Improved Multipurpose Forages for the Developing World

SBA3

ANNUAL REPORT 2008

CIAT
Centro Internacional de Agricultura Tropical
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Project Overview and Rationale

Rationale

Livestock development is recognized as a key element for increasing the income of poor smallholders given the increased demand for animal products that is being experienced in developing countries. Recent analysis indicates evolving market opportunities for forages as prices for alternative, mostly grain-based feeds are increasing and consumers request higher quality products. However, a high proportion of smallholder crop/livestock systems in the tropics are located in areas with prolonged dry seasons and with land in different stages of degradation. This leads to an inadequate supply of high quality feed for livestock in particular in the dry season. In addition, in many cases smallholders with livestock and limited land (i.e. in Southeast Asia) do not have easy access to fodder and have to walk long distances to harvest forages. On the other hand, tropical forages are one of the few opportunities available to a large number of smallholder farmers to produce high value or added value products, due to the fact that forages can be grown not only under favorable conditions but also in marginal environments. Improved tropical forages could play a key role in maintaining and improving agricultural productivity through their effects on soil fertility, restoring degraded lands, reducing deforestation and mitigating the effects of climate change. Thus, development and expansion of high yielding and high quality forages, particularly at the crop-livestock interface, can enable smallholders to be more competitive, with positive effects on poverty alleviation; improved food security and related effects on health are additional benefits. At the same time forages can contribute to nutrient cycling via animal manure, resource conservation and reversing land degradation, with further potential for adaptation to climate change through the provision of ecosystem services (e.g. carbon sequestration, inhibition of biological nitrification, improved soil and water quality).

To address the issues of scarcity of feed resources for livestock encountered by small producers and to capture emerging opportunities, the research portfolio of CIAT includes the Outcome Line entitled Improved Multipurpose Tropical Multipurpose Forages for the Developing World which is housed in the Sharing the Benefits of Agrobiodiversity Research for Development Challenge (RDC). The goal of the work on forages is to conserve and exploit the genetic diversity either the natural variation or through breeding of tropical grasses and legumes to improve the livelihoods of poor rural livestock producers. This is done by integrating improved forages in smallholder systems through linkages to traditional and emerging markets and by contributing to greater access of poor urban consumers to high quality animal products that are safe, while taking advantage of the potential of forages to enhance the natural resource base and provide environmental services.

To accomplish the objectives of the Tropical Forage Outcome Line, the research is being organized around three major outcomes: 1) Forage germplasm developed through selection and breeding, 2) Forages as high value products developed to capture differentiated markets for smallholders, and 3) Forages integrated into smallholder systems for realizing the benefits of improved grasses and legumes in crop/livestock (including cattle, small ruminants. pigs, and/or poultry) systems through adaptation, innovation and adoption, aiming at higher livelihood security through higher resource use efficiency.

Partnerships are formed with private seed industry, ARIs, universities and NARS to carry out strategic research to: breed Brachiaria hybrids; develop screening methods based on improved knowledge of mechanisms of adaptation of forage species to biotic and abiotic stresses; develop targeting, processing and evaluation techniques and employ operational research principles to define forages for specific production and market niches; and develop improved and more sustainable crop/livestock and feeding systems using an innovation systems approach.

As an activity across outcomes to target and deliver our research products, we form partnerships with different groups to define environmental and market niches, document on-farm performance of released grass and legume cultivars, and quantify the impact of selected forages in improving livelihoods and protecting the environment. Capacity building remains an important component of our agenda, to improve: a) our research capacity through pre- and post-graduate thesis research and strengthening/benefiting from the research capacity of partners, and b) our capacity to deliver research products in different environments. Capacity building includes group and individual training and activities in the area of knowledge management.

Alignment to CGIAR Priorities

Among the CGIAR Research Priorities (2005-2015), livestock is recognized as being crucial to improve the livelihoods of many poor rural and peri-urban farmers in tropical regions. It is recognized, however, that for poor farmers to capitalize on evolving commodity markets, there is a need to improve the availability of improved feed resources in areas of both low and high potential. This implies the challenge of developing forages capable of producing high quality biomass to feed ruminant animals in environments characterized by pest and disease pressures, low fertility soils, long dry seasons and/or poorly drained soils. Development of forage-based feeding systems for monogastric animals to complement existing home-grown feed resources and replace expensive commercial concentrates is also seen as an important research product to assure improved productivity and competitiveness of swine, poultry and fish production in smallholder systems.

To address the priorities of the CGIAR on livestock, the Tropical Forage Outcome Line of CIAT has the global mandate of developing forage-based technologies for extensive and intensive crop/livestock systems in diverse environments. Selected forages are expected to perform well in low fertility soils and to reduce seasonal variation in both feed quality and quantity and as a result reduce livestock mortality and increase productivity. In addition, grasses and legumes with broad adaptation to soils and climate in sub-humid and humid environments can contribute to better use of family labor (especially women) and to recuperate degraded soil/pastures in pastoral and crop/livestock systems through the capacity of grasses with deep root systems to improve physical structure of soils and of legumes to improve both soil structure and soil fertility through deep tap root systems and biological N2 fixation. Furthermore, improved forages, mainly legumes, contribute to i) soil improvement through improved soil organic matter quality thereby enhancing soil biological activity and below-ground biodiversity, and ii) nutrient cycling via improved manure quality thereby increasing productivity of subsequent crops.

The benefits of multipurpose forages are captured by forming strong research linkages with the RDC dealing with People and Agroecosystems, and with the TSBF (Tropical Soil Biology and Fertility) Institute of CIAT. These internal linkages together with external partnerships will contribute to better targeting of research products to environments and clients, thus facilitating improved and more equitable linkages of farmers to markets.

Specific activities carried out by the Tropical Forage Outcome Line to contribute to the CGIAR System Priorities (SP) are:

- Characterization of the genetic diversity in legume collections from the Gene Bank of CIAT, other CG Centers and research institutions to select new alternatives with superior forage quality, yield and resistance to biotic and abiotic stress factors (SP 1b, 2b, 3b);
- Development of methodologies for screening forages for quality and major abiotic and biotic constraints (SP 2b);
- Breeding to develop superior grasses (Brachiaria) that combine quality attributes with adaptation to major abiotic and biotic constraints (SP 2b, 2c, 2d, 3b);
- Development of a molecular map of Brachiaria and discovery of genes associated with adaptation to abiotic stresses (SP 2b, 2d, 3b).
- Development of methods for evaluating forages in different production systems with farmer participation (SP 5b);
- Development of Data Bases and Decision Support Tools to help target forages to different environments and production systems (SP 5a);
- Income generation from livestock through improved forages for feeding ruminants and monogastric animals and improved equity in value chains (SP 3b, also 2c and 5b, and spillover effects on 3c);
- Analysis of trade-offs between use of legumes for soil enhancement or as animal feed resource on crop/livestock productivity and environmental quality (SP 4b); and
- Capacity building consisting of short and long term training of individuals, group training and knowledge management (SP 5a)

Outcomes Description

Changes from previous MTP Outcomes

To capture emerging market and research opportunities targeted to smallholder farmers, CIAT in 2007 refocused its forage research into the Tropical Forage Outcome Line entitled Improved Tropical Multipurpose Forages for the Developing World. The outcome line concept is now fully implemented. As stated in last years MTP this is an evolutionary change building on past experiences and competencies while responding to a changing external context. The products and Outcomes described in the former Mega Project entitled Tropical Grasses and Legumes: Optimizing Genetic Diversity for Multipurpose Use presented in the MTP 2007 - 2009 were maintained. However, they were reorganized under the newly defined outcomes, and from 2010 onwards will follow the new outcome line structure. The inclusion of targeting and delivery of research products, as integral parts across the new outcomes, and more concretely addressing emerging market opportunities for forage-based high value and added value products and livestock other than cattle (such as monogastrics), are receiving greater emphasis. To achieve the more focused targeting and delivery of research results, research work will integrate more strongly with the People and Agroecosystems RDC and emphasize current and new partnerships with the private sector and NGOs.

The major change in contrast to the MTP 2008 - 2010 is the revision of outcome 1, to include germplasm selection and breeding to develop superior forage options. While we continue our emphasis on breeding of *Brachiaria* grasses, the revision reflects better CIAT's work on selection of forage legumes and indicates opportunities for the selection and breeding of other forage grasses and legumes. CIAT intends to strengthen its work on forages and the environment. While recognizing that income generation to alleviate poverty remains the key driver in smallholder crop-livestock systems, environmental issues and resilience of systems become increasingly linked to achieve eco-efficient agriculture for sustainable livelihoods. CIAT will capitalize on past and present accomplishments in the areas of abiotic stress physiology, soil-plant-animal relationships, nutrient cycling and biological nitrification inhibition to develop forward looking research for protecting the environment.

These changes are in line with CIAT's recent document on strategic directions with a main focus on eco-efficient agriculture. To achieve the balance between economic, ecological, social and environmental impacts, CIAT forages will further emphasize the application of systems research to climate change. Complementary to developing forages with high tolerance to both drought and waterlogging to *adapt to climate change* (Outcome 1), to increase *income generation* opportunities (Outcome 2) and improve *systems performance* (Outcome 3), we will strengthen our research on integration of forages in crop-livestock systems to protect the environment.

We aim to increase our research efforts on quantifying the benefits of improved forages with deep and abundant root systems in reducing global warming potential through improved carbon sequestration and reduced emissions of methane and nitrous oxide. This research includes the development of forage options that are most suitable for environmental protection. The major challenge for this objective is maximizing agricultural Outcome per unit of input in integrated production systems, including the assessment and quantification of the environmental effects of forage-based livestock production in relation to economic Outcome. The results from this research are anticipated to have a positive impact on *adaptation* to and *mitigation of climate change.*

In 2008 we have consolidated our research for development activities, and our Outcomes are increasingly directed towards an outcome and market driven approach. As part of this effort we are intensifying our research on developing forages for monogastric animals, increasing on-station research and extending the field work from Southeast Asia to Latin America and Sub Saharan Africa. In line with our mandate we are also strengthening the global reach of our work. Responding to the EPMR recommendations in 2007 we have recently employed a Forage Expert for Central America, and a Forage Expert for East Africa is being recruited, to be working with partners in the region by early 2009. We have also secured support in livestock economics for the coming years
Budget limitations have required further prioritization of forage research and related consolidation of staff.

However, funding for 2008 has stabilized, but as stated in last years MTP maintenance of core resources at the current level will be essential to deliver the outcomes stated in this document and also to respond to new challenges. Additional resources are sought to implement in consultation with other centers and partners our strategy in Eastern and Southern Africa to strengthen our work on the contribution of forages for more healthy agroecosystems. A key component in this approach is the improved collaboration with CIAT-TSBF, and the People and Agroecosystems

RDC to integrate forages into production systems and to realize their economic and environmental benefits.

Impact Pathways by Outcome

Outcome 1: Forage germplasm developed through selection and breeding.
To contribute to the improvement of livelihoods of poor rural livestock owners through high quality forages (outcomes 1 and 2) adapted to major biotic and abiotic constraints, forage researchers rely on natural genetic diversity from core germplasm collections housed in the Genetic Resources Unit of CIAT and other international and national centers. Artificial hybridization to create novel genetic variation is used when major limitations in successful commercial cultivars have been identified and when evaluation of large germplasm collections has failed to identify the required character combinations (e.g., spittlebug resistance and acid soil tolerance in *Brachiaria*). Screening methods and selected genotypes with superior forage quality, resistant to major pests and diseases and adapted to acid, low fertility soils, to poorly drained soils and to drought, are the outcome targets to be used by different partners engaged in research and development activities.

Outcome 2: Forages as high value products developed to capture differentiated markets for smallholders
To improve the efficiency of partners to better target forages to diverse environments, production systems and market niches, the forage team collaborates with the RDC on People and Agroecosystems to develop methods of participatory evaluation of forages, decision support tools and more effective and equitable market interactions. Selected forage genotypes are evaluated and disseminated with and by partners in different environments and production systems. The superior grass and legume genotypes are released and promoted by NARS and private seed companies, and adapted and adopted by farmers to intensify and diversify their production systems.

Outcome 3: Forages integrated into smallholder systems for realizing the benefits of improved grasses and legumes in crop/livestock (including cattle, small ruminants. pigs, and/or poultry) systems through adaptation, innovation and adoption, aiming at higher livelihood security through higher resource use efficiency. For its work in Sub-Saharan Africa, Southeast Asia and Latin America and the Caribbean, CIAT Tropical Forages Outcome Line is collaborating with ILRI and CIAT-TSBF, with complementary research priorities and expertise to integrate forages in diverse crop/livestock systems, particularly in Sub-Saharan Africa and Southeast Asia. This partnership and the interaction with the private sector have allowed us to amplify networks for delivery of research outcomes. Information sharing through knowledge tools such as SoFT (www.tropicalforages.info) reaches a wide audience ranging from researchers and development practitioners to educational institutions, and complements our continued efforts of individual and group training. A particular objective for the revision of SoFT is the linkage of SoFT with forage germplasm distribution.

Adoption of new forage varieties results in more income to livestock farmers through more efficient use of land and labor, and more animal products for urban consumers, with impacts demonstrated in Latin America and the Caribbean and Southeast Asia.

International Public Goods

In the past a number of strong organizations in developed countries (e.g., Australia, USA) were involved in development of forages for sub-tropical and tropical environments. Currently the only suppliers of improved forages with an international mandate are CIAT, ILRI and ICARDA. The forage work carried out by these CGIAR Centers is complementary. For example, forages developed at ICARDA are mostly for the arid and semi-arid regions. ILRI is concentrating its work on maintaining and characterizing forage diversity, with forages integrated in systems through partners (including CIAT) along other feed components in Sub-Saharan Africa and Asia. Forages developed by CIAT are targeted for tropical lowlands and mid-altitude hillsides. EMBRAPA in Brazil is an additional important participant in tropical forage R&D, but with a national mandate.

