a la biomasa aérea total (Cuadro 1).

En cuanto al efecto de los materiales evaluados (Cuadro 2), se encontró diferencias entre ellos (P<0.01) para las variables número de hojas verdes/tallo, peso verde de tallos/planta, peso verde total/planta y la contribución porcentual de hojas a la biomasa total, correspondiendo los valores más altos a los materiales Oc-23 y Oc-24, siendo el primero quien superó a todos los materiales en todas las variables, excepto en el porcentaje de hojas, para el cual se obtuvo el mayor valor en el caso del material Oc-25. Estos materiales presentaron un comportamiento semejante para el número de tallos por plantón, peso verde de hojas/planta, peso de 10 hojas y rendimiento, indicadores de importancia si se tiene presente que la investigación se desarrolló bajo condiciones de disponibilidad limitada de humedad.

Estación lluviosa

Durante el período de lluvias, la frecuencia de corte afectó todas las variables morfo-agronómicas en tithonia (Cuadro 3), con niveles de significancia de P<0.001 para la mayoría de ellas, excepto para el número de tallos por plantón (P<0.01). Las variables expresadas en peso alcanzaron los valores más alto a los 80 días de rebrote; lo mismo ocurrió para el número de hojas amarillas y secas, pero la contribución porcentual de las hojas a la biomasa total tendió a disminuir a medida se incrementó la edad de rebrote (Cuadro 3).

En el Cuadro 4 se observa que los materiales de tithonia evaluados solo presentaron diferencias en el caso del número de hojas verdes/tallo (P=0.0366), la contribución porcentual de las hojas a la biomasa total (P=0.001) y el rendimiento de biomasa aérea total (P=0.0027).

Los materiales con valores superiores para el número de hojas verdes/tallo fueron Oc-10, Oc-23 y Oc-24, sin diferencias (P<0.05) entre ellos. En cambio, la mayor contribución de hojas a la biomasa total se presentó en Oc-24 y Oc-25, pero estos a su vez presentaron rendimientos más bajos (P<0.05) que Oc-23 (Cuadro 4). Para el resto de variables morfo-agronómicas (número de tallos/plantón; peso verde de tallos y de hojas/planta y peso de 10 hojas) no se detectaron diferencias entre los materiales estudiados.

En el periodo lluvioso, solo la variable peso verde total de la planta presentó interacción significativa (P=0.0035) para los factores frecuencia de corte × materiales destacados (Cuadro 5). El mayor peso verde total/planta correspondió al material Oc-23

Cuadro 1. Efecto de la frecuencia de corte sobre las variables morfo-agronómicas en *T. diversifolia*, durante la estación poco lluviosa.

Variables	Frecuencia, días			E.E. (Significación)
	40	60	80	
Número de tallos/plantón	11.71[c]	20.96[a]	14.82[b]	±0.99 (P=0.001)
Número de hojas verdes/tallo	7.26[a]	7.72[a]	5.94[b]	±0.34 (P=0.001)
Peso verde de hojas, g/planta	4.56[b]	6.45[a]	5.65[ab]	±0.69 (P=0.05)
Peso verde de tallos, g/planta	2.57[b]	3.83[b]	5.13[a]	±0.60 (P=0.001)
Peso verde total, g/planta	8.06[b]	12.60[a]	14.05[a]	±1.01 (P=0.001)
Peso verde de 10 hojas, g	6.24[b]	6.16[b]	9.07[a]	±0.78 (P=0.001)
Hojas, % biomasa aérea total	65.63[a]	64.72[a]	51.99[b]	±1.70 (P=0.001)
Rendimiento, t MS/ha	1.79[b]	2.92[a]	1.73[b]	±0,37 (P=0.001)

[a,b,c] Letras distintas en una misma fila indican diferencias significativas según Duncan (1955) para P<0.05.

Cuadro 2. Efecto del material vegetal sobre las variables morfo-agronómicas en *T. diversifolia*, durante la estación poco lluviosa.

Variables /	Materiales				E.E. (Significación)
	Oc-10	Oc-23	Oc-24	Oc-25	
Número de tallos/plantón	16.50	16.89	16.38	14.87	±1.05 (P=0.2533)
Número de hojas verdes/tallo	6.70[b]	7.68[a]	7.11[ab]	6.40[b]	0.33 (P=0.0043)
Peso verde de hojas, g/planta	5.14	6.50	6.14	4.39	±0.85 (P=0.0780)
Peso verde de tallos, g/planta	3.50[bc]	5.23[a]	4.23[ab]	2.41[c]	±0.72 (P=0.0046)
Peso verde total, g/planta	11.45[ab]	13.59[a]	12.43[a]	9.08[b]	±1.41 (P=0.0025)
Peso de 10 hojas, g	6.98	7.73	7.76	6.15	±0.80 (P=0.1712)
Hojas, % biomasa aérea total	60.27[b]	57.17[b]	59.73[b]	65.94[a]	±1.48 (P<0.0001)
Rendimiento, t MS/ha	2.14	2.48	2.51	1.45	±0.42 (P=0.0580)

[a,b,c] Letras distintas en una misma fila indican diferencias significativas según Duncan (1955) para P<0.05

en la frecuencia de 80 días, el cual difirió (P<0.05) del resto de tratamientos. En el caso de las otras variables morfo-agronómicas, no se detectó significancia para la interacción frecuencia de corte × materiales destacados.

Comportamiento Anual

En los análisis realizados para el acumulado anual, ninguna de las variables morfo-agronómicas presentó significancia para la interacción frecuencia de corte × materiales destacados; en cambio la frecuencia de corte afectó significativamente (P<0.001) todos los atributos evaluados (Cuadro 6).

Para la mayoría de las variables, los valores más altos correspondieron a la frecuencia de 80 días, excepto para el número de tallos/plantón y número de hojas verdes/ tallo, que presentaron los valores más altos para cortes a los 60 días, y en el caso de la contribución porcentual de las hojas a la biomasa total, el mayor valor correspondió a la frecuencia de 40 días. Como era de esperar, la menor contribución de hojas a la biomasa total se alcanzó con la frecuencia de 80 días. En términos generales, el rendimiento de biomasa aérea y el peso de 10 hojas tendieron a incrementar a medida aumentó la edad de rebrote; en cambio, el porcentaje de hojas mostró la tendencia opuesta (Cuadro 6).

Cuadro 3. Efecto de la frecuencia de corte sobre las variables morfo-agronómicas en *T. diversifolia*, durante la estación lluviosa.

Variables	Frecuencia, días			E.E. (Significación)
	40	60	80	
Número de tallos/plantón	11.89 b	13.28 a	13.11 a	±0.37 (P=0.01)
Número de hojas verdes/tallo	10.28 ab	10.70 a	9.60 b	±0.25 (P=0.001)
Número de hojas secas/tallo	0.35 b	0.45 b	1.34 a	±0.12 (P=0.001)
Número de hojas amarillas/ tallo	0.39 b	0.42 b	0.94 a	±0.09 (P=0.001)
Peso verde de hojas, g/planta	11.20 b	14.99 b	43.86 a	±3.10 (P=0.001)
Peso verde de tallos, g/planta	8.63 c	21.81 b	78.53 a	±5.90 (P=0.001)
Peso de 10 hojas, g	13.04 b	13.94 b	32.77 a	±3.47 (P=0.001)
Hojas, % biomasa aérea total	57.73 a	43.22 b	36.13 c	±1.63 (P=0.001)
Rendimiento, t MS/ha	4.88 c	9.50 b	16.93 a	±1.62 (P=0.001)

a,b,c Letras distintas en una misma fila indican diferencias significativas según Duncan (1955) para P<0.05.

Cuadro 4. Efecto del material vegetal sobre las variables morfo-agronómicas en *Tithonia diversifolia*, durante el periodo lluvioso.

Variables	Materiales				E.E. (Significación)
	Oc-10	Oc-23	Oc-24	Oc-25	
Número de tallos/plantón	12.22	13.76	12.63	12.43	±0.72 (P=0.1674)
Número de hojas verdes/tallo	10.18 ab	10.53 a	10.28 ab	9.79 b	±0.24 (P=0.0366)
Peso verde de hojas, g/planta	22.78	23.78	25.08	21.78	±1.88 (P=0.3565)
Peso verde de tallos, g/planta	35.99	42.68	37.65	28.97	±5.13 (P=0.0856)
Peso de 10 hojas, g	22.62	22.68	24.39	23.31	±1.79 (P=0.7378)
Hojas, % biomasa aérea total	44.49 bc	41.74 c	46.71 ab	49.82 a	±1.70 (P=0.001)
Rendimiento, t MS/ha	10.99 b	12.03 a	9.18 b	9.55 b	±1.43 (P=0.0027)

a,b,c Letras distintas en una misma fila indican diferencias significativas según Duncan (1955) para P<0.05

Cuadro 5. Efecto de la interacción frecuencias de corte × material vegetal de *Tithonia diversifolia* sobre el peso verde total por planta (g), durante la estación lluviosa.

Variables	Materiales				E.E. (Significación)
	Oc-10	Oc-23	Oc-24	Oc-25	
40	23.81 e	24.63 e	22.83 e	19.95 e	±13.11 (P=0.0035)
60	70.88 bc	54.23 cd	36.65 de	36.93 de	
80	91.05 b	127.88 a	90.78 b	75.73 b	

a,b,c,d,e Letras distintas en una misma fila indican diferencias significativas según Duncan (1955) para P<0.05.

Cuadro 6. Efecto de la frecuencia de corte sobre las variables morfo-agronómicas en *Tithonia diversifolia*, en el total anual.

Variables	Frecuencia, días			E.E. (Significación)
	40	60	80	
Número de tallos/plantón	12.29 [b]	17.11 [a]	13.96 [b]	±0.62 (P=0.001)
Número de hojas verdes/tallo	8.42 [b]	9.01 [a]	8.32 [b]	±0.17 (P=0.001)
Peso verde de hojas, g/planta	7.87 [b]	10.71 [b]	24.77 [a]	±1.39 (P=0.001)
Peso verde de tallos, g/planta	5.60 [b]	12.84 [b]	41.82 [a]	±2.95 (P=0.001)
Peso verde total, g/planta	15.44 [c]	31.24 [b]	55.21 [a]	±1.04 (P=0.001)
Peso de 10 hojas, g	9.64 [b]	10.06 [b]	25.92 [a]	±1.53 (P=0.001)
Hojas, % biomasa aérea total	61.68 [a]	53.98 [b]	44.05 [c]	±1.37 (P=0.001)
Rendimiento anual, t MS/ ha	6.66 [b]	12.41 [a]	17.24 [a]	±1.93 (P=0.001)
Rendimiento en época poca lluviosa, %	26.8	23.5	10.0	

[a,b,c] Letras distintas en una misma fila indican diferencias significativas según Duncan (1955) para P<0.05.

Cuadro 7. Efecto del material vegetal sobre las variables morfo-agronómicas en *Tithonia diversifolia*, en el total anual.

Variables	Materiales				E.E. (Significación)
	Oc-10	Oc-23	Oc-24	Oc-25	
Número de tallos/plantón	14.35	15.32	14.50	13.65	±0.72 (P=0.1747)
Número de hojas verdes/tallo	8.43 [bc]	9.11 [a]	8.69 [ab]	8.09 [c]	±0.23 (P=0.0016)
Peso verde de hojas, g/planta	13.96	15.15	15.62	13.08	±1.14 (P=0.1289)
Peso verde de tallos, g/planta	19.77 [ab]	23.96 [a]	20.94 [ab]	15.68 [b]	±2.69 (P=0.0373)
Peso verde total, g/planta	36.68 [ab]	41.25 [a]	31.27 [bc]	26.66 [c]	±1.51 (P=0.0002)
Peso de 10 hojas, g	14.80	15.21	16.08	14.73	±1.08 (P=0.5801)
Hojas, % biomasa aérea total	52.38 [b]	49.43 [c]	53.24 [b]	57.88 [a]	±1.21 (P<0.0001)
Rendimiento anual, t MS/ha	12.73 [b]	13.88 [a]	11.07 [b]	10.73 [b]	±0.98 (P=0.0022)
Rendimiento en época poca lluviosa, %	16.8	17.8	22.6	13.5	

[a,b,c] Letras distintas en una misma fila indican diferencias significativas según Duncan (1955) para P<0.05.

Los materiales de tithonia evaluados mostraron diferencias significativas (P<0.05) para el número de hojas verdes/tallo, peso verde de tallos/planta y peso verde total/planta, contribución porcentual de las hojas y rendimiento de biomasa aérea total (Cuadro 7). Nuevamente, el material Oc-23 presentó el rendimiento más alto, pero la menor contribución de las hojas a la biomasa aérea total. En contraste, la respuesta opuesta se observó en el caso del material Oc-25 (Cuadro 7).