The research products of CIAT's Tropical Forages Outcome Line are in line with the mandate of the CGIAR of producing international public goods (IPGs). The IPGs of the research products of the Tropical Forages Outcome Line can be grouped into the following categories:

1. Defining mechanisms/processes (to assist in the development of screening methods)

- Understanding how forage quality affects monogastric productivity and product quality
- Understanding how grasses resist pests (spittlebug) and diseases (*Rhizoctonia*)
- Understanding how forages adapt to acid soils with high levels of aluminum and low levels of phosphorus
- Understanding how forages adapt to drought and waterlogging
- Understanding how grasses inhibit biological nitrification in soil
- Understanding how and to what extent leguminous forages fix nitrogen and contribute to soil fertility and/or animal production

2. Developing screening and evaluation methods (to select improved genotypes)
   - Forage quality (i.e., crude protein and in vitro digestibility) for ruminants and monogastrics
   - Biotic constraints (i.e., spittlebugs and *Rhizoctonia* foliar blight)
   - Abiotic constraints (i.e., adaptation of forages to low soil nutrient status and high Al; adaptation to drought and to poorly drained soil conditions)
   - Selection of forages by farmers using participatory methods

3. Developing superior grass and legume genotypes and cultivars (for increasing livestock productivity and protecting the environment)
   - Grasses and legumes selected from germplasm collections that have broad adaptation to environmental factors prevailing in target areas and with multiple functions in crop/livestock production systems
   - Grasses and legumes with high forage quality and combined resistance to biotic and abiotic constraints
   - Accessing new forage genetic resources remains of high priority though it is severely constrained under the current writing of the International Treaty and the Convention on Biological Diversity
   - Understanding trade-offs between use of forages for soil enhancement or as animal feed.

4. Targeting and delivery of research results through dissemination of forage germplasm and decision support tools
   - Documented conservation and distribution of germplasm by the Genetic Resources Unit, with support for larger quantities of seed of selected materials from the forage seed unit
   - Protocols for indexing diseases of quarantine importance that limit the flows of germplasm between LAC, Africa and Southeast Asia
   - Decision Support Tools with information on adaptation, uses and management of different forage species.

Elaboration of Partners Roles

Through partnerships with different organizations from developed and developing countries, the Tropical Forage Outcome Line conducts research to develop improved grasses and legumes as feed resources. In what follows we present some key partnerships and the nature of the work being done as it relates to the three outcomes of the Tropical Forage Outcome Line shown in parenthesis.

1. Australia CSIRO and QDPI; Germany U of Hohenheim; ILRI and FAO: (Outcome 3) Development of a tool - Selection of Forages in the Tropics (SoFT). Funds from ACIAR, DFID and BMZ.

2. Cambodia DAHP, DA Kampong Cham and RUA: (Outcome 3) Improved feeding systems for more efficient beef cattle production in Cambodia. Funds from ACIAR via UNE.

3. Colombia CORPOICA; Nicaragua INTA; (Outcome 1) Desarrollo de Genotipos de *Brachiaria* spp. Adaptados a Suelos con Drenaje Deficiente para Aumentar Producción Bovina y Adaptar Sistemas de Pastoreo al Cambio Climático en América Latina. Funds from FONTAGRO.

4. Colombia CORPOICA -CVS-CARSUCRE-GANACOR-FEGASUCRE: (Outcome 3) Implementation and transfer of technologies for restoration of degraded pastures for beef production systems in the departments of Córdoba, Sucre and Atlántico. Funds from MADR.

5. Colombia Universidad de Cauca, Fondo Ganadero del Cauca: (Outcome 3) Increase of productivity, competitiveness and sustainability of small and medium livestock producers in the watersheds of Patía and plateau of Popayán. Funds from MADR.

6. Costa Rica SIDE; Guatemala ICTA and MAGA; Honduras DICTA; Nicaragua IDR; IICA and ILRI: (Outcome 2). Analysis of the beef chain in Central America. Funds from CFC.

7. France ANR: (Outcome 3) Biodiversity and environmental services at landscape level in the Amazon. Funds from ANR.

8. Germany CIM Integrated Experts: (Outcomes 1 to 3) Forage Conservation and Feed Systems for Monogastrics; Forage experts for Central America and Eastern Africa. Funds from BMZ /CIM.

9. Germany U of Hohenheim; Colombia CORPOICA and U del Cauca, (Outcomes 2 and 3) Development of multipurpose forage legumes for smallholder crop/livestock systems in the hillsides of Latin America. Funds from Volkswagen Foundation.

10. Germany U of Hohenheim; Nicaragua INTA; Honduras DICTA: (Outcomes 2 and 3) Demand-Driven Use of Forages in Fragile, Long Dry Season Environments of Central America to Improve Livelihoods of Smallholders. Funds from BMZ.

11. Germany U of Hannover; Nicaragua INTA: (Outcome 1) Developing Brachiaria hybrids with combined resistance to drought and aluminum toxicity. Funds from BMZ.

12. Germany U. of Hohenheim; U Rostock; Colombia U del Cauca; U Nacional de Colombia; Nicaragua INTA; Rwanda ISAR; (Outcome 2). More chicken and pork in the pot, and money in pocket: Improving forages for monogastric animals with low-income farmers. Funds from BMZ.

13. Honduras and Nicaragua MIS Consortium: (Outcome 3) Quesungual Slash and Mulch Agroforestry System (QSMAS): Improving Crop Water Productivity, Food Security and Resource Quality in the Sub-Humid Tropics. Funds from IWMI.

14. Lao PDR National Agriculture and Forestry Research Institute; Australia Queensland Department of Primary Industries and Fisheries; Canada Nutrition Prairie Swine Centre, Saskatoon: (Outcome 2) Forage legumes for supplementing village pigs in Lao PDR. Funded by ACIAR.

15. Mexico PAPALOTLA Seed company and national partners: (Outcome 1) Breeding and evaluation of Brachiaria hybrids. Funds from PAPALOTLA.

16. Switzerland ETHZ; Nicaragua INTA: (Outcome 3). Improved feeding systems for dairy cattle in tropical smallholder farms. Funds from ZIL-SDC.

17. Switzerland ETHZ; Nicaragua INTA: (Outcome 3). Realizing the benefits of cover crop legumes in smallholder crop/livestock systems. Funds from ZIL-SDC.

18. Switzerland ETHZ; Nicaragua INTA; ILRI-Colombia: (Outcome 3). Trade-off analysis of using legumes for soil enhancing or as animal feed resource. Funds from Systemwide Livestock Program (SLP).

19. Thailand World Vision Khon Kaen University: (Outcome 3) Improving the reliability of rain-fed, rice/livestock-based farming systems in North East Thailand. Funds from ACIAR via WorldVision.

20. Viet Nam ILRI, National Institute of Animal Husbandry and Tay Nguyen University: (Outcome 2) Enhancing livelihoods of poor livestock keepers through increasing use of fodder. Fund from IFAD via SLP.

1. Logframe (2008). Improved Multipurpose Forages for the Developing World: Product Linea SBA3

Targets	Products	Intended User	Outcome	Impact
PRODUCT 1	Long term production and environmental benefits of multipurpose grasses and legumes secured through conservation, documentation and distribution, of forage germplasm	CIAT, CG centers, NARS, forage networks and development projects in LAC, Sub-Saharan Africa and Southeast Asia, and other users anywhere in the world interested in clean and documented forage genetic resources.	Conservation, multiplication, documentation and worldwide availability of tropical forage germplasm under mandate of CIAT	Short and long term availability of forage germplasm to ensure sustainable agriculture based production of smallholders in the tropics
PRODUCT 1 Targets 2008 **(recurrent activities)**	Tropical forage collection of 23,140 materials is maintained fully viable, clean, and documented, and available at any time for distribution to any bona fide user, according to procedures set in the MTA/ SMTA of the Treaty. 1,400 accessions/ year conserved in long-term conservation (-20C) at CIAT and safely duplicated at CIMMYT as security back-up. Identified, clean and documented germplasm of forages (anticipated at 600 samples/ year) is distributed to users in accordance with international standards (plant quarantine, IP norms as applicable) Forage legume germplasm taxonomy better understood	CIAT forage projects in LAC, Sub-Saharan Africa and Southeast Asia, forage networks, development projects, NARS, CG centers, others users anywhere in the world interested in clean and documented for forage genetic resources. Forage scientists, breeders, agrostologists, forage networks and consortia from both public and private sectors Taxonomists, Forage scientists and breedeers	On demand availability of forage germplasm to users throughout the world Forage genetic resources adapted to specific agronomic and market conditions are better known and used troughout the entire forage/animal production chain Improved description of forage legume genera andspecies	

1. Logframe (2008). Improved Multipurpose Forages for the Developing World: Product Linea SBA3

Targets	Products	Intended User	Outcome	Impact
PRODUCT 2	Improved Brachiaria grasses	CIAT and NARS researchers and seed companies	New cultivars of *Brachiaria* with high feed quality and resistance to major biotic and abiotic stress factors are released by partners and adopted by farmers in LAC, Asia and Africa	Increased efficiency of livestock production through feeding high quality grasses
Product 2 Targets 2008	A reliable, high throughput screening methodology, based on artificial inoculation, for assessing Rhizoctonia foliar blight resistance is developed A screening method to assess waterlogging tolerance in *Brachiaria* hybrids streamlined in the breeding program	NARS researchers, CIAT researchers NARS researchers, CIAT researchers	Sexual tetraploid *Brachiaria* hybrids with high resistance to *Rhizoctonia* foliar blight identified and introgression of resistance into the tetraploid sexual breeding population initiated Selected *Brachiaria* hybrids tolerant to waterlogging tested in different regions in LAC and Asia	
PRODUCT 3	Forages as and for high value products developed to capture differentiated markets for smallholders	CIAT and NARS researchers, and seed companies	New stress adapted cultivars of *Brachiaria* and high quality legumes with resistance to prevalent pests and diseases to capture emerging markets are released by partners and adopted by farmers in LAC and Southeast Asia	Increased efficiency of livestock production and income of smallholder farmers through planting forage grasses and legumes that are adapted to major production constraints and market opportunities
Product 3 Targets 2008	At least 3 legume varieties with high nutritional quality, capable of improving village pig production by at least 30% in extensive production systems identified	CIAT and NARS researchers	Small pig producers in extensive production systems in Asia evaluate and adopt forage legumes as supplementary feed	

1. Logframe (2008). Improved Multipurpose Forages for the Developing World: Product Linea SBA3

Targets	Products	Intended User	Outcome	Impact
PRODUCT 4	Benefits of multipurpose grasses and legumes realized in crop/ livestock systems through adaptation, innovation and integration	CIAT, ARIs and NARS researchers, and seed companies	New cultivars of *Brachiaria* and legumes with adaptation to production constraints released by partners and adopted by farmers in LAC, Asia and Africa	Increased profitability and sustainability of livestock/crop production and improved NRM through planting multipurpose forage species adapted to production constraints
Product 4 Targets 2008	3 perennial and annual herbaceous legume accessions that perform well under residual soil moisture and that are suited for hay and silage production identified Released CaNaSTA for targeting forages (and other crops) to specific environmental and market niches	NARS researchers and development programs NARS researchers and development programs	Livestock and non-livestock farmers in dry hillsides adopt annual legumes to make high quality hay and silage Researchers and development workers are using CaNaSTA to target forages to specific production and market niches	

2. Outcome targets 2008. Improved Multipurpose Forages for the Developing World: Product Linea SBA3

TARGETS 2008	Fully Achieved	75% Achieved	>50% Achieved	<50% Achieved	Cancelled	Deferred	EXPLANATION
OUTCOME 1 Tropical forage collection of 23,140 materials is maintained fully viable, clean, and documented, and available at any time for distribution to any bona fide user, according to procedures set in the MTA/ SMTA of the Treaty. 1,400 accessions/ year conserved in long-term conservation (-20C) at CIAT and safely duplicated at CIMMYT as security back-up.	X (1,480; also 1,086 to Svalbard in 2008)						GRU Annual Report 2008, also GPG2 Annual Report for 2008.
Identified, clean and documented germplasm of forages (anticipated at 600 samples/ year) is distributed to users in accordance with international standards (plant quarantine, IP norms as applicable)			X				(332 samples distributed in 2008; GRU responds to requests, and is not responsible for less requests than anticipated) GRU Annual Report 2008, also GPG2 Annual Report for 2008.
Forage legume germplasm taxonomy better understood	X						(245 Desmodium accessions were identified by Harvard specialist) GRU Annual Report 2008.

x

2. Outcome targets 2008. Improved Multipurpose Forages for the Developing World: Product Linea SBA3

TARGETS 2008	Fully Achieved	75% Achieved	>50% Achieved	<50% Achieved	Cancelled	Deferred	EXPLANATION
OUTCOME 2 A reliable, high throughput screening methodology, based on artificial inoculation, for assessing Rhizoctonia foliar blight resistance is developed	X						CIAT SBA3 Annual Report 2008, forthcoming http://www.ciat.cgiar.org/forrajes/index.htm
A screening method to assess waterlogging tolerance in *Brachiaria* hybrids streamlined in the breeding program	X						Rao, I. M., J. Rincon, R. Garcia, J. Ricaurte and J. Miles. 2007. Screening for tolerance to waterlogging in *Brachiaria* hybrids. Poster paper presented at ASA-CSSA-SSSA International Annual Meeting, New Orleans, LA, USA. 4-8 November, 2007. CIAT SBA3 Annual Report 2008, forthcoming http://www.ciat.cgiar.org/forrajes/index.htm

2. Outcome targets 2008. Improved Multipurpose Forages for the Developing World: Product Linea SBA3

TARGETS 2008	Fully Achieved	75% Achieved	>50% Achieved	<50% Achieved	Cancelled	Deferred	EXPLANATION
OUTCOME 3 At least 3 legume varieties with high nutritional quality, capable of improving village pig production by at least 30% in extensive production systems identified	X						Phengsavanh, P.; Stür, W. (2008). Farmer-led research in village pig production in Lao PDR. In: Thorpe W and Tesfaye Jemaneh. (eds). 2008. Pig systems in Asia and the Pacific: How can research and development enhance benefits to the poor? Proceedings of a regional workshop held in Bangkok, Thailand, 23–24 November 2006, co-organized by APHCA, FAO-RAP and ILRI. ILRI (International Livestock Research Institute), Nairobi, Kenya, p. 57-63. http://www.ilri.org/Infoserv/webpub/fulldocs/Pig%20Systems_proceeding/PigSystems_Asia_Pacific.pdf Phengsavanh, P.; Stür, W.; Keonouchanh, S. (2008). Adoption of the forage legume 'Stylo 184' (*Stylosanthes guianensis* CIAT 184) in smallholder pig systems in Lao PDR. Proceeding of the 13th AAAP congress: Animal Agriculture and the role of small holder farmers in a global economy, held in Hanoi, Vietnam 22-27 Sept 2008. CIAT SBA3 Annual Report 2008, forthcoming http://www.ciat.cgiar.org/forrajes/index.htm Martens, S.; Avila, P.; Franco, L.H.; Peters, M. (2008): Canavalia Brasiliensis and Vigna unguiculata at Different Growth Stages. In: Tielkes E. (Ed.) Competition for Resources in a Changing World: New Drive for Rural Development: International research on food security, natural resource management and rural development; book of abstracts / Tropentag 2008 Stuttgart-Hohenheim. Göttingen, 209.