Discusión

La capacidad de producción forrajera de *Tithonia diversifolia* está determinada entre otros factores por el estado fenológico. Esta especie presenta una marcada tolerancia a la poda, se recupera de forma rápida luego de cortes sucesivos y además posee una elevada tasa de rebrote, lo que le permite producir gran cantidad de biomasa (Lugo et al. 2012; Londoño et al. 2019). Reyes et al. (2008) señalan que las plantas forrajeras en los trópicos crecen rápidamente durante los períodos de alta precipitación y temperatura, y que los cortes realizados en árboles forrajeros en las diferentes estaciones del año (época seca vs época húmeda) y en diferentes fases de desarrollo (reproductivo *vs* vegetativo), pueden influir en el rebrote siguiente.

Con relación al resultado obtenido en este estudio respecto al efecto de la frecuencia de corte sobre las características morfo-agronómicas en la estación poco lluviosa, Lugo et al. (2012) encontraron que este factor afectaba la producción de biomasa en *Tithonia diversifolia*, y al igual que en este estudio encontraron que el intervalo de cosecha óptimo sería a los 60 días; en cambio la altura de corte no la afectaba. Por otro lado, en cuanto a las variaciones en las características morfo-agronómicas y de rendimiento en función de la edad de corte, observadas durante la estación poco lluviosa (Cuadro 1), los resultados de este estudio coinciden con lo reportado por Cabanilla-Campos et al. (2021), quienes además sugieren que estos atributos, acompañados de las características nutricionales del forraje, hacen de la *Tithonia diversifolia* una especie forrajera valiosa para la alimentación animal.

Al efectuar un análisis integrando el comportamiento de los indicadores estudiados en el período menos lluvioso, se puede decir que con la edad de rebrote de 80 días se produce un forraje caracterizado por mayor presencia de tallos, mientras que con la frecuencia de 60 días ocurre lo inverso, hay una mayor cantidad de hojas, así como el peso de hojas por planta, % de hojas, número de hojas por tallo y rendimiento/ha. Resultados similares fueron obtenidos por Senarathne et al. (2018) trabajando con tithonia en Sri Lanka.

Cabe anotar que Botero-Londoño et al. (2019) encontraron que las características de la hoja en *Tithonia diversifolia* presentaban una alta correlación con las demás características productivas del cultivo, razón por cual éstas pueden ser un referente de fácil medición para determinar las atributos productivos y nutricionales de la planta. En ese sentido, en relación con el comportamiento de los indicadores monitoreados para los diferentes materiales evaluados en el presente estudio (Cuadro 2), se observó que todos presentaron un mayor peso de hojas que de tallos. Los materiales Oc-23 y Oc-24 se mostraron como los más deseables desde el punto de vista forrajero, ya que alcanzaron los rendimientos más altos, un mayor número de hojas verdes por tallo y un mayor peso/planta, lo cual compensa el hecho que tenga una proporción de hojas menor que el Oc-25, pues al final la producción total de hojas será mayor en Oc-23 y Oc-24.

El hecho que se tenga un mayor número de hojas senescentes (amarillas y secas) con la frecuencia de corte cada 80 días en la estación poco lluviosa (Cuadro 3), es un aspecto negativo desde el punto de vista de la producción de forraje de calidad, pero es algo esperado dado que la senescencia de hojas ocurre a medida avanza la edad de la planta (Vargas Velázquez et al. 2022), y es más evidente bajo condiciones de menor disponibilidad de humedad. En cambio, con las frecuencias de corte cada 40 y 60 días no solo hubo más hojas verdes, sino que además las hojas representaron una proporción mayor de la biomasa aérea total, lo cual es relevante desde el punto de vista de la oferta de follaje comestible para el ganado (Cadena-Villegas et al. 2020; Vargas Velázquez et al. 2022).

Es posible que en años con mayor precipitación en la época lluviosa que la observada en este estudio, los rendimientos podrían ser más altos, pues durante el período cubierto por el estudio, hubo una diferencia de 663.9 mm menos por año y 38 días menos con lluvia en la época lluviosa, comparado a la media histórica, lo cual debe haber afectado el desarrollo de las plantas, pues tithonia es una especie que se comporta mejor cuando la disponibilidad de humedad no es limitante (dos Santos Silva et al. 2021).

El comportamiento observado al analizar la información anual (Cuadros 6 y 7) es muy semejante a la reflejada en los análisis parciales por época (Cuadros 1, 2, 3 y 4). En ellos queda demostrada la necesidad de efectuar un análisis integrando los diferentes indicadores evaluados en esta investigación, pues la definición del mejor tratamiento no puede basarse solo en el rendimiento, sino que debe considerarse también otros indicadores morfo-agronómicos tales como el número de tallos/plantón y de hojas verdes/tallo, el peso de hojas verdes y su contribución porcentual a la biomasa producida. Esto último es de particular importancia porque las hojas son el componente que presenta los mayores valores de proteína cruda y digestibilidad (Lezcano et al. 2012).

Con relación a la contribución de la producción en la estación poco lluviosa respecto al acumulado anual, este osciló entre 10.0 y 26.8% en función de la frecuencia de corte (Cuadro 6), y entre 13.5 y 22.6% cuando se compararon los materiales estudiados (Cuadro 7). Resultados similares fueron obtenidos por Uu-Espens et al. (2021) quienes indicaron que el rendimiento de forraje en la época lluviosa fue 2.7 veces mayor que en la época seca (2.4 *versus* 0.9 t MS/ha). Así mismo, Navas-Panadero y Montaña (2019) observaron una mayor producción de tithonia en la época de lluvias, pues su producción de biomasa se ve influenciada por el factor precipitación, al igual que en el caso de muchos otros forrajes (Navale et al. 2022).

En cuanto al efecto de la frecuencia de corte sobre el rendimiento anual (Cuadro 6), es evidente que el mayor rendimiento se presentó con el intervalo entre cortes más largo (80 días), lo que también fue observado en el periodo de mayor precipitación (Cuadro 4), mientras que en el período de poca precipitación el mayor rendimiento se alcanzó a los 60 días (Cuadro 1), debido a que se presentó una mayor senescencia de hojas cuando se extendió la fase de rebrote (Cuadro 3).

La mayor producción de biomasa forrajera de tithonia a los 80 días también fue observada por Guatusmal-Gelpud et al. (2020), pero cuando consideraron la calidad nutricional del forraje, ellos obtuvieron los mejores valores a los 60 días de rebrote. Por otro lado, Ruiz et al. (2013; 2016), al estudiar la curva de crecimiento de diferentes materiales de tithonia encontraron un crecimiento estable y adecuado en ambas estaciones climáticas y los mejores valores correspondieron al intervalo de 60–75 días, el cual también fue considerado como óptimo por Polo y Medina (2021) trabajando con tithonia en Panamá.

El patrón de respuesta de la producción de tithonia en respuesta a la prolongación del intervalo entre cortes, tanto en la época poco lluviosa como lluviosa (Cuadros 1 y 3), y en el rendimiento anual (Cuadro 6), coincide con lo expresado por Stür et al. (1994), quienes señalan que en el nuevo crecimiento de plantas defoliadas ocurre primero un rebrote lento debido a la poca cantidad de área foliar, seguido por un período de máxima productividad, en el cual la producción de hojas aumenta marcadamente, y luego una fase donde la planta presenta incrementos en la altura y aumenta la producción de biomasa leñosa; mientras que la cantidad de hojas permanece estable o con pequeños incrementos.

Los cuatros materiales seleccionados de tithonia incluidos en este estudio (Oc-10, 23, 24 y 25) mostraron semejanza en cuanto al número de tallos/plantón, el peso verde de hojas/planta y el peso de 10 hojas (Cuadros 2, 4 y 7), indicadores de importancia si se tiene en cuenta que esta investigación enfrentó condiciones atípicas en cuanto a la disponibilidad de humedad. El material Oc-25 fue el más afectado por las condiciones de sequía en el período poco lluvioso (Cuadro 2) en comparación a los otros materiales, pero se desarrolló mejor en la estación lluviosa (Cuadro 7). Este aspecto se debe tener presente al seleccionar la zona para su explotación.

Por otro lado, si bien el material Oc-23 presentó el mayor rendimiento anual de biomasa aérea total (Cuadro 7), el análisis de otros atributos morfo-agronómicos importantes como la contribución porcentual de hojas a la biomasa total no lo hacen más destacado que el resto, lo que confirma la importancia de no basar exclusivamente en el rendimiento, las decisiones sobre qué material recomendar para un sitio.

Con base en los resultados obtenidos se puede concluir que los cuatro materiales de tithonia evaluados presentan características adecuadas para la producción de forraje bajo corte, aún en ausencia de fertilización y riego. Por ello, no sería lógica la discriminación de alguno de ellos para este fin productivo, sino seleccionarlos de acuerdo a las condiciones de sitio donde se desea implantar la tithonia.

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Research Paper

Farmers' evaluation and economic viability of *Urochloa* grasses grown on Nitosol and Vertisol in middle elevations in Ethiopia

Evaluación de los agricultores y viabilidad económica de los pastos Urochloa *cultivados en Nitosol y Vertisol en elevaciones medias en Etiopía*

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Abstract

This field study was carried out in the Ethiopian mid-elevations on Vertisol and Nitosol to determine effects of fertilizer use and identify more productive *Urochloa* grass varieties and cultivars based on farmers' variety evaluation and partial budget analyses. The study evaluated *Urochloa brizantha* cultivars 'La Libertad' and 'Marandu', *Urochloa* hybrid cultivars 'Mulato I' (Mulato I) and 'Mulato II' (Mulato II) and *Urochloa mutica* species. Data on farmers' variety selection were gathered at 45 and 90 days after planting. Pair wise preference ranking was used to record farmers' variety preferences and partial budgeting was used for economic analysis. Farmers selected *Urochloa* grass varieties or cultivars based on a variety of factors, including plant height, number of tillers, leafiness and smoothness. Mulato II, *U. mutica* and Mulato I were chosen in first, second and third rank, respectively, based on evaluation using farmers' criteria. *U. mutica* and Mulato II showed the highest gross benefit and benefit-cost ratio when fertilizer was applied at both sites. *U. mutica* produced the highest dry matter yield at both sites. *U. mutica* and Mulato II were selected as having superior production to meet requirements for fodder quantity in the research areas.

Keywords: Benefit-cost ratio, criteria, dry matter yield, fertilizer effects, partial budget analysis.

Resumen

Este estudio de campo se llevó a cabo en las elevaciones medias de Etiopía en suelos Vertisole y Nitosoles para determinar los efectos del uso de fertilizantes e identificar variedades y cultivares de pasto *Urochloa* más productivos basándose en la evaluación de variedades por los agricultores y análisis de presupuesto parcial. El estudio evaluó los cultivares de *Urochloa brizantha* 'La Libertad' y 'Marandu', los cultivares híbridos de *Urochloa* 'Mulato I' (Mulato I) y 'Mulato II' (Mulato II) y la especie de *Urochloa mutica*. Los datos sobre la selección de variedades por parte de los agricultores se recopilaron a los 45 y 90 días después de la siembra. Se utilizó una clasificación de preferencias por pares para registrar las preferencias de variedades por los agricultores y se utilizó la técnica de presupuesto parcial para el análisis económico. Los agricultores seleccionaron variedades o cultivares de pasto *Urochloa* en función de una variedad de factores, incluida la altura de la planta, el número de macollos, la frondosidad y la suavidad. Mulato II, *U. mutica* y Mulato I fueron elegidos en primer, segundo y tercer lugar, respectivamente, con base en la evaluación realizada con criterios de los agricultores. *U. mutica* y Mulato II mostraron el mayor beneficio bruto y la mejor relación beneficio-costo cuando se aplicó fertilizante en ambos sitios. *U. mutica* produjo el mayor rendimiento de materia seca en ambos sitios. Se seleccionaron *U. mutica* y Mulato II por tener una producción superior para cumplir con los requisitos de cantidad de forraje en las áreas donde se desarrolló la investigación.

Palabras clave: Análisis de presupuesto parcial, efectos de fertilizantes, relación costo-beneficio, rendimiento de materia seca.

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Introduction

Improved forages are crucial to supplement crop residues as feed. For the majority of ruminant livestock in the tropics, forage grasses serve as their primary source of nourishment. Higher herd densities on current pastures and increasing the yields of forage crops can both reduce strain on increasingly limited land resources and improve accessibility and reduce the cost of animal products (Fuglie et al. 2021). Although a wide variety of forages have been introduced in tropical regions, most attempts have overlooked farmers' preferences (Fuglie et al. 2021). Farmers have identified selection criteria through focus group discussions based on their extensive knowledge on forage production or feed resource identification (Misiko et al. 2008). Selection criteria, including drought tolerance, soil erosion control, plant height, growth habit, leaf color, disease and insect tolerance, and suitability for grazing and cut-and-carry have been used to select cultivars of *Urochloa* grass.