2. Outcome targets 2008. Improved Multipurpose Forages for the Developing World: Product Linea SBA3

TARGETS 2008	Fully Achieved	75% Achieved	>50% Achieved	<50% Achieved	Cancelled	Deferred	EXPLANATION
							Martens S., Avila P., Franco L.H., Peters M. (2008): Rapid Assessment of Ensilability of Vigna Unguiculata and Canavalia Brasiliensis as an Option for Alternative Pig Feeding. In: Tielkes E. (Ed.) Competition for Resources in a Changing World: New Drive for Rural Development: International research on food security, natural resource management and rural development; book of abstracts / Tropentag 2008 Stuttgart-Hohenheim. Göttingen, 448. Martens, S.; Avila, P.; Gil, J.L.; Franco, L.H.; Peters, M. (2008): Silage Quality of the Legumes Vigna unguiculata and Canavalia brasiliensis Solely and with Sweet Potato Roots as an Alternative Pig Feeding. In: Tielkes E. (Ed.) Competition for Resources in a Changing World: New Drive for Rural Development: International research on food security, natural resource management and rural development; book of abstracts / Tropentag 2008 Stuttgart-Hohenheim. Göttingen, 447. L.S.Muñoz, P. Sarria, S. Martens, M. Peters, P.A. Aguirre and C.A. Montoya. Nutritional characterization of Vigna unguiculata as alternative protein source for monogastric animals. In: Organizing Committee of IGC/IRC Congress (ed.) Multifunctional Grasslands in a Changing World. Proceedings of the International Grassland Congress and the International Rangeland Congress, 29 June-5 July 2008, Hohot, China, 728.

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TARGETS 2008	Fully Achieved	75% Achieved	>50% Achieved	<50% Achieved	Cancelled	Deferred	EXPLANATION
OUTCOME 4 3 perennial and annual herbaceous legume accessions that perform well under residual soil moisture and that are suited for hay and silage production identified	X						Reiber, C.; Schultze-Kraft, R.; Peters, M.; Cruz, H. (2008) Smallholder innovation of hay and silage technologies in Central America as an alternative to improve adoption of forage conservation. Proceedings of thr XXI. International Grassland Congress/VIII. International Rangeland Congress, 29th June – 5th July, 2008, Hohhot, China, 1113 CIAT SB 3 Annual Report 2007, Pages 121-142, 148-149 http://www.ciat.cgiar.org/forrajes/index.htm
Released CaNaSTA for targeting forages (and other crops) to specific environmental and market niches		X					O'Brien, R. (2008) Visualising Uncertainty in Spatial Decision Support. Proceedings of the 8th International Symposium on Spatial Accuracy Assessment in Natural Resources and Environmental Sciences, *Shanghai, P. R. China, June 25-27, 2008, pp. 335-340* *CaNaSTA, Crop Niche Selection in Tropical Agriculture: a Spatial Decision Support Tool* ***http://csusap.csu.edu.au/~robrien/canasta/index.htm*** While CaNaSTA is used internally in CIAT, user-friendliness needs to be improved and documentation developed before eventual release

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3. Research Highlights 2008

- **A quick screening technique for resistance to adult spittlebug damage was developed and tested**

  The Forage Program has made significant progress in the characterization and development of antibiosis resistance to nymphs in *Brachiaria* grasses. In previous years, no major attention had been given to the screening of germplasm for resistance to adults. In 2007 we developed a method to screen for adult damage and to study categories of resistance to adult feeding damage. We used twenty-day old plants infested with four neonate adults per plant until all adults died, usually 8-10 days after infestation. Results of those studies suggested a need to incorporate routine screening for tolerance to adult feeding damage as an additional selection criterion in the breeding scheme. To facilitate the process and assist the *Brachiaria* breeding program, in 2008 we developed a simpler, fast technique that can be used to screen hundreds of genotypes in a very short period of time. We used leaf cages to house isolated adults feeding for 7 days on a leaf of a fully grown *Brachiaria* plant. After screening more than nine hundred genotypes, we concluded that the leaf cage technique can be used to massively discard obviously susceptible genotypes.

- **Response of *Brachiaria* grasses to combined stress factors of drought and aluminum toxicity**

  A greenhouse study was conducted to determine differences in regulation of water use, water use efficiency (WUE) and shoot growth of six *Brachiaria* genotypes (and *Brachiaria* hybrid cv. Mulato 2 (CIAT 36087)) that were subjected to a combined stress of drought and Al toxicity in soil. *B. decumbens* CIAT 606 and *B. brizantha* CIAT 26110 cv. Toledo were found to be superior in their ability to tolerate the combined stress conditions of terminal drought and Al toxicity. The superior performance of these two genotypes was attributed to a delay in stomatal closure combined with efficient use of the moisture stored in the soil for plant growth during the dehydration process. Two genotypes, *B. ruziziensis* 44-02 and *B. brizantha* CIAT 6294 cv. Marandu were found to be sensitive to the combined stress conditions due to early stomatal closure that impacted their ability to use water to produce the shoot biomass. Two *Brachiaria* hybrids, cv. Mulato (CIAT 36061) and cv. Mulato 2 (CIAT 36087) showed greater demand for water with their higher growth rate and an intermediate type of response with moderate ability to adjust shoot growth to the decreasing soil moisture.

- **Realizing the benefits of *Canavalia brasiliensis* in smallholder crop-livestock systems in the hillsides of Central America**

  Canavalia brasiliensis (Canavalia) shows potential to fix a significant amount of N. When completely removed for utilization as forage, it bears the risk of soil N depletion unless N would be recycled to the plot by animal manure. Integration of Canavalia increased average dry matter biomass availability with three tonnes per hectare and resulted in a significantly higher milk production of almost one kg/animal/day ($p<0.01$) with no negative effect on milk quality. The farmers recognize the positive effect of Canavalia both on soil fertility and on milk production. They showed significant interest in integrating Canavalia in their cropping system as a partial substitution to chemical fertilizers, to benefit from increased milk production during the dry season and to recuperate degraded soils.

4. PROJECT OUTCOME: Impact from adopting improved grasses for fish farming in Vietnam

(Outcome of 10 year collaboration in Viet Nam, indicated in MTP for that time period)

Authors: W. Stur (CIAT), T.T. Khanh (Tay Nguyen University), V.H. Yen (NAFRI), L.H. Binh (NIAH), P. Phengsavanh (NAFRI), P. Horne (ACIAR), F. Holmann (CIAT)

While fishing must surely be one of the oldest recorded sources of livelihood, it is only comparatively recently that fish have become important components of the diets of the majority of the world's people, especially those living in developing countries. Consumption of fish and seafood products reached 14 kg per capita in developing countries in 2001, nearly twice the level recorded in the early 1970s, while population in those countries doubled over the same period. Most of the net growth in fish production over the past 20 years has come from the development of fish farming, especially in the developing countries of Asia. The majority of the growth in fish production has come from aquaculture, which ranges from simple ponds utilizing naturally occurring food sources to highly intensive systems with water control, aeration, and supplemental feeding. With global fish supply struggling to keep pace with projected demand over the next 20 years, technology will play a crucial role. Production growth in aquaculture will come from (a) expansion of area; (b) from increased intensity of input use, especially feed; and (c) from technological improvements in both inputs and organisms (*Delgado et al*., 2003)[1].

In Vietnam, NARS's partners, together with the International Center for Tropical Agriculture (CIAT), begun testing improved grasses to increase fish production in 1997 in the province of Tuyen Quang. In 2005, CIAT and partners were working with about 1700 farmers and 500 of them were using improved grasses to feed herbivorous fish, replacing or complementing the traditional feed sources of specific native vegetation, cassava, rice bran, and banana stem. The main grasses adopted for herbivorous fish production were the grasses Panicum maximum ("Simuang"), Paspalum atratum ("Terenos"), and to a small extent Pennisetum purpureum (Napier). Herbivorous fish production in Tuyen Quang was practiced exclusively by smallholders, with a mean fish pond size of 1540 m2 and a mean forage plot size of 697 m2.

Farmers who adopted improved grasses were able to harvest 63% more fish by weight as well as to obtain 10.7% higher price per kilo of fish harvested because farmers received a "premium" due to the sale of heavier, larger fish (US$0.93/kg vs. $0.84/kg). Thus, forage adopters produced 2.3 times more income per pond than farmers who produced fish in the traditional way (ie. US$299 vs $90). The benefit : cost ratio of fish production was 72% higher for forage adopters than for non-adopters (2.56 vs. 1.49). Using planted forages for herbivorous fish production also reduced the amount of time needed to collect feed for fish ponds. The combination of higher fish production and reduced labour requirements resulted in higher economic returns to labour, which was was 5 times higher for forage adopters than for non-adopters (i.e., US$1.35/hr vs. $0.26/hr).

All forage adopters mentioned they invested the extra income from fish in the education of their children and in the acquisition of household needs. About half of them invested in the improvement of their overall standard of living. Twenty-seven percent in expanding cattle production and 17% increased fishpond area.

Adoption of planted grasses for herbivorous fish production has spread to neighboring provinces in northern Vietnam and other provinces where CIAT and NARS partners had introduced forages for smallholder livestock production. A recent survey of forage adopters in Ea Kar district, Daklak province in the central highlands of Vietnam showed that the grass Panicum maximum "Simuang" had been adopted for fish feeding by 1306 of a total of 3082 housholds with fish ponds; this equates an adoption rate of 42%.

The 10-year collaboration between CIAT and NARS in Vietnam in evaluating and validating improved forages has now translated into more market-oriented, profitable fish production for smallholder farmers in Vietnam.

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[1] Delgado, Christopher L.; Wada, Nikolas; Rosegrant, Mark W.; Meijer, Siet; Ahmed, Mahfuzuddin (2003). Outlook for fish to 2020. Meeting Global Demand. Ifpri International Food. Policy Research Institute

Outcome 1. Forage germplasm developed through selection and breeding

1.1 Selection of *Brachiaria* genotypes for high digestibility and other quality attributes

Contributors: S. Martens, P. Avila (CIAT)

1.1.1 Screening of sexual and apomictic *Brachiaria* hybrids for digestibility and protein

Rationale

Improved forage grasses should produce high animal performance under managed grazing. This implies high forage nutritive quality, mainly assessed by in vitro digestibility and crude protein content.

We have not developed a robust sampling and sample preparation methodology for forage quality determinations that can routinely handle the hundreds or thousands of samples generated by a productive plant breeding program. This is an important area where attention is required.

Materials and Methods

A small field trial was established at the CIAT-Quilichao experiment station. This trial includes 28 selected BR06 hybrids, plus five check entries (CIAT 00606 [cv. Basilisk]; CIAT 06294 [cv. Marandu]; CIAT 36087 [cv. Mulato II]; and two promising hybrid selections that have not yet been released: BR02/1752 and BR02/1794). The trial includes four replications; the experimental unit is a single-row plot, 2 m wide, of five plants, spaced 1 m apart in the row.

Results and Discussion

Samples have not yet been taken for forage quality determinations

1.2 Breeding *Brachiaria* for resistance to biotic and abiotic constraints

Contributors: J. Miles, C. Cardona, I.M. Rao, G. Sotelo, J. Rincón (CIAT)

1.2.1 Begin second breeding cycle using recurrent selection on combining ability

Rationale

Selection in our *B. decumbens*/*B. brizantha* synthetic sexual breeding population was on "per se" phenotypic performance for the first six 2-yr cycles (see previous Annual Reports and Miles et al. 2006). In 2005, a breeding scheme of selection on testcross performance (selection on combining ability [Hull 1945]), involving a 3-yr cycle was implemented. A second cycle of selection on combining ability was initiated during 2008.

Materials and Methods

An SX08 population of 1,120 individuals was produced from seed harvested from a crossing block of 31 selected SX05 clones that was established in 2007.

Based on seedling vigor and reaction of individual seedlings to adult spittlebug (*Zulia carbonaria*) damage, the original population was culled to 706 individuals.

The 706 individual SX08 seedlings were transplanted on a 5-m square grid in an established pasture of *B. decumbens* at CIAT's Popayán experiment station. A 1.5-m area around each transplanted seedling was maintained clear of weeds and *B. decumbens* plants. The SX08 transplants flowered and were presumably pollinated predominantly by pollen from the surrounding *B. decumbens* plants, which, owing to the cool ambient temperature at 1,750 m elevation at the CIAT-Popayán station, flowers continuously.

Results and Discussion

Open pollinated seed was hand harvested from the SX08 maternal plants. Crude seed from each SX08 plant was weighed, filled caryopses separated using a standard laboratory seed blower, and full caryopses weighed. A measure of "seed fill" was obtained as grams full seed/grams crude seed. These values ranged over the 706 SX08 clones from 0.00 to 79.14%.

Based on caryopsis fill and clean seed yield, the 706 testcross families were culled to 208. Testcross seed was acid scarified and sown in flats in the greenhouse in mid-December 2008. Additional families have been culled based on poor germination, leaving 186 families at the time of writing (13FEB09).

1.2.2 Seed of 28 apomictic BR06 hybrids delivered to Papalotla for further multiplication and evaluation

Rationale

Our strategy for achieving diffusion and adoption of the products of our *Brachiaria* breeding program has been the formation of an alliance with a private, Mexico-based, international forage seed company – Semillas Papalotla. Promising apomictic hybrids are delivered to Semillas Papalotla on an exclusive commercialization basis, under the assumption that exclusivity will provide a stimulus to more aggressive movement of superior cultivars.

Materials and Methods

Of several thousand testcross progeny individual clones generated in 2006, 353 were "pre-selected" on the basis of observations on an unreplicated, single-plant at each of two field trials, as promising. OP seed on these 353 single plants was recovered by enclosing inflorescences in mesh bags. Weight of filled caryopses was expressed as a proportion of crude seed yield, and the selections were culled to 164 on this criterion. Progeny tests conducted during 2007 identified approx. 50% apomictic hybrids, as expected. Based on caryopsis fill, seed yield, spittlebug reaction and visual assessment of growth habit and plant vigor, 28 hybrids were chosen for more advanced agronomic evaluation and selection for possible commercial release. These advanced stages of agronomic evaluation were conducted by Semillas Papalotla at three testing sites. These agronomic evaluations are on-going as of this writing.