A top-down methodology has typically been used to evaluate and select varieties based on chemical composition and agronomic data. For variety selection, this kind of selection strategy is essential but insufficient. Participating farmers' opinions on variety evaluation and selection are required to increase acceptance (Roothaert et al. 2003). Most agriculture researchers have been trained in dissemination techniques that follow a clearly prescribed pattern. However, these techniques do not allow farmers to experiment or make decisions at every stage. Participatory approaches take time, while donors and national organizations may require quick results. The required flexibility of participatory approaches implies a lack of structure, which many new practitioners find difficult (Roothaert et al. 2003). Participatory selection of lablab (Hunegnaw et al. 2016), cowpea (Walie et al. 2016) and sweet lupin (Mekonnen et al. 2016) varieties for intercropping with maize was shown to be the successful choice of an individual farmer. The variety selection process uses a preference-ranking approach with pair-wise ranking to prioritize selection parameters (de Boef and Thijssen 2007). These approaches highlight the rationale for farmer's selection of feed. Since 1970, Ethiopian farmers have gradually been introducing improved forage species to complement the country's natural feed supplies, but adoption rates are still low owing to land scarcity, lack of improved forage seed/planting material, lack of awareness and poor extension services hindering forage technology adoption (EARO 2002; Gebremedhin et al. 2003; Beshir 2014).

Nitrogen fertilizer improves crude protein content, voluntary feed intake and digestibility, as well as dry matter yield (Aderinola 2007) but there is limited local economic information to encourage use of fertilizer for forage production (Sodeinde et al. 2006). Use of fertilizers to increase fodder productivity is restricted due to farmers' inability to afford them (Sodeinde et al. 2006). There is little information being made available to Ethiopian farmers on the economic impact of growing *Urochloa* cultivars and species in Ethiopia and use of inorganic fertilizer. This study was carried out to determine productivity, economic viability of fertilizer use and farmer perception of adaptation and productivity of these cultivars on Nitosol and Vertisol in Ethiopia.

Materials and Methods

The study was carried out concurrently on station at the Andassa Livestock Research Center (ALRC) at the Medabit Forage Trial Site and on farm at Ambo Mesk, North Mecha District (Mecha) West Gojam Zone, Amhara Region, Ethiopia. ALRC is located at 11°9' N and 37°9' E at an elevation of 1,730 masl. The soil in the area (Table 1) is Vertisol (Mekonnen et al. 2016). Ambo Mesk is situated between 11° 10′ to 11° 32′ N and 37° 04′ to 37° 17′ E at an elevation of 1,998 masl. The Mecha district primarily has Nitosol (Yeheyis et al. 2012). In both districts, the rainfall pattern is monomodal (Figure 1) (Hunegnaw et al. 2022). The duration of the experiment was during the rainy season from 1 June 2020 to 30 October 2020.

The experiment was established as root splits in a randomized complete block design with subplots (fertilizer and cultivar) and 3 replications at ALRC and Mecha districts. The study evaluated *Urochloa brizantha* cultivars 'La Libertad' (La Libertad) and 'Marandu' (Marandu), *Urochloa* hybrid cultivars 'Mulato I' (Mulato I) and 'Mulato II' (Mulato II) and *Urochloa mutica* grass with and without fertilizer (Table 2). Intra- and inter-row spacing was kept constant at 0.5 m and plots of 9 m^2 (3 m × 3 m) and blocks were separated by 0.5 and 1 m, respectively. Fertilizer was applied at planting at a rate of 100 kg nitrogen, phosphorus and sulfur (NPS)/ha and urea was applied 30 d after planting at a rate of 50 kg urea/ha. Two harvests (90 d after establishments for first harvest on 30 August 2020 and 60 d after first harvests for second cut on 30 October 2020) were carried out in the main rainy season and annual yield was estimated from them.

Plant height, tiller number, and yield were recorded at 90 d for first cut after establishment and 60 d later for second cut. Ten plants were chosen at random from the center 3 × 3 m of each plot. After measuring plant height and counting tiller number, plants were harvested at 10 cm height by cutting with a sickle. Farmers' perception was measured by variety selection at the vegetative stage (45 d after planting) and again at harvest at 90 d. Cost and benefit data were gathered for partial budget analysis at every production stage.

Farmer forage selection

Based on their interest in the technologies, willingness to take part in cultivar/variety evaluation, and prior experience with increased forage production, 20 farmers including 6 female farmers, representing community organizations were selected to participate in selection at both sites of ALRC and Mecha. Forage experts from the district agricultural office, researchers from the ALRC (focusing on feed, nutrition, and

Table 1. Soil chemical composition.

Soil type	Soil chemical composition				
	pH	Organic carbon (%)	Organic matter (%)	Total nitrogen (%)	Available phosphorus (ppm)
Vertisol	6.94	1.41	2.42	0.22	4.57
Nitosol	5.45	1.64	2.86	0.23	7.49

Source: Hunegnaw et al. 2022

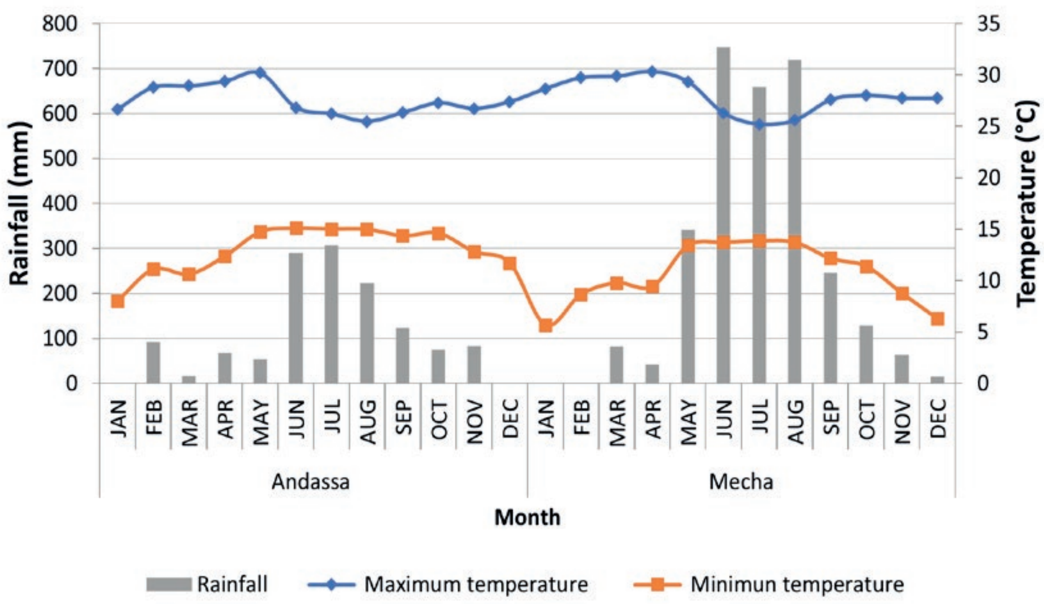

Figure 1. Monthly rainfall (mm) and maximum and minimum temperature (°C) of experimental sites (Hunegnaw et al. 2022).

Table 2. Grasses tested in treatment combinations.

Grasses	With fertilizer (WF)	Without fertilizer (WO)
Urochloa mutica (UM)	UMWF	UMWO
Urochloa Hybrid cultivar 'Mulato I'(UMI)	UMIWF	UMIWO
Urochloa Hybrid cultivar 'Mulato II' (UMII)	UMIIWF	UMIIWO
Urochloa brizantha cultivar 'Marandu' (UMU)	UMUWF	UMUWO
Urochloa brizantha cultivar 'La Libertad' (ULA)	ULAWF	ULAWO

extension), and kebele development agents (DAs) were also involved in recording farmers' perceptions in the field. Following an explanation of the study goals, farmers had the opportunity to visit all experimental plots and develop criteria for cultivar/varieties/species selection using their traditional knowledge.

Urochloa grass selection criteria were captured using pair-wise matrix ranking and preference ranking techniques. The pair-wise matrix ranking method was used to determine the weight of each criterion for farmers. Farmers voted for each criterion and rated the grasses using a preference ranking approach proposed by de Boef and Thijssen (2007). Selection criteria were scored and used to determine overall weighted ranking of *Urochloa* grasses. Comparisons of all *Urochloa* grasses were made using the sum of all selection criteria weighted values according to preference ranking.

Partial budget analysis

The method documented by CIMMYT (1988) was used to perform the partial budget analysis considering only variable costs across experimental treatments to determine the economic viability of fertilizer application. This method was selected because of easy applicability to on farm participatory research conditions. Data on all variable expenses associated with fertilizer costs (including the cost of NPS and urea) were recorded from farmers. At each site, the average yield of each treatment in the trial was recorded. The average cost of purchasing 100kg of NPS at cooperatives was USD 41/100kg and the average cost of purchasing urea was USD 34.7/100kg. There was no field price or market price for *Urochloa* hay at the sites but the price of 1kg *Urochloa* hay has been valued at up to USD 0.12/kg (Walie et al. 2018). In the current study, the market price estimate for *Urochloa* hay was set at USD 0.09/kg. Adjusted yield was used to reflect the yield that farmers can achieve on their farms, estimated at 10% less than yields recorded in these replicated trials with and without fertilizer using identical methods (CIMMYT 1988). Gross benefit (GB) was calculated from the predicted market price and adjusted dry matter yield. Gross profit (GP) for each cultivar was determined by deducting the total expenditures from the gross field benefit and the benefit-cost ratio calculated as gross benefit divided by total variable cost that was incurred in the experiment.

Data Analysis

Analysis of variance (ANOVA) was used to analyze data on plant height, tiller number and total dry matter yield. The F test was used for analysis of variance and Duncan's multiple range test (DMRT) ($P<0.05$) was used to compare treatment means for the variables for which the F test was significant. Reductions were deemed statistically significant at a level of ($P<0.05$).

Results

The interaction effects between fertilizer application, cultivar and soil type had significant ($P<0.001$) effect on plant height, number of tillers per plant and dry matter yield of *Urochloa* grasses (Table 3). Plant height increased with fertilizer application at both sites for all cultivars and species. Plant height of grasses grown on Vertisol was higher than for plants grown on Nitosol. All parameters increased with application of fertilizer with the highest yields being obtained from UMWF and UMIIWF grown on both soils.

Farmers' selection criteria

Farmers' selection criteria were ranked pair wise to determine which trait was considered most crucial for forage selection on Vertisol (Table 4) and Nitosol (Table 5). Plot cover, leafiness (number of leaves per plant), plant height (visible observation of the growing condition) and smoothness/softness (feeling leaves with fingers) were determined as criteria for selection on both soils.

Farmers' variety evaluation of Urochloa grass

Farmers' preference ranking for *Urochloa* grass showed Mulato II was preferred, followed by Mulato I and *U. mutica* (Table 6). Farmers considered plot cover, linked to tiller number, and plant height as significant factors influencing forage productivity.

Table 3. Effect of fertilizer, cultivars and soil type on plant height, number of tillers per plant and dry matter yield of *Urochloa* grasses.

Soil type	*Urochloa*	Plant Height (m)	NTPP (count)	Dry matter yield (t/ha)
Vertisol	UMWF	1.55a	40bc	20.37a
	UMIIWF	0.82d	46a	18.61b
	UMIWF	0.52fg	36.3efg	11.07e
	UMUWF	0.51fg	29.8j	7.13g
	ULAWF	0.49fg	26.2k	5.7jkl
	UMWO	1.12c	32.2hi	6.95gh
	UMIIWO	0.55f	36.3efg	6.5hi
	UMIWO	0.37ij	31.03ij	5.33kl
	UMUWO	0.32jk	26.67k	3.85n
	ULAWO	0.35jk	24.9k	2.75o
Nitosol	UMWF	1.45b	41.67b	17.19c
	UMIIWF	0.62e	45.27a	13.29d
	UMIWF	0.52fg	39cd	11.55e
	UMUWF	0.5fg	37.67de	6.02ij
	ULAWF	0.46gh	36.03efg	5.87jk
	UMWO	0.85d	20.33l	5.27l
	UMIIWO	0.42hi	34.8fg	8.2f
	UMIWO	0.36ij	31.17ij	5.65jkl
	UMUWO	0.38ij	37.0def	4.44m
	ULAWO	0.3k	34.0gh	3.47n
	SEM	0.04	0.86	0.63
	CV	5.6	3.74	3.78
	SL	***	***	***

NTPP=number of tillers per plant; SEM=standard error of mean; CV=coefficient of variation; SL=significance level. Means within columns with different letter are significant at P<0.001

Table 4. Pair-wise ranking matrix of selection criteria for grasses grown on Vertisol.