Results and Discussion

Three 50-gm samples of seed of each of 28 promising, apomictic hybrids was delivered, as materials "under development", under the Standard Material Transfer Agreement, to Semillas Papalotla in April 2008.

1.3 Screening *Brachiaria* genotypes for spittlebug resistance

Highlights

- A quick screening technique for resistance to adult spittlebug damage was developed and tested.

  The Forage Program has made significant progress in the characterization and development of antibiosis resistance to nymphs in Brachiaria grasses. In previous years, no major attention had been given to the screening of germplasm for resistance to adults. In 2007 we developed a method to screen for adult damage and to study categories of resistance to adult feeding damage. We used twenty-day old plants infested with four neonate adults per plant until all adults died, usually 8-10 days after infestation. Results of those studies suggested a need to incorporate routine screening for tolerance to adult feeding damage as an additional selection criterion in the breeding scheme. To facilitate the process and assist the *Brachiaria* breeding program, in 2008 we developed a simpler, fast technique that can be used to screen hundreds of genotypes in a very short period of time. We used leaf cages to house isolated adults feeding for 7 days on a leaf of a fully grown *Brachiaria* plant. After screening more than nine hundred genotypes, we concluded that the leaf cage technique can be used to massively discard obviously susceptible genotypes.

- Very high levels of antibiotic resistance to nymphs of *Zulia pubescens* were detected in elite apomictic hybrids (series BR06) selected for good agronomic performance. These results complement those obtained in 2007 with *Aeneolamia varia*, *A. reducta*, and *Zulia carbonaria*.

- High levels of antibiosis resistance to nymphs of *Prosapia simulans* were found in 20 hybrids (different series) selected for Papalotla in previous years.

- Field screening of genotypes in Caquetá continued. In most cases, results confirmed resistance levels detected under greenhouse conditions.

- Significant progress was made in the understanding of mechanisms involved in the resistance of *Brachiaria* genotypes to adult feeding damage. A quick screening technique for resistance to adult spittlebug damage was developed and tested.

1.3.1 Continuous mass rearing of spittlebug species in Palmira and Macagual

Contributors: G. Sotelo, C. Cardona (CIAT)

Rationale

A permanent supply of insects is essential in the process of evaluating genotypes for resistance to spittlebug. At present, the progress made in mass rearing of nymphs and in obtaining eggs from adults collected in the field allows us to conduct simultaneous screening of large number of *Brachiaria* genotypes for resistance to both nymphs and adults of all major spittlebug species present in Colombia. Insects produced in our mass rearing facilities are used for greenhouse evaluations in Palmira and field evaluations in Caquetá. These techniques have been used for mass rearing of spittlebug species and mass screening of genotypes in Brazil and Mexico.

1.3.2 Identify *Brachiaria* genotypes resistant to spittlebug

Contributors: C. Cardona, G. Sotelo, J. W. Miles (CIAT)

Rationale

Various species and genera of tropical grassland spittlebugs are still considered to be the greatest biotic threat to Brachiariagrass pastures in the neo-Tropics. While great advances have been made in enhancing mean resistance to nymphs of six Colombian spittlebug species in our synthetic sexual breeding population (Miles et al. 2006), continued monitoring is warranted to avoid regression of the resistance that has been achieved. In addition, preliminary studies suggest that resistance to adult spittlebug damage is genetically independent of resistance to nymphs (Zúñiga et al. 2008) and hence, will require deliberate selection to achieve high levels of resistance.

1.3.2.1 Greenhouse screening of *Brachiaria* accessions and hybrids for resistance to six spittlebug species

Rationale

Assessment of resistance to spittlebugs is an essential step in the process of breeding superior *Brachiaria* cultivars at CIAT. In 2008, screening of selected hybrids was conducted under greenhouse and field conditions.

Materials and Methods

Screenings for resistance in the greenhouse were conducted with nymphs of *Zulia pubescens* and *Prosapia simulans*. Test materials were usually compared with six checks fully characterized for resistance or susceptibility to *A. varia*. Plants were infested with six eggs per plant of the respective spittlebug species and the infestation was allowed to proceed without interference until all nymphs were mature (fifth instar stage) or adult emergence occurred.

Plants (5 per genotype) were scored for symptoms using a damage score scale (1, no visible damage; 5, plant dead) developed in previous years. Percentage nymph survival was calculated. Materials were selected on the basis of low damage scores (<2.0 in a 1-5 scale) and reduced percentage nymph survival (<30%).

Results and Discussion

A set of 28 apomictic hybrids of the series BR06 were screened for resistance to nymphs of *Z. pubescens*. All were highly resistant (Table 1). These hybrids had been evaluated for resistance to other species in 2007.

Table 1. Levels of resistance to nymphs of *Zulia pubescens* detected in a set of 28 apomictic hybrids of the series BR06NO. Reconfirmation test.

Type of genotype	Damage scores	Percentage nymph survival
	Hybrids	
Mean of 28 BR06 hybrids	1.6 ± 0.12b	7.7 ± 3.57b
	Commercial checks	
CIAT 6294 ('Marandú')	1.8 ± 0.15	13.3 ± 6.48
CIAT 36087 ('Mulato II')	1.4 ± 0.13	3.3 ± 3.32
Mean commercial checks	1.6 ± 0.62b	8.3 ± 3.53b
	Resistant checks	
CIAT 36062	1.2 ± 0.11	5.0 ± 2.54
SX01NO/0102	1.2 ± 0.11	10.0 ± 3.68
Mean resistant checks	1.2 ± 0.11c	7.5 ± 1.77b
	Susceptible checks	
CIAT 0606 ('Basilisk')	3.6 ± 0.23	73.2 ± 7.11
CIAT 0654	3.5 ± 0.22	62.9 ± 4.38
Mean susceptible checks	3.6 ± 0.21a	68.5 ± 3.64a

Means of 5 replications per genotype. Means within a column followed by the same letter are not significantly different at the 5% level according to Scheffe's multiple range test for arbitrary comparisons.

Twenty of the 23 hybrids evaluated for Papalotla were highly resistant to *P. simulans* (Table 2). The other 3 were susceptible.

Table 2. Levels of resistance to nymphs of *Prosapia simulans* detected in a set of 23 apomictic hybrids selected for Papalotla.

Type of genotype	Damage scores	Percentage nymph survival
	Hybrids	
Mean of 3 susceptible hybrids	3.0 ± 0.24b	66.7 ± 3.64a
Mean of 20 resistant hybrids	1.9 ± 0.16bc	5.2 ± 3.27c
	Commercial checks	
CIAT 6294 ('Marandú')	1.6 ± 0.09	0 ± 0.00
CIAT 36087 ('Mulato II')	1.3 ± 0.12	0 ± 0.00
Mean commercial checks	1.4 ± 0.10c	0.0 ± 0.00d
	Resistant checks	
CIAT 36062	2.1 ± 0.09	40.0 ± 6.62
SX01NO/0102	1.2 ± 0.12	0 ± 0.00
Mean resistant checks	1.6 ± 0.31c	20.0 ± 14.1b
	Susceptible checks	
CIAT 0606 ('Basilisk')	3.7 ± 0.12	66.7 ± 5.26
CIAT 0654	4.4 ± 0.18	73.3 ± 11.3
Mean susceptible checks	4.0 ± 0.24a	70.0 ± 2.33a

Means of 5 replications per genotype. Means within a column followed by the same letter are not significantly different at the 5% level according to Scheffe's multiple range test for arbitrary comparisons.

1.3.2.2 Field screening of *Brachiaria* accessions and hybrids for resistance to four spittlebug species

Contributors: C. Cardona, G. Sotelo, J. W. Miles (CIAT)

Rationale

Assessment of spittlebug resistance under natural levels of infestation in the field is difficult due to the focal, unpredictable occurrence of the insect. This problem has been overcome since 1998 when we developed a technique that allows us to properly identify resistance under field conditions. Evaluating for resistance under field conditions is important because it allows us to reconfirm levels of resistance identified under greenhouse conditions.

Materials and Methods

Using the experimental unit described in our 1998 CIAT Forages Annual Report, the genotypes (usually 10 replicates) are initially infested in the greenhouse with an average of 10 eggs per tiller. Once the infestation is well established, with all nymphs feeding on the roots, the units are transferred to the field and transplanted 10-15 days after infestation. The infestation is then allowed to proceed without interference until all nymphs have developed and adults emerge some 30-35 days thereafter.

The plants are then scored for damage by means of the 1-5 visual scale utilized in greenhouse screenings. The number of tillers per plant is counted before and after infestation and a tiller ratio (tillers per plant at the end of the infestation process/tillers per plant at the beginning of the infestation process) is then calculated. Using this methodology, 8 screening trials (two with *A. varia*, two with *Zulia carbonaria,* two with *Z. pubescens*, and two with *Mahanarva trifissa*) were conducted in Caquetá in 2008.

The main purpose of these trials was to reconfirm resistance in 28 BR06 apomictic hybrids previously evaluated in Palmira resistance to nymphs under greenhouse conditions

Results and Discussion

Using tiller ratios (the ratio between tillers per plant at the end of the infestation process and tillers per plant at the beginning of the infestation process) as the main selection criterion, we found that most (26) of the 28 BR06 hybrids tested were resistant to all four spittlebug species tested (Table 3). Two hybrids (BR06NO/0204 and BR06NO/0850) showed intermediate resistance to all spittlebug species.

Table 3. Tiller ratios (tillers per plant at the end of the infestation process/tillers per plant at the beginning of the infestation process) in selected *Brachiaria* genotypes tested for resistance to four spittlebug species under field conditions in Caquetá, Colombia.

Genotype	Spittlebug species			
	Aeneolamia varia	*Zulia carbonaria*	*Zulia pubescens*	*Mahanarva trifissa*
Mean 2 intermediate hybrids	0.76 ± 0.03b	0.83 ± 0.02b	0.77 ± 0.02b	0.78 ± 0.00b
Mean 26 resistant hybrids	0.93 ± 0.06a	0.96 ± 0.01a	0.93 ± 0.01a	0.93 ± 0.06a
CIAT 6294 (‘Marandu’)	1.00 ± 0.00a	1.00 ± 0.00a	0.99 ± 0.09a	1.00 ± 0.00a
CIAT 36062 (Resistant check)	0.99 ± 0.04a	0.96 ± 0.01a	0.97 ± 0.16a	0.99 ± 0.09a
CIAT 36087 (‘Mulato 2’)	0.99 ± 0.04a	1.00 ± 0.00a	1.00 ± 0.00a	1.00 ± 0.00a
CIAT 0606 (susceptible check)	0.42 ± 0.14c	0.53 ± 0.02c	0.54 ± 0.02c	0.60 ± 0.14c
CIAT 0654 (susceptible check)	0.41 ± 0.17c	0.42 ± 0.01c	0.48 ± 0.03c	0.58 ± 0.13c

Means of 10 replications per genotype per species per trial; 2 trials with each spittlebug species. Means within a column followed by the same letter are not significantly different at the 5% level according to Scheffe’s multiple range test for arbitrary comparisons. Each species analyzed separately.

1.3.3 Identify host mechanisms for spittlebug resistance in *Brachiaria*

1.3.3.1 Studies on tolerance to adult feeding damage as a component of resistance to spittlebug

Contributors: E. Zúñiga, L. Aguirre, C. Cardona, G. Sotelo, J. W. Miles (CIAT)

Rationale

Rapid progress has been made in the incorporation of antibiosis resistance to nymphs in sexual and apomictic hybrids developed through a recurrent selection breeding scheme. Given that adults can be more damaging than nymphs, it is widely accepted that antibiosis to nymphs should be combined with an acceptable level of tolerance to adult feeding damage. The mechanism of resistance to adult feeding damage in *Brachiaria* (tolerance) was studied and reported in detail in 2006 and 2007. In 2008 a new quick screening technique was developed and tested. This allowed us to initiate mass screening of bred materials for resistance to adults of several spittlebug species.

Materials and Methods

Three spittlebug species were utilized: *A. varia*, *A. reducta*, and *Z. carbonaria*. A new screening technique (a leaf cage to house isolated adults feeding for 7 days on a leaf of a fully grown *Brachiaria* plant) (Photo 1) was developed. This was compared with the “plastic bottle” technique (Photo 2) (BOTELLA PLASTICA) reported in 2007 (twenty-day old plants infested with four neonate adults per plant until all adults died, usually 8-10 days after infestation). The following genotypes, well known for their reaction to nymphal attack were used: 1) CIAT 0654, an accession highly susceptible to spittlebug nymphs; 2) CIAT 0606 cv. ‘Basilisk’, a cultivar that is highly susceptible to spittlebug nymphs; 3) CIAT 6294, ‘Marandu’, resistant to nymphs of several spittlebug species; 4) CIAT 36062, an apomictic hybrid that is highly resistant to nymphs of *A. varia* (F.); 5) CIAT 36087 cv. ‘Mulato II’ an apomictic hybrid commercial cultivar with multiple resistance to spittlebug nymphs; and 6) SX01NO/0102, a sexual hybrid clone, highly resistant to nymphs of six spittlebug species. In all cases percentage adult survival was recorded on a daily basis. The two techniques were compared using a split-plot design in which techniques were main plots and genotypes were sub-plots. Five repetitions per technique-genotype combination were used. Damage scores in a 1-5 visual damage score scale were taken 7-10 days after infestation

Photo 1. Leaf cage used to house isolated adults feeding for 7 days on a leaf of a fully grown *Brachiaria* plant

To measure chlorophyll loss as a result of adult feeding, we used a SPAD-502 chlorophyll meter 7-10 days after infestation. Four representative readings per plant were taken and their averages were recorded. SPAD index values (percentage chlorophyll loss) were then calculated with respect to the uninfested checks. At the end of all trials, when all insects had died, plants (or leaves in the case of the leaf cage technique) were cut and dried in an oven at 40^{o} C. Percentage biomass losses were calculated with respect to the uninfested checks. Damage scores and percentage biomass losses were used to calculate functional plan loss indices.

Photo 2. Plastic bottles used to infest seedlings of *Brachiaria* with 4-6 spittlebugs per plant

Results and Discussion

At the levels of infestation used in these experiments, adult survival was not affected by the genotypes. This confirmed previous results indicating that antibiosis does not seem to play a role in resistance to adult feeding damage. As shown in Table 4, damage scores differed among genotypes from highly susceptible reactions (damage scores > 3.0 in CIAT 0654 and CIAT 0606) to tolerance reactions (damage scores < 2.0 recorded on CIAT 6294 and CIAT 36087). In general, and as expected, damage scores and percentage biomass losses (Figure 1) were higher when 4 adults per plant were used (plastic bottle technique). However, rankings of genotypes using the two techniques were similar, suggesting that the leaf cage system is equally reliable to discriminate between susceptible and resistance genotypes.

Table 4. Damage scores and ranking of genotypes obtained with two techniques used to infest *Brachiaria* plants with adults of three spittlebug species.

Genotype	**Damage scores**		**Ranking**	
	Leaf cage (one adult per leaf)	**Plastic bottle (four adults per plant)**	**Leaf cage (one adult per leaf)**	**Plastic bottle (four adults per plant)**
Aeneolamia varia				
CIAT 6294 (‘Marandu’)[a]	1.8cA	1.6cA	4	5
CIAT 36087 (‘Mulato II’)[a]	1.2dB	1.4cA	6	6
CIAT 36062[b]	1.9cB	2.7bcA	3	4
SX01NO/0102[b]	1.6cdB	3.0bA	5	3
CIAT 0606[c]	2.7aB	4.1aA	1	1
CIAT 0654[c]	2.0bB	3.4bA	2	2
Aeneolamia reducta				
CIAT 6294 (‘Marandu’)	1.6bA	1.6dA	6	5
CIAT 36087 (‘Mulato II’)	1.7bA	1.5dA	5	6
CIAT 36062	1.8bB	2.1cA	3	3
SX01NO/0102	2.2aA	2.0cA	4	4
CIAT 0606	2.5aA	2.4bA	1	2
CIAT 0654	2.3aA	2.8aA	2	1
Zulia carbonaria				
CIAT 6294 (‘Marandu’)	1.4dA	1.4dA	5	5
CIAT 36087 (‘Mulato II’)	1.4dB	2.1cA	5	4
CIAT 36062	1.5cB	2.2cB	4	3
SX01NO/0102	1.8cB	2.2cB	3	3
CIAT 0606	2.7bB	3.4bB	2	2
CIAT 0654	3.5aB	4.2aB	1	1

[a] Commercial, nymph-resistant check
[b] Nymph-resistant check
[c] Nymph-susceptible check
Means of five replications per genotype per method. Means within a column followed by the same lowercase letter and within a row followed by the same uppercase letter are not significantly different according to Fisher’s protected LSD (α = 0.05).

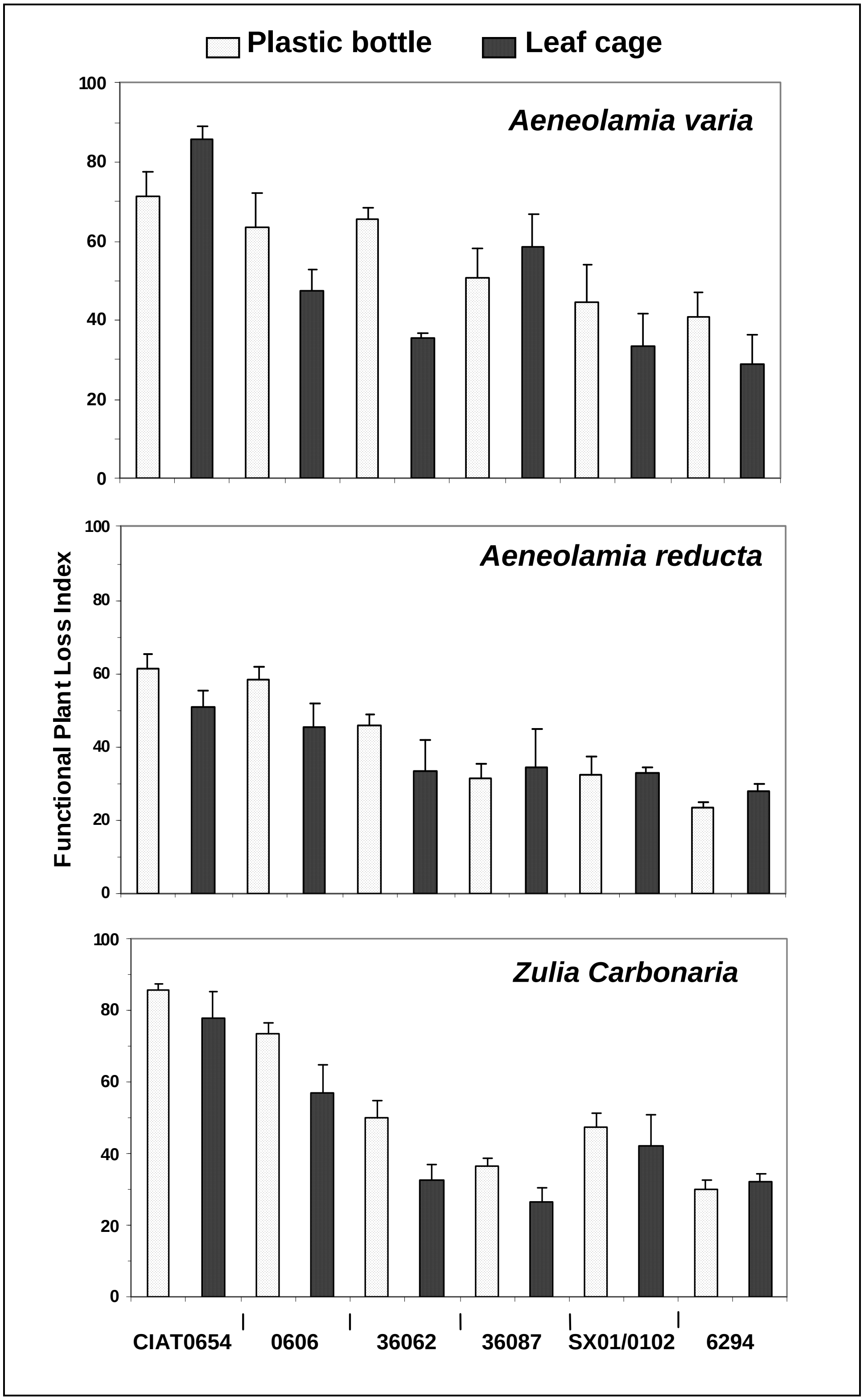

Figure 1. Functional plant loss indexes (percentage) obtained with two techniques used to infest plants of six *Brachiaria* genotypes with adults of three spittlebug species.

Using the leaf cage technique we also studied the effect of insect gender on the expression of resistance to adult feeding damage. Six genotypes (CIAT 0654, CIAT 0606, CIAT 6294, CIAT 36087, CIAT 36062 and SX01NO/0102 were used. Results clearly indicated that on all six genotypes tested females of all three spittlebug species (*A. varia, A. reducta, Z. carbonaria*) caused significantly higher levels of damage and significantly higher chlorophyll and biomass losses than males (Tables 5 and 6).

Table 5. Damage scores, percentage chlorophyll losses, amount of excreta per insect and biomass losses recorded on six *Brachiaria* genotypes infested with adult males and females of three spittlebug species.

Adult gender	Damage scores		Percentage chlorophyll loss		Excreta (cc per adult)	FPLI[b] (Mean ± SEM)
	4 DAI[a]	8 DAI	4 DAI	8 DAI		
			Aeneolamia varia			
Female	2.6a	3.7a	26.6a	43.5a	3.7a	68.1 ± 2.44
Male	2.1b	2.7b	20.0b	30.0b	1.9b	62.9 ± 2.35
			Aeneolamia reducta			
Female	2.2a	3.1a	22.9a	40.7a	5.0a	70.4 ± 2.84
Male	1.7b	2.3b	15.2b	23.7b	2.8b	55.8 ± 2.74
			Zulia carbonaria			
Female	2.9a	3.7a	38.7a	53.9a	11.8a	82.2 ± 1.53
Male	2.2b	3.0b	20.6b	38.3b	8.3b	69.8 ± 2.02

[a] Days after infestation

[b] Functional Plant Loss Index

Means of 10 replications per gender per species. Means within a column followed by the same letter are not significantly different at the 5% level (Fischer's LSD test). Each species analyzed separately.

Table 6. Percentage chlorophyll losses caused by females and males of three spittlebug species on five *Brachiaria* genotypes.

Genotype	Female-induced	Male-induced
Aeneolamia varia		
CIAT 0654 (nymph-susceptible check)	68.0 ± 5.83aA	47.5 ± 7.50aB
CIAT 0606 (nymph-susceptible check)	59.8 ± 5.16aA	42.9 ± 5.19aB
SX01NO/0102 (nymph-resistant check)	46.1 ± 4.39bA	29.6 ± 3.65bB
CIAT 36087 ('Mulato II', nymph-resistant check)	19.9 ± 3.26dA	17.5 ± 4.48cA
CIAT 6294 ('Marandu', nymph-resistant check)	29.7 ± 4.83cA	12.7 ± 1.99cB
Aeneolamia reducta		
CIAT 0654 (nymph-susceptible check)	52.9 ± 2.63aA	36.3 ±6.99aB
CIAT 0606 (nymph-susceptible check)	51.6 ± 3.91aA	30.1 ±4.91aB
SX01NO/0102 (nymph-resistant check)	44.1 ± 2.88bA	18.5 ±3.64bB
CIAT 36087 ('Mulato II', nymph-resistant check)	34.8 ± 3.86cA	17.3 ±2.80bB
CIAT 6294 ('Marandu', nymph-resistant check)	23.2 ± 3.85dA	18.0 ±3.03bA
Zulia carbonaria		
CIAT 0654 (nymph-susceptible check)	76.6 ± 3.45aA	59.8 ± 5.70aB
CIAT 0606 (nymph-susceptible check)	62.4 ± 6.40bA	50.7 ± 4.75aB
SX01NO/0102 (nymph-resistant check)	51.6 ± 3.00bA	41.5 ± 4.34bB
CIAT 36087 ('Mulato II', nymph-resistant check)	59,5 ± 4.31bA	31.4 ± 5.04cB
CIAT 6294 ('Marandu', nymph-resistant check)	19.2 ± 4.53cA	18.7 ± 2.66dA

Means ± SEM of 10 replications per genotype per sex. Means within a column followed by the same lowercase letter and within a row followed by the same uppercase letter are not significantly different according to Fisher's protected LSD ($\alpha = 0.05$). Each species analyzed separately.

1.3.3.2 Mass screening for tolerance to adult feeding damage

Contributors: G. Sotelo, C. Cardona, J. W. Miles (CIAT)

Materials and Methods

Using the leaf cage technique, 906 SX08 seedlings were opportunistically screened for tolerance to adult spittlebug damage. Adult insects were not sexed and only a single leaf per plant was infested with a single insect. While the culling of the initial population may have achieved some gain, we concluded that damage of a single, unsexed adult insect on a single leaf is not highly repeatable. This technique may be used to discard obviously susceptible genotypes but is not completely reliable to identify resistant ones.

Better results were obtained when 72 apomictic hybrids (coded MX and BR) were screened using female adults and three repetitions in time (Table 7).

Table 7. Damage scores recorded on plants of *Brachiaria* genotypes following feeding by female adults of *Aeneolamia reducta*

Genotype	Damage scores
Mean 47 susceptible hybrids	3.7 ± 0.24a
Mean 19 intermediate hybrids	2.5 ± 0.15b
Mean 6 resistant hybrids[a]	1.6 ± 0.10c
CIAT 6294 (‘Marandu’, nymph-resistant commercial check)	1.3 ± 0.14c
CIAT 36087 (‘Mulato II’, nymph-resistant commercial check)	2.2 ± 0.50bc
CIAT 36062 (nymph-resistant check)	1.7 ± 0.32c
SX01NO/0102 (nymph-resistant check)	2.7 ± 0.43b
CIAT 0606 (nymph-susceptible check)	3.6 ± 0.71a
CIAT 0654 (nymph-susceptible check)	3.2 ± 0.56a

[a] MX02NO/2531, BR02NO/0465, BR02NO/1752, BR04/3207, BR05NO/0563, BR 05NO/1467
Means ± SEM of 3 replications per genotype. Means within a column followed by the same letter are not significantly different at the 5% level according to Scheffe’s multiple range test for arbitrary comparisons.

1.4 Define interactions between host and pathogen in *Brachiaria*

1.4.1 Evaluation of *Brachiaria* hybrids for resistance to *Rhizoctonia solani*

Rationale

Rhizoctonia foliar blight remains a serious disease of commercial Brachiariagrass cultivars. Two early hybrid cultivar releases (cvv. Mulato and Mulato II) were found to be quite susceptible to Rhizoctonia foliar blight and our synthetic breeding population also exhibits general susceptibility. Hence, the development of high capacity, high throughput, and reliable screening methodology is imperative.

Materials and Methods

Methodology development continues. Important advances have been achieved. A series of studies of factors that might affect disease severity and uniformity of disease symptoms under conditions of artificial inoculation were conducted. Selection of pathogen isolate for vigorous growth in Petrie dishes, "pregermination" of sclerotia, placement of inoculum on the plant, time from inoculation to assessment of disease symptoms were all found to affect development of disease symptoms. We have settled, at least temporally, on the following procedures: Young tillers (single stem) are vegetatively propagated and grown in soil in a short section of PVC tubing, as described by Cardona *et al.* (1999). The above-ground portion of each individual propagule is enclosed in a 500 ml, clear plastic drinking water bottle, both to increase relative humidity around the plant foliage, and also physically to isolate individual plants from contact with one another. Inoculum, in the form of a small (~5mm diameter) agar disk with actively growing mycelium is placed in the axil between the leaf blade and the stem of each of the two oldest leaves. Symptoms are classified on a 9-point scale, about 1 wk following inoculation, depending on disease development on the susceptible check(s).

Results and Discussion

We have evaluated several sets of *Brachiaria* genotypes as our methodology has evolved over the year. Differences in disease development can be detected, but the bulk of our breeding materials appear to be quite susceptible. The single genotype that consistently shows a high level of resistance is the *B. brizantha* germplasm accession, CIAT 16320, whose resistance was originally reported by Kelemu et al. (1995).

1.4.1.1 Screen 31 SX05 selections for reaction to Rhizctonia foliar blight and assess genetic variation for resistance

Rationale

Selection on resistance to Rhizoctonia foliar blight in our synthetic sexual breeding population will improve resistance of the population itself, as well as increase the resistance of apomictic hybrids developed from it.

Materials and Methods

Thirty-one SX05 sexual selections were recombined to form the most recent version of the sexual breeding population (SX08). The 31 SX05 clones were evaluated for reaction to Rhizoctonia.

Results and Discussion

Mean disease scores among 31 SX05 clones ranged from 1.9 to 4.9 on a visual scale from 1 (= most resistant) to 5 (= most susceptible). The mean of the 31 clones was 3.6. Several SX08 (half-sib) families, those derived from the most susceptible SX05 clones, were culled. However, this cull was probably not very effective as only five clones were discarded. Future evaluation and selection will need to be conducted, with larger populations and more intense selection.

1.5 Genotypes of *Brachiaria* with adaptation to abiotic constraints

1.5.1 Edaphic adaptation of *Brachiaria*

Highlights

- Significant progress has been made in identifying both apomictic and sexual clones of *Brachiaria* with greater level of Al resistance. A group of nine sexual (SX05NO/1955, SX05NO/1962, SX05NO/1948, SX05NO/2105, SX05NO/2207, SX05NO/2234, SX05NO/2206, SX05NO/1953 and SX03NO/0846) and six apomictic (BR06NO/0531, BR06NO/1278, BR06NO/0012, BR06NO/1175, BR05NO/0334 and BR05NO/0537) genotypes were identified with greater level of Al resistance compared with the respective parents. Both sexual and apomictic genotypes have improved root development under very high aluminum level in solution.

- Among the 12 *Brachiaria* genotypes evaluated for root development under Al toxic soil conditions, *Brachiaria decumbens* was found to be outstanding in developing fine root system while the *Brachiaria* hybrid cv. Mulato was superior in shoot biomass production. The thicker root system of cv. Mulato was associated with its superior ability to produce shoot biomass. This study confirmed the sensitivity of *Brachiaria ruziziensis* to Al toxic soil conditions and this was attributed to its poor root system development.

1.5.1.1 Phenotypic differences in aluminum resistance of selected Brachiaria genotypes

Contributors: J. Ricaurte, R. García, J. W. Miles, I. M. Rao (CIAT)

Rationale

Since 2001, we have implemented a screening procedure using hydroponics to identify aluminum (Al)-resistant *Brachiaria* hybrids that were preselected for spittlebug resistance. In 2005, we evaluated the BR04NO series of 139 apomictic/sexual hybrids of *Brachiaria* and identified 9 hybrids (BR04NO/1018, BR04NO/1552, BR04NO/1900, BR04NO/2110, BR04NO/2128, BR04NO/2166, BR04NO/2179, BR04NO/2201 and BR04NO/2681) that were superior to the *B. decumbens* parent in terms of Al resistance. In 2006, we evaluated 103 clones of the BR05NO series, 60 clones of the RZ05NO series, and 88 clones of the SX05NO series together with 3 parents and 8 checks for their level of Al resistance. Among the 103 hybrids (apomictic/sexual) of the BR05 population evaluated, nine hybrids (BR05NO/0406, BR05NO /0563, BR05NO /0334, BR05NO /0830, BR05NO /1173, BR05NO /0671, BR05NO /0120, BR05NO /0048, and BR05NO /0537) were superior to the *B. decumbens* parent in terms of root length with Al in solution. Among the 88 hybrids (sexual) of SX05 population evaluated, none was superior to the *B. decumbens* parent in terms of total root length with Al in solution but 2 sexual hybrids (SX05NO/1953 and SX05NO/1968) were superior in their ability to produce fine roots in the presence of Al in solution compared to the rest of the hybrids tested. In 2007, we evaluated 192 clones of the cross between *B. ruziziensis* x *B. decumbens* for phenotypic differences in Al resistance. We found transgressive segregation for Al resistance as was observed before with another population of the same cross. Several clones were found to be superior in their level of Al resistance than the Al resistant parent, *B. decumbens*. These data are being used to identify QTLs related to Al resistance in *Brachiaria*. This year we evaluated three groups of preselected genotypes from previous populations including 31 (SX03, SX05, BR02, BR04 and BR05 and checks), 79 (MX02, BR02, BR04, BR05, BR06 and checks); and 43 (31 SX05 and 12 checks) with and without Al in solution for their level of Al resistance.

Materials and methods

Three groups of *Brachiaria* hybrids generated from the breeding program along with checks were evaluated under hydroponic conditions for their level of Al resistance. A first group of three incomplete sets (separate experiments) of 31 *Brachiaria* genotypes (3 SX03, 8 SX05, 4 BR02, 3 BR04, 5 BR05 and 8 checks), a second group of three incomplete sets (separate experiments) of 79 genotypes (10 MX02, 5 BR02, 8 BR04, 20 BR05, 28 BR06 and 8 checks), and a third group of four incomplete sets (separate experiments) of 43 genotypes (31 clones of the SX05 population and 12 checks) were evaluated with 0 and 200 µM of Al in solution for their level of Al resistance under greenhouse conditions at CIAT-Palmira. The sets were incomplete because some of the hybrids did not root well in each experiment. Mean values from all the experiments are reported for each group of genotypes. Stem cuttings of all genotypes were rooted in a low ionic strength nutrient solution in the glasshouse for nine days. Equal numbers of stem cuttings with about 5 cm long roots were transferred into a solution containing 200 µM $CaCl_2$, pH 4.2 (reference treatment) and a solution containing 200 µM $CaCl_2$ and 200 µM $AlCl_3$, pH 4.2 (Al treatment). The solutions were changed every second day to minimize pH drifts. At harvest, on day 21, after transfer, root systems were harvested. Roots were scanned on a flatbed scanner with transparency unit (EPSON 4800). Image analysis software (WinRHIZO v 2003b) was used to determine root length and average root diameter.

Results and discussion

As reported in previous years, Al resistant clones combine greater values of total root length per plant with lower values of mean root diameter relative to the mean values of the population when exposed to 21 days with toxic level of Al in solution. We found significant phenotypic variation in total root length and mean root diameter under both without and with Al treatment (Figures 1 and 2).

Total root length of the 31 *Brachiaria* genotypes was markedly decreased with Al (Table 8, Figure 2). The mean root length was 415 cm plant^{-1} under without Al treatment and this value decreased to 234 cm plant^{-1} with Al treatment showing a reduction of 44%. The mean root diameter increased from 0.355 mm to 0.446 mm (31%) with exposure to Al (Table 8, Figure 3). The decrease in root length and increase in root diameter with Al exposure is due to Al toxicity effect on root elongation process. Two apomictic hybrids (BR05NO/0334 and BR05NO/0537) were superior to apomictic parent *B. decumbens* CIAT 606 in terms of root length with and without Al in solution (Table 8, Figures 3 and 3). Two sexual hybrids (SX05NO/1953 and SX03NO/0846) were superior to the sexual parent *B. ruziziensis* 44-02 in terms of root length with and without Al in solution (Table 8, Figures 3 and 5).

Total root length of the 79 *Brachiaria* genotypes was markedly decreased with Al (Table 9, Figure 6). The mean root length was 451 cm plant^{-1} under without Al treatment and this value decreased to 295 cm plant^{-1} with Al treatment showing a reduction of 35%. The mean root diameter increased from 0.355 mm to 0.446 mm (13%) with exposure to Al (Table 9, Figure 7).

Table 8. Root length and mean root diameter of 31 *Brachiaria* genotypes evaluated with (200 µM Al) and without Al (0 µM Al) in solution.

Genotypes	**Root length (cm)**		**Average diameter (mm)**	
	0 Al	**200 µMal**	**0 Al**	**200 µMAl**
BR05NO/0334	898	539	0.340	0.385
BR05NO/0537	726	409	0.274	0.326
Bdec CIAT606	507	391	0.284	0.335
BR05NO/0406	547	372	0.260	0.271
BR05NO/0563	591	371	0.289	0.317
BR05NO/0830	542	367	0.292	0.358
BR04NO/2201	569	357	0.261	0.316
Bhum CIAT679	518	333	0.242	0.281
Bdic CIAT6133	651	329	0.273	0.325
BR02NO/1372	566	315	0.277	0.324
SX05NO/1953	625	280	0.308	0.382
SX03NO/0846	464	240	0.337	0.383
CIAT36061	523	239	0.438	0.553
BR04NO/2681	299	229	0.324	0.361
SX05NO/2167	413	228	0.348	0.381
BR04NO/2110	521	221	0.301	0.373
BR02NO/1485	439	206	0.352	0.452
BR02NO/1752	466	188	0.403	0.452
SX05NO/1968	490	170	0.322	0.405
Bbriz CIAT6294	463	169	0.361	0.528
SX05NO/2313	277	161	0.338	0.402
SX05NO/2413	359	161	0.408	0.585
SX05NO/1918	363	148	0.326	0.472
SX03NO/0881	338	131	0.413	0.479
SX05NO/2332	257	118	0.364	0.461
CIAT36087	186	84	0.644	0.743
Bruz 44-02	194	68	0.433	0.537
SX05NO/2547	327	61	0.353	0.481
SX03NO/2367	108	48	0.449	0.545
Bbriz CIAT26110	146	41	0.475	0.760
BR02NO/0465	106	30	0.480	0.791
Mean	**445**	**234**	**0.355**	**0.446**
$LSD_{0.05}$	***175***	***104***	***0.076***	***0.088***

Five apomictic hybrids (BR06NO/1278, BR06NO/0531, BR06NO/0012, BR06NO/1175 and BR05NO/0334) were superior to apomictic parent *B. decumbens* CIAT 606 in terms of root length with and without Al in solution (Table 9, Figure 6). Two of them (BR06NO/0012 and BR06NO/1175) generated finer root system than *B. decumbens* CIAT 606 with high Al in solution (Table 9, Figure 7).

Table 9. Root length and mean root diameter of 79 *Brachiaria* genotypes evaluated with (200 µM Al) and without Al (0 µMAl).

Genotypes	Root length (cm plant^{-1})		Average diameter (mm)		Genotypes	Root length (cm plant^{-1})		Average diameter (mm)	
	0 Al	200µMAl	0 Al	200µMAl		0 Al	200µMAl	0 Al	200µMAl
BR06NO/1278	518	611	0.3106	0.3268	BR06NO/1415	527	275	0.2880	0.3302
BR06NO/0531	727	600	0.3260	0.3611	MX02NO/03641	455	270	0.3990	0.4041
BR06NO/0012	778	585	0.2888	0.3051	BR06NO/1454	479	269	0.3147	0.3643
BR06NO/1175	757	566	0.2811	0.3074	BR05NO/01609	447	268	0.2998	0.3335
BR05NO/00334	636	553	0.3544	0.3673	BR05NO/01435	408	266	0.2930	0.3396
Bdec CIAT606	606	480	0.2805	0.3182	BR06NO/2058	318	262	0.3823	0.4171
BR06NO/0423	706	469	0.2966	0.3194	BR06NO/1388	414	261	0.2866	0.3155
BR06NO/0387	379	455	0.3080	0.3251	BR05NO/00743	360	258	0.2950	0.3206
BR06NO/2020	659	448	0.3291	0.3321	BR05NO/01520	389	256	0.3568	0.4188
BR06NO/0204	613	446	0.3189	0.3292	BR06NO/1433	344	235	0.2757	0.3056
BR05NO/00537	784	436	0.2878	0.3370	MX02NO/03626	347	233	0.3802	0.4339
BR04NO/02069	520	429	0.2856	0.3135	MX02NO/03426	471	231	0.4238	0.4714
BR06NO/1348	466	423	0.3240	0.3264	BR05NO/01449	344	213	0.3338	0.4061
BR04NO/01018	503	417	0.3042	0.3444	MX02NO/02552	272	211	0.4152	0.4483
BR05NO/00637	497	408	0.2817	0.3371	BR05NO/00931	452	206	0.2958	0.3377
BR05NO/00563	674	406	0.2668	0.2894	BR06NO/1567	334	196	0.3121	0.3703
BR06NO/1922	495	400	0.2885	0.3252	BR04NO/02405	372	191	0.4012	0.4379
BR06NO/0850*	530	394	0.2575	0.3033	BR02NO/1794	436	188	0.3999	0.4458
BR06NO/1696	662	381	0.2878	0.2935	BR04NO/03025	234	183	0.2817	0.3297
CIAT36061	634	368	0.4352	0.4849	BR05NO/01426	328	178	0.3491	0.3770
BR05NO/00744	460	350	0.2753	0.3096	BR05NO/01738	238	175	0.3234	0.3812
BR06NO/0584	466	347	0.2949	0.3456	Bbriz CIAT6294	343	168	0.3062	0.4076
BR06NO/1254	338	346	0.3588	0.3670	BR05NO/01469	439	164	0.2990	0.4514
BR06NO/1000	678	345	0.2765	0.3106	BR04NO/01061	331	150	0.3211	0.4299
BR05NO/01702	418	331	0.3209	0.3588	BR04NO/02515	336	148	0.3179	0.4143
BR02NO/1372	456	324	0.2775	0.3041	MX02NO/01614	242	143	0.3508	0.3859
BR05NO/00760	417	320	0.2872	0.3284	Bdic CIAT6133	218	139	0.2729	0.2734
BR06NO/2204	537	316	0.3052	0.3476	MX02NO/01769	349	123	0.3129	0.3741

Continues…

Table 9. Root length and mean root diameter of 79 *Brachiaria* genotypes evaluated with (200 µM Al) and without Al (0 µMAl).

Genotypes	**Root length (cm plant^{-1})**		**Average diameter (mm)**		**Genotypes**	**Root length (cm plant^{-1})**		**Average diameter (mm)**	
	0 Al	**200µMAl**	**0 Al**	**200µMAl**		**0 Al**	**200µMAl**	**0 Al**	**200µMAl**
BR05NO/01467	520	315	0.3101	0.3569	Bruz 44-02	225	113	0.4068	0.4053
BR06NO/1832	582	314	0.2918	0.3200	BR05NO/01706	244	107	0.2696	0.3067
BR05NO/01586	467	311	0.3089	0.3703	MX02NO/02090	177	105	0.3405	0.3943
BR06NO/1932	385	310	0.3281	0.3466	BR04NO/03207	149	104	0.2978	0.3785
BR06NO/0206	493	298	0.3223	0.3509	CIAT36087	180	103	0.5408	0.6425
BR06NO/1132	630	293	0.2877	0.3285	MX02NO/03731	202	98	0.5290	0.5623
BR05NO/00549	684	287	0.2939	0.3730	BR04NO/02774	255	91	0.3681	0.4749
BR02NO/1752	595	287	0.4121	0.4282	MX02NO/02531	79	91	0.4865	0.4480
BR06NO/1366	517	285	0.3343	0.3641	BR02NO/1718	229	82	0.4593	0.5508
MX02NO/02775	325	277	0.3565	0.3894	Bbriz CIAT 26110	75	49	0.5142	0.6797
BR06NO/0405	364	276	0.3248	0.3313	BR02NO/0465	87	33	0.4215	0.6752
Bhum CIAT679	626	276	0.2267	0.2816					
					Mean	**451**	**295**	**0.3317**	**0.3740**
					LSD0.05	***138***	***101***	***0.0410***	***0.0513***

* This clone was not a hybrid. It was later identified as *B. decumbens* CIAT 606.

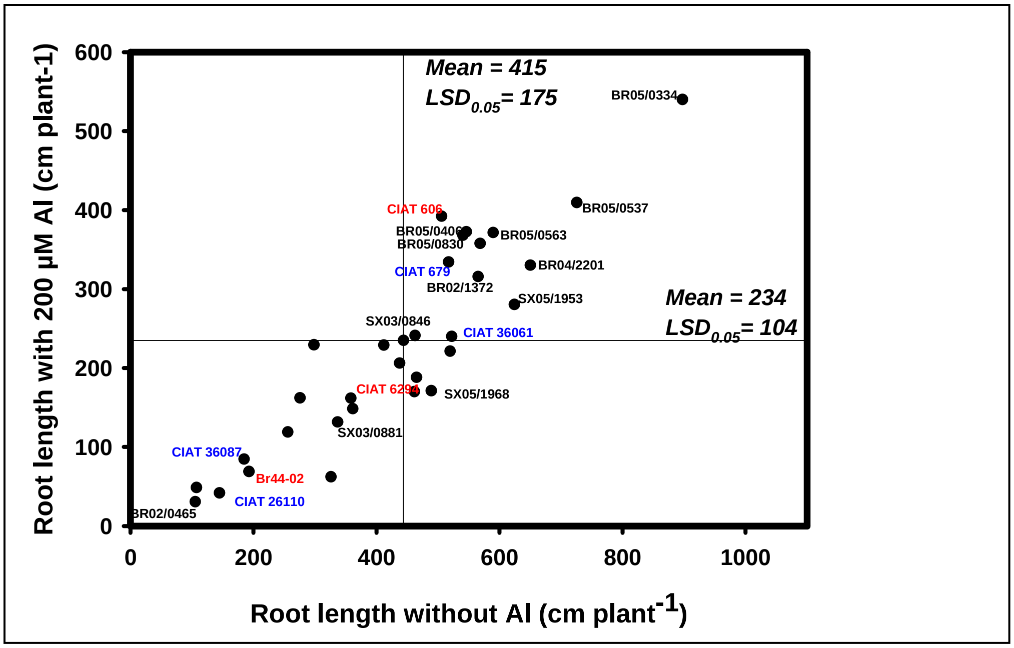

Figure 2. Relationship between total root length with Al and total root length without Al in solution of 31 *Brachiaria* gentoypes. Gentoypes that developed greater root length under both conditions were identified in the upper, right hand quadrant.

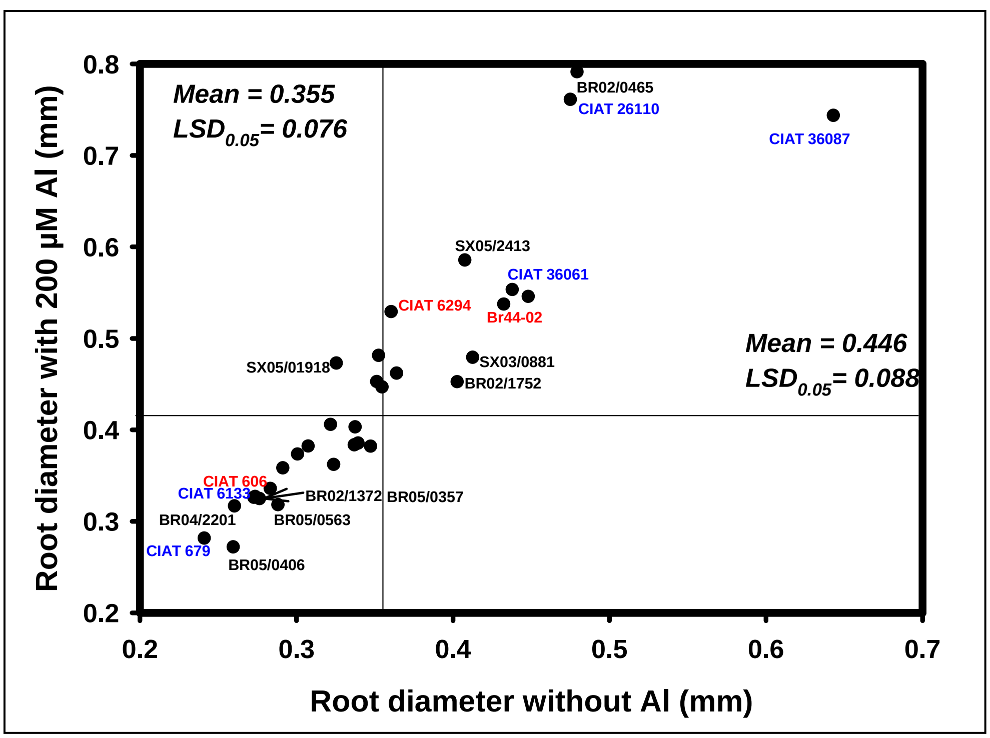

Figure 3. Relationship between mean root diameter with Al and mean root diameter without Al in solution of 31 *Brachiaria* gentoypes. Gentoypes that developed finer roots under both conditions were identified in the lower, left hand quadrant.

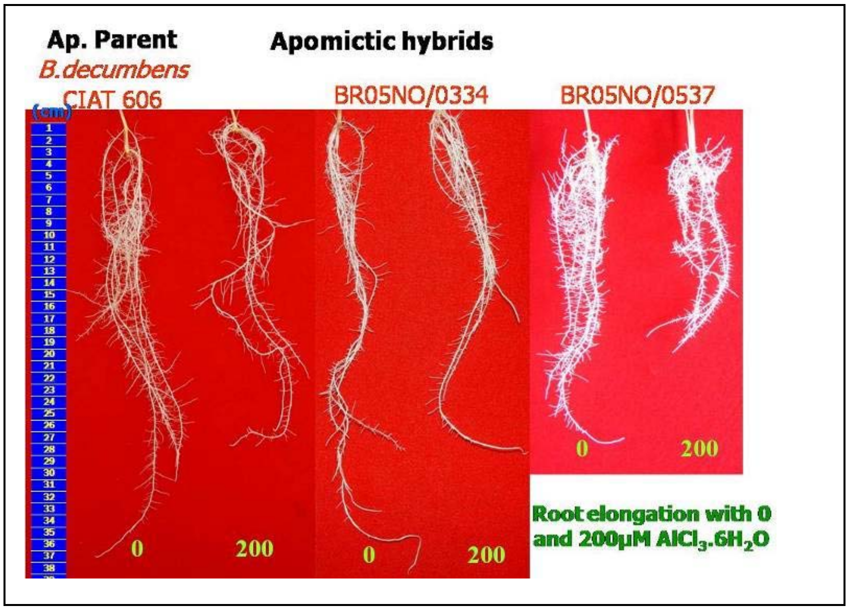

Figure 4. Two outstanding apomictic *Brachiaria* hybrids in root length production with 0 and 200 µM Al in solution, compared with their apomictic parent.

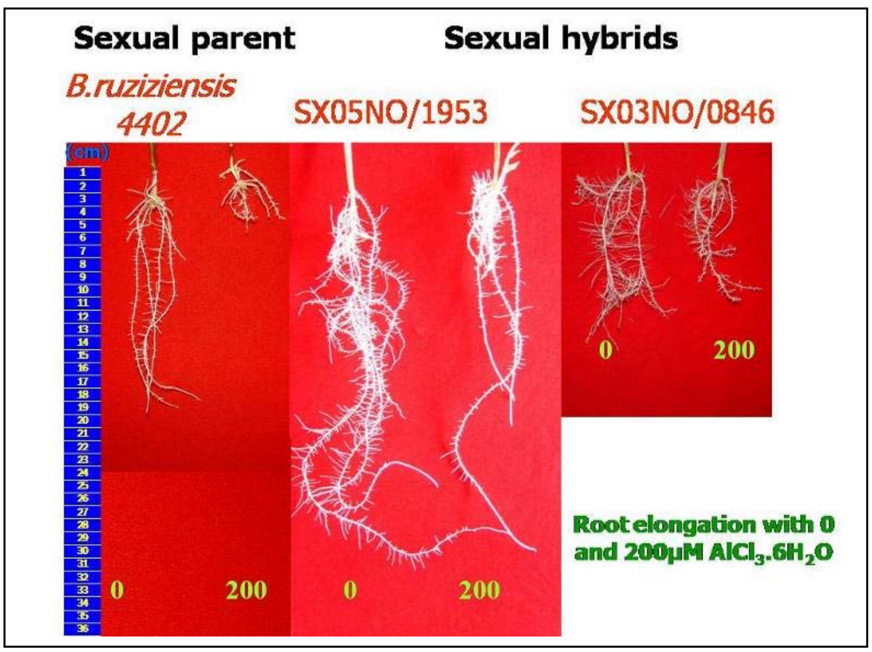

Figure 5. Two outstanding sexual *Brachiaria* gentoypes in root length production with 0 and 200 µM Al in solution, compared with their sexual parent.

Table 10. Root length and mean root diameter of 43 *Brachiaria* genotypes evaluated with (200 µM Al) and without Al (0 µM Al) in solution.

Genotypes	**Root length (cm plant^{-1})**		**Average diameter (mm)**	
	0 Al	**200 µMAl**	**0 Al**	**200 µMAl**
BRO2 NO 1372	805	410	0.2847	0.3229
Bdec CIAT 606	589	376	0.2705	0.3213
CIAT 36061	545	231	0.4256	0.5432
BRO2 NO 1752	562	195	0.3890	0.4582
Bhum CIAT 679	471	173	0.2428	0.2954
BRO2 NO 1245	402	167	0.3098	0.4442
Bdic CIAT 6133	207	166	0.2626	0.2833
SX05 NO 1955	341	164	0.3544	0.4385
SX05 NO 1962	354	162	0.3140	0.3677
SX05 NO 1948	313	155	0.3739	0.4716
SX05 NO 2105	339	152	0.3380	0.4098
SX05 NO 2207	489	151	0.3994	0.5102
SX05 NO 2234	177	148	0.3443	0.2847
Bbriz CIAT 6294	410	146	0.3516	0.5303
SX05 NO 2206	338	141	0.3619	0.4724
SX05 NO 1963	446	132	0.3526	0.4505
SX05 NO 2440	269	132	0.3708	0.5076
SX05 NO 2108	239	127	0.4103	0.5123
SX05 NO 2446	286	125	0.3715	0.4697
SX05 NO 1905	252	121	0.4411	0.5166
SX05 NO 2031	224	119	0.3769	0.4348
SX05 NO 1949	328	118	0.3796	0.5142
SX05 NO 2015	235	111	0.4656	0.5760
SX05 NO 2000	240	100	0.3802	0.5534
SX05 NO 2155	118	98	0.3467	0.3547
SX05 NO 2343	432	91	0.3344	0.4910
SX05 NO 2560	256	90	0.3748	0.4670
SX05 NO 1990	247	88	0.3568	0.4149
SX05 NO 1907	176	86	0.3748	0.4593
SX05 NO 2480	243	85	0.4329	0.5295
SX05 NO 2421	183	81	0.4965	0.6427
CIAT 36087	212	78	0.5715	0.7922
SX05 NO 2180	114	77	0.4863	0.6052
SX05 NO 2008	185	76	0.3889	0.4783
BRO2 NO 1485	170	74	0.4173	0.4919
Bruz 44-02	202	72	0.4362	0.5054
SX05 NO 1985	174	68	0.3973	0.5641
SX05 NO 2045	155	65	0.4224	0.6095
SX05 NO 1964	281	63	0.3638	0.5330
SX05 NO 2280	139	57	0.4808	0.5927
SX05 NO 1988	196	54	0.3610	0.4737
Bbriz CIAT 26110	154	50	0.4936	0.7166
SX05 NO 2010	156	49	0.3940	0.5187
Mean	**317**	**137**	**0.3811**	**0.4873**
$LSD_{0.05}$	***122***	***62***	***0.0474***	***0.0837***

Total root length of the 43 *Brachiaria* genotypes was markedly decreased with Al (Table 10, Figure 8). The mean root length was 317 cm plant^{-1} under without Al treatment and this value decreased to 137 cm plant^{-1} with Al treatment showing a reduction of 57%. The mean root diameter increased from 0.381 mm to 0.487 mm (28%) with exposure to Al (Table 10, Figure 11). Under high Al in solution, 80% (24 clones) of the sexual genotypes generated more root length than the sexual parent (*B.ruziziensis* 44-02). A total of 7 clones (SX05NO/1955, SX05NO/1962, SX05NO/1948, SX05NO/2105, SX05NO/2207, SX05NO/2234 and SX05NO/2206) were found to be outstanding in root length with high Al (Table 10, Figure 8). Six sexual genotypes had finer root system (SX05NO/2234, SX05NO/1962, SX05NO/2105, SX05NO/1955, SX05NO/1948 and SX05NO/2206) with high Al in solution (Table 10, Figure 9).

Correlation coefficients between total root length and other root attributes of three groups of *Brachiaria* genotypes evaluated with 0 and 200 µM Al solution are shown in Table 11. Significant negative correlation was observed between total root length and mean root diameter for all three groups of genotypes under both with and without Al indicating that the genotypes that were resistant to Al produced much finer roots.

Significant positive association was observed between total root length and root volume or surface area under both with and without Al in solution for all three groups of genotypes indicating the importance of root vigor for Al resistance. Results from these three groups of genotypes indicate the progress made so far in the breeding program in developing Al resistant apomictic and sexual hybrids of *Brachiaria*. It is important to note that some clones were markedly superior to *B. decumbens* CIAT 606 in terms of both root vigor and Al resistance.

Table 11. Correlation coeficients between total root length and other root attributes of three groups of *Brachiaria* genotypes evaluated with 0 and 200 µM Al solution under glasshouse conditions at CIAT-Palmira.

Group of genotypes	Root attributes	Root length (m plant^{-1})	
		0 µM Al	200 µM Al
31	Root diameter (mm)	-0.49**	-0.64**
	Root volume (cm^3 plant^{-1})	0.62**	0.60**
	Surface area (cm² plant^{-1})	0.91**	0.93**
	Specific root length (m g^{-1})	0.354**	0.41**
79	Root diameter (mm)	-0.32**	-0.47**
	Root volume (cm^3 plant^{-1})	0.68**	0.71**
	Surface area (cm² plant^{-1})	0.92**	0.94**
43	Root diameter (mm)	-0.42**	-0.48**
	Root volume (cm^3 plant^{-1})	0.73**	0.57**
	Surface area (cm² plant^{-1})	0.93**	0.91**

** significant at the probability level of 0.01

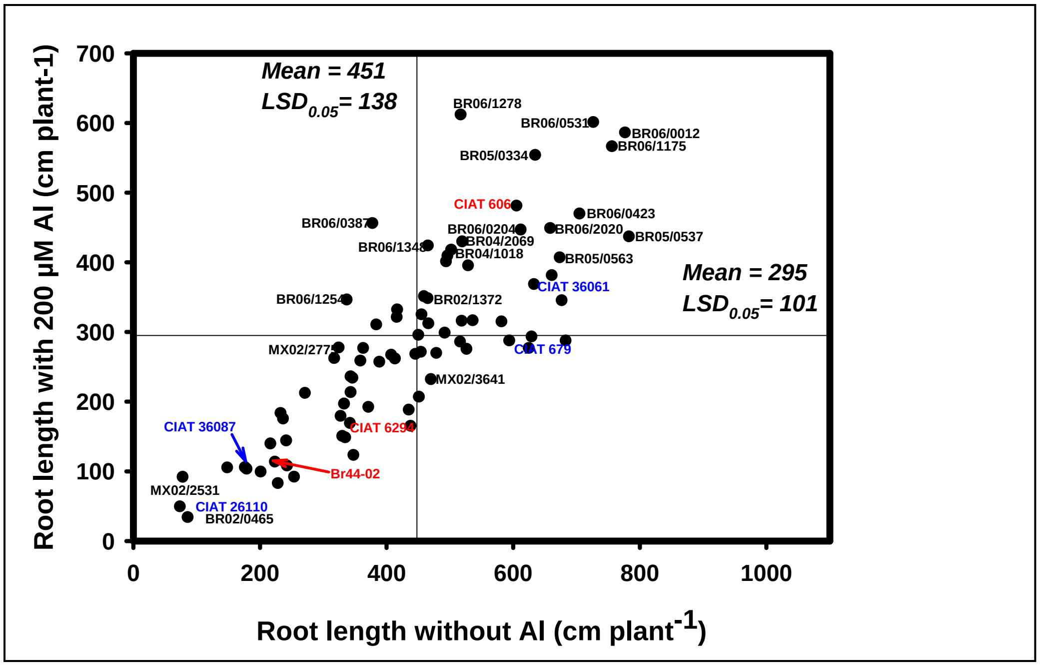

Figure 6. Relationship between total root length with Al and total root length without Al in solution of 79 *Brachiaria* gentoypes. Gentoypes that developed greater root length under both conditions were identified in the upper, right hand quadrant.

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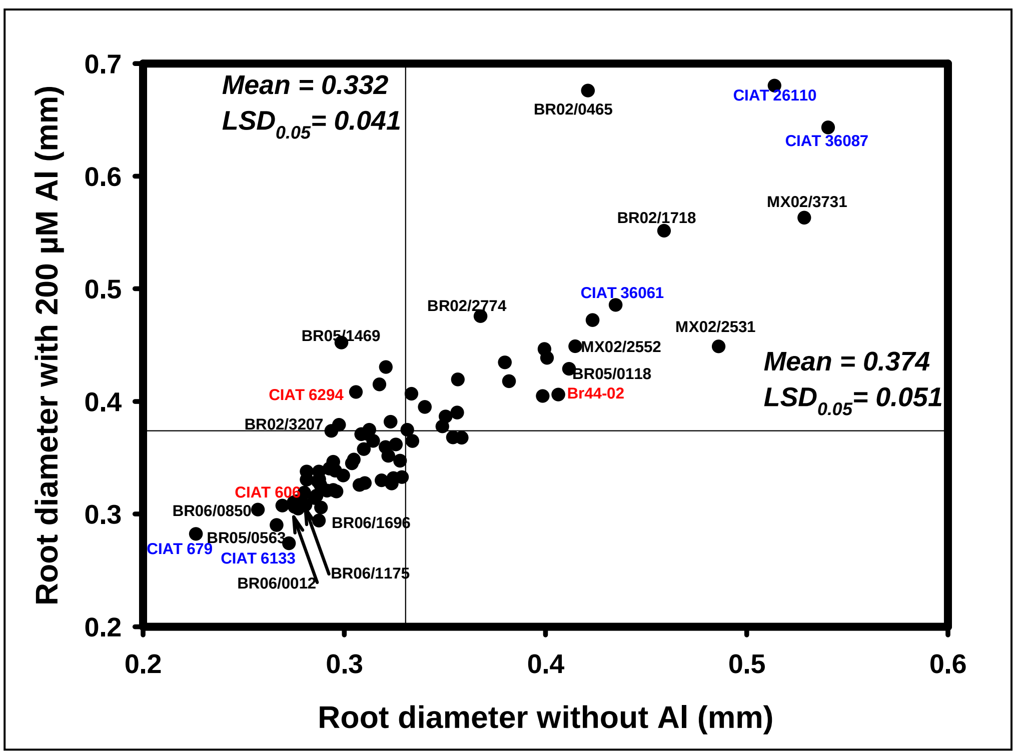


Figure 7. Relationship between mean root diameter with Al and mean root diameter without Al in solution of 79 *Brachiaria* gentoypes. Genotypes that developed finer roots under both conditions were identified in the lower, left hand quadrant.

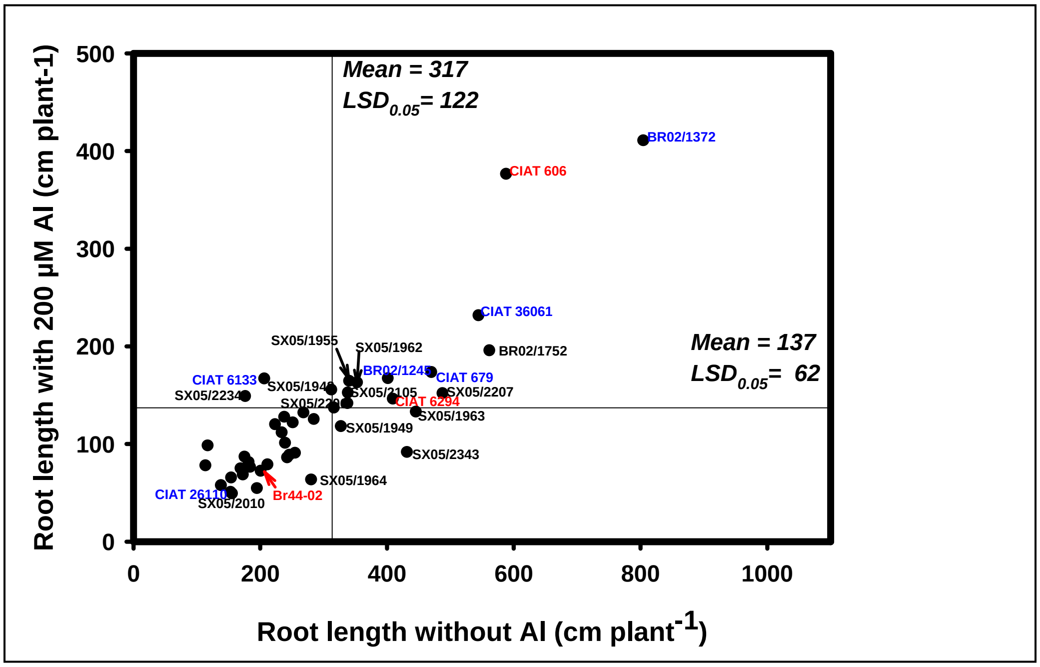


Figure 8. Relationship between total root length with Al and total root length without Al in solution of 31 *Brachiaria* gentoypes SX05N0/ and 12 checks. Genotypes that developed greater root length under both conditions were identified in the upper, right hand quadrant.

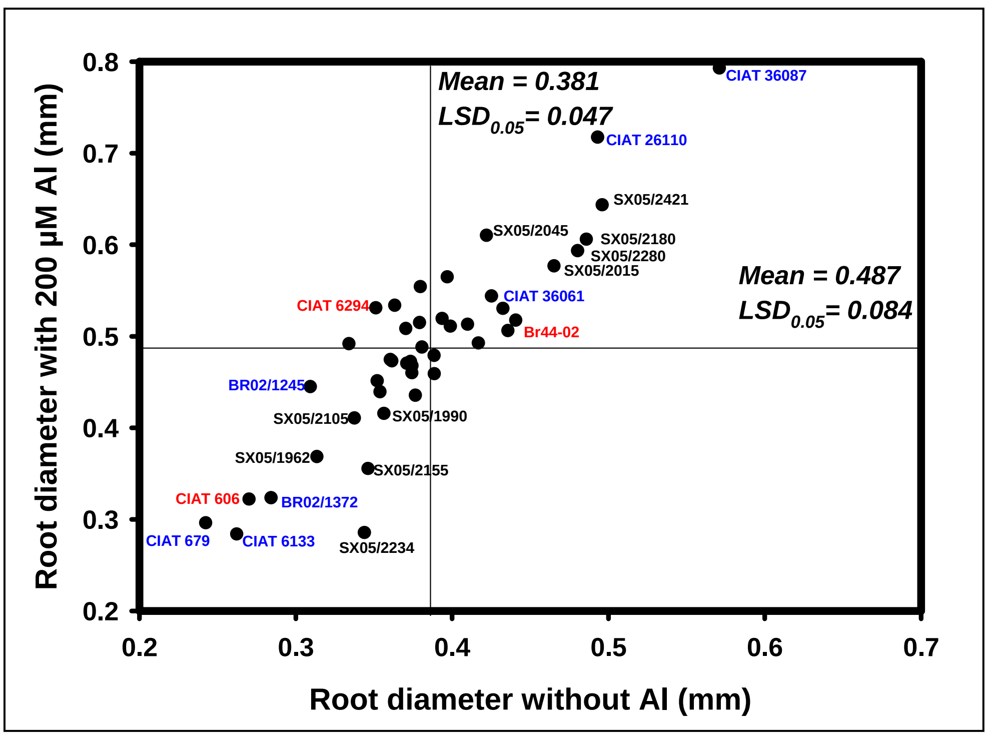


Figure 9. Relationship between mean root diameter with Al and mean root diameter without Al in solution of 31 *Brachiaria* gentoypes SX05N0/ and 12 checks. Genotypes that developed finer roots under both conditions were identified in the lower, left hand quadrant.

Conclusions

Significant progress has been made in identifying both apomictic and sexual hybrids of *Brachiaria* with greater level of Al resistance. A group of nine sexual (SX05NO/1955, SX05NO/1962, SX05NO/1948, SX05NO/2105, SX05NO/2207, SX05NO/2234, SX05NO/2206, SX05NO/1953 and SX03NO/0846) and six apomictic (BR06NO/0531, BR06NO/1278, BR06NO/0012, BR06NO/1175, BR05NO/0334 and BR05NO/0537) genotypes were identified with greater level of Al resistance compared with the respective parents. Both sexual and apomictic genotypes have been improved for root development under very high aluminum levels in solution.

1.5.1.2 Differences in shoot and root attributes of 12 *Brachiaria* genotypes subjected to aluminum toxic soil conditions

Contributors: V. Hoyos, J. Polania, R. García, J. W. Miles and I.M. Rao (CIAT)

Rationale

The most prominent symptom of aluminum toxicity is the inhibition of root growth. Recently, we developed a soil tube method to quantify genotypic differences in root growth and development under individual and combined stress factors of aluminum toxicity and drought stress. Last year, we determined differences in shoot and root growth responses among 12 *Brachiaria* genotypes that are subjected to three watering regimes for a period of 21 days using the soil tube method under greenhouse conditions. We found that *Brachiaria decumbens* CIAT 606 is well adapted to both intermittent and terminal drought stress conditions. Among the *Brachiaria* hybrids tested, Mulato CIAT 36061 performed better under both intermittent and terminal drought stress. The superior performance of *B. decumbens* under drought stress was associated with greater production of roots in subsoil layers. The superior performance of Mulato CIAT 36061 was associated with greater ability for leaf expansion under drought stress conditions. Among the 12 genotypes tested, the sexual hybrid SX03/0881 was least adapted to drought stress conditions. As part of a BMZ funded project, we used this greenhouse soil tube method to evaluate the shoot and root growth responses of 12 genotypes of *Brachiaria* that were subjected to Al-toxic soil conditions.

Materials and methods

A greenhouse experiment was conducted to determine differences in shoot and root attributes among 12 *Brachiaria* genotypes (3 parents: *Brachiaria decumbens* CIAT 606, *Brachiaria ruziziensis* 44-02, *Brachiaria brizantha* CIAT 6294 cv. Marandú; 2 commercial hybrids: Mulato CIAT 36061 and Mulato 2 CIAT 36087; 4 apomictic hybrids: BR02-1372, BR02-1752, BR02-0465 and BR02-1485; and 3 sexual hybrids: SX03-0881, SX03-0846 y SX03-2367) as affected by Al toxicity in soil (Figure 10). Plants were sown in 80 cm plastic cylinders using one stolon per tube containing 5.5 kg of soil from Matazul farm in the Llanos of Colombia (with 78.2% Al saturation) with a bulk density of 1.33 g cm^{-1}.

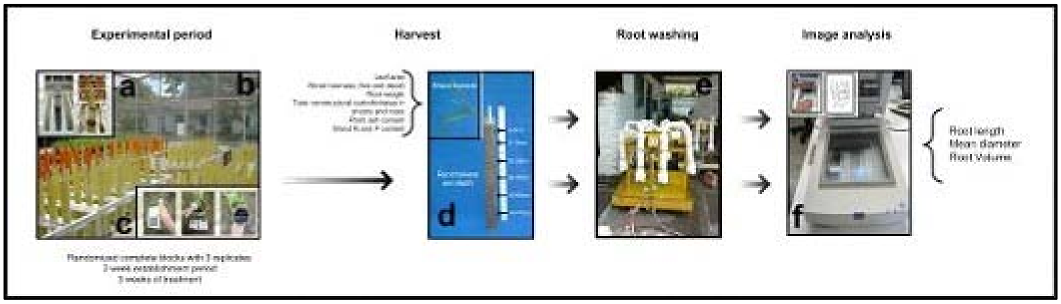


Figure 10. Methodology for screening *Brachiaria* genotypes, a) plastic