Criteria	Plot cover	Plant height	Leafiness	Tiller number	Smoothness/ leaf softness	Score/ Frequency	Rank
Plot cover		1	1	1	1	4	1
Plant height			2	4	2	2	3
Leafiness				4	5	1	4
Tiller number					4	3	2
Smoothness/leaf softness						0	5

Table 5. Pair-wise ranking matrix of selection criteria for grasses grown on Nitosol.

Criteria	Plot cover	Plant height	Leafiness	Tiller number	Smoothness/ leaf softness	Score/ Frequency	Rank
Plot cover		2	3	4	1	1	4
Plant height			3	4	2	2	3
Leafiness				4	3	3	2
Tiller number					4	4	1
Smoothness/leaf softness						0	5

Economic viability of fertilizer application

The overall partial budget analysis is presented in detail in Table 7 and 8. The highest gross profit in the Vertisol was obtained from UMWF (USD 856) followed by UMIIWF (USD 763.4) (Table 7). Similarly, the highest gross profit in the Nitosol soil was obtained from UMWF (USD 750) followed by UMIIWF (USD 589.6) (Table 8). The gross profit among cultivars, fertilizer, and soil type differed with dry matter yield differences among experimental *Urochloa* grasses cultivars for both fertilizers and soil type. The benefit-cost ratio obtained from Mulato II and *U. mutica* (2.2 on Nitosol and 2.1 on Vertisol) implies that growing *Urochloa* grasses with fertilizer is profitable for farmers.

Table 6. Farmers' preference ranking.

	Selection criteria	Weighted value	*Urochloa* grasses and weighted score values				
			UMI	UMII	UM	UMU	ULA
Vertisol (ALRC)	Plot cover	5	125	120	120	65	70
	Tiller number	4	72	88	80	64	56
	Plant height	3	60	60	69	51	15
	Leafiness	2	30	60	24	56	30
	Leaf Smoothness	1	15	30	20	20	10
	Total score	-	302	358	313	256	181
	Rank	-	2	1	3	4	5
Nitosol (Mecha)	Plot cover	2	24	44	52	16	24
	Tiller number	5	70	110	85	75	45
	Plant height	3	48	48	60	36	18
	Leafiness	4	56	104	60	48	52
	Leaf Smoothness	1	16	22	16	16	10
	Total score	-	214	328	273	191	149
	Rank	-	3	1	2	4	5

Table 7. Partial budget analysis *Urochloa* grass cultivars and species grown on Vertisol with and without fertilizer.

Description	*Urochloa* grass cultivars/varieties (Treatments)									
	ULAWO	UMUWO	UMIWO	UMIIWO	UMWO	ULAWF	UMUWF	UMIWF	UMIIWF	UMWF
DMY (Kg/ha)	2,750	3,850	5,330	6,500	6.950	5,700	7,130	11,070	18,610	20,370
ADMY (Kg/ha) (A)	2,475	3,465	4,797	5,850	6,255	5,130	6,417	9,963	16,749	18,333
Cost of NPS/ha (100kg)	0	0	0	0	0	41	41	41	41	41
Cost of Urea/ha (50kg)	0	0	0	0	0	17.4	17.4	17.4	17.4	17.4
Harvesting cost/ha	128.5	160.8	270.3	310.5	350.4	270.4	370.1	448.3	660.5	708.1
(TVC) (B)	128.5	160.8	270.3	310.5	350.4	328.8	428.5	506.6	718.8	766.5
Price (USD/kg) (C)	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Gross benefit (USD) (A*C)(D)	219.0	306.6	424.5	517.7	553.56	454	567.9	881.7	1,482.3	1,622.5
Gross profit (D-B) (USD)	90.5	145.8	154.2	207.2	203.2	125.2	139.4	375.1	763.4	856
Benefit-cost ratio (B/C)(USD)	1.7	1.9	1.6	1.6	1.6	1.38	1.32	1.7	2.1	2.1

USD=US dollar; DMY=Dry matter yield; ADMY=Adjusted dry matter yield; NPS=Nitrogen, phosphorous and sulfur; TVC=Total variable cost.

Table 8. Partial budget analysis *Urochloa* grass cultivars and species grown on Nitosol with and without fertilizer.

Description	*Urochloa* grass cultivars/varieties (Treatments)									
	ULAWO	UMUWO	UMIWO	UMIIWO	UMWO	ULAWF	UMUWF	UMIWF	UMIIWF	UMWF
DMY (Kg/ha)	3,470	4,440	5,270	5,660	8,200	5,870	6,020	11,550	13,290	17,190
ADMY (Kg/ha) (A)	3,123	3,996	4,743	5,085	7,380	5,283	5,418	10,395	11,961	15,471
Cost of NPS/ha (100kg)	0	0	0	0	0	41	41	41	41	41
Cost of Urea/ha (50kg)	0	0	0	0	0	17.4	17.4	17.4	17.4	17.4
Harvesting cost/ha	140.5	240.8	270.5	280.5	320.2	290.5	280.1	390.4	430.5	560.8
(TVC) (B)	140.5	240.8	270.5	280.5	320.2	348.8	338.5	448.7	488.8	619.2
Price (USD/kg) (C)	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Gross benefit (USD) (A*C)(D)	276.4	353.6	419.7	450.0	653.1	467.5	479.5	919.9	1,058.5	1,369.2
Gross profit (D-B) (USD)	135.9	112.8	149.2	169.5	332.9	118.7	141	501.2	589.6	750
Benefit-cost ratio (B/C)(USD)	1.9	1.4	1.5	1.6	2.0	1.3	1.4	2	2.2	2.2

USD=US dollar; DMY=Dry matter yield; ADMY=Adjusted dry matter yield; NPS=Nitrogen, phosphorous and sulfur; TVC=Total variable cost.

Discussion

Plant height increases with fertilizer could be associated with increased root development and efficient nutrient uptake, allowing the plant to continue to increase in height (Berihun 2005). Taller plants on Vertisol could indicate lower adaptation to soil acidity of the red soil (pH 5.45). Tiller number increases the chances of survival and forage yield (Laidlaw 2005) and is an indicator of efficient utilization of nutrients. Kizima et al. (2014) reported that application of optimal levels of nitrogen fertilizer significantly increased tiller number of *Cenchrus ciliaris* grass. The highest yield of *Urochloa* grass could be attributed to the formation of additional tillers which conveyed an increase in leaf formation, leaf elongation and stem development from application of fertilizer (Crowder and Chheda 1982). The highest yield was recorded on cultivars with fertilizer at both sites. The overall evaluation found that *U. mutica* and Mulato II provided sufficient biomass to address forage shortages and enhance livestock production and productivity in the study areas.

Farmers selected grasses based on plant height, leafiness, smoothness, number of tillers and plot cover. Cheruiyot et al. (2020) reported that farmers often preferred cultivars with smooth leaves since they were easier to cut and handle because the hairs on the leaves cause skin irritation. Additionally, farmers believe that Mulato II is superior because the animals prefer softer leaves. The results of this investigation are consistent with other reports (Cheruiyot et al. 2020) on *Urochloa* grasses and the opportunity cost of adopting improved planted forages (Maina et al. 2022). In order to promote and multiply cultivars in future, farmers would need to increase the availability of planting materials through use of root splits or cuttings (Ramadhan et al. 2015).

Assessment of plot cover and plant height as significant factors influencing forage productivity was supported by Zewdu et al. (2006), who found a direct correlation between increased foliage and plant height.

The benefit-cost ratio for all treatments was found to be higher than the lowest acceptable rate of return (CIMMYT 1988) with fertilizer application increasing gross benefits and benefit-cost ratios of *U. mutica*, Mulato II and Mulato I on both soils. The partial budget analysis accounts for costs that vary over the course of the experiment period and is easy to apply in on farm participatory research conditions. The limitation of this approach is not considering the fixed costs so that net benefits and net profits from each experimental unit cannot be calculated. Application of fertilizer to La Libertad grown on Nitosol and Marandu grown on Vertisol in the current study was not economically profitable, indicating there is no benefit to apply fertilizer to *Urochloa* cultivars with low yields. The current study confirms that applying fertilizer to more productive *Urochloa* grasses, such as *U. mutica* and Mulato II was profitable. Maina et al. (2022) reported that the production of different *Urochloa* cultivars under farmer's field conditions resulted in higher gross benefit than growing Napier grass.

Conclusions

The farmers' selection criteria ranked tiller number and plant height as important traits for forage development and Mulato II and *U. mutica* as preferred forages. *U. mutica* and Mulato II had the highest gross benefit and benefit-cost ratio at both sites. Studies on availability of planting materials from farmers will be essential to promote and multiply cultivars in the future for further adoption. Additional adaptation and feeding studies are needed in a range of environments to fully test the potential of these grasses under farmers' management strategies.

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(Note of the editors: All hyperlinks were verified 24 May 2024).

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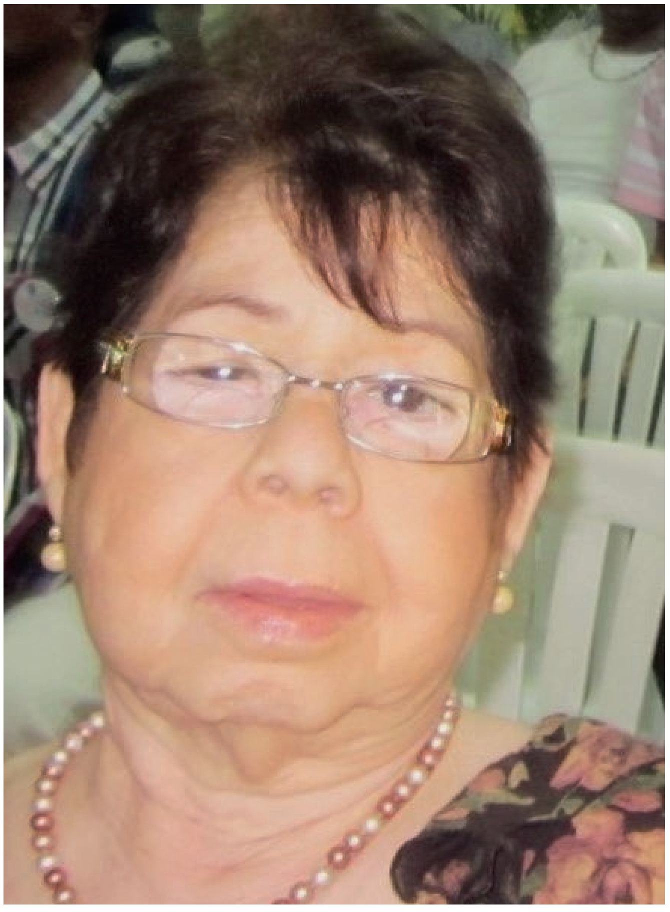
En memoria de Yocasta Soto de Rosa



Con gran dolor participamos que el 27 de febrero (Día de la Independencia de la República Dominicana) nos dejó la Ing. Yocasta Soto de Rosa, pionera de la investigación en pasturas en la República Dominicana. Ella participó activamente en los trabajos de la Red Internacional de Evaluación de Pasturas Tropicales (RIEPT), liderada por el Programa de Forrajes Tropicales del Centro Internacional de Agricultura Tropical (CIAT), con el apoyo financiero del Centro Internacional de Investigaciones para el Desarrollo de Canadá (CIID). Yocasta fue la primera ingeniera agrónoma de la República Dominicana, quien obtuvo su grado en la Universidad de Barcelona (España) en 1968, donde fue becada por el gobierno dominicano, pues la Universidad Autónoma de Santo Domingo (UASD) aún no ofrecía ese grado. Posteriormente participó en cursos de especialización en pastos y lechería en Australia, Nueva Zelanda, Puerto Rico y Colombia.

En su carrera profesional en República Dominicana destaca el haber sido Líder del Programa de Pastos y Forrajes y Directora del Centro Nacional de Investigaciones Pecuarias (CENIP) y Encargada del Programa Nacional de Producción Animal en la Dirección de Ganadería del Ministerio de Agricultura. Además, fue Docente del curso de Pastos en la Universidad Pedro Henríquez Ureña (UNPHU), la Pontificia Universidad Católica Madre y Maestra (UCAMAYMA) y el Instituto Superior de Agricultura (ISA). Por sus contribuciones al desarrollo de la agropecuaria nacional el gobierno dominicano le otorgó la Medalla al Mérito de la Orden Duarte, Sánchez y Mella.

Yocasta ha dejado una huella imborrable en el sector pecuario dominicano no solo por sus aportes en la investigación en pastos, sino también por su contribución en la formación de nuevos cuadros de profesionales en el área de Pastos y su liderazgo en la promoción de jóvenes investigadores en diferentes ramas de la zootecnia. Algunos de sus discípulos continúan su trabajo en el Instituto Dominicano de Investigaciones Agropecuarias y Forestales (IDIAF) y en las universidades públicas y privadas del país. Paz a sus restos y mucha fortaleza a su familia y colegas dominicanos.

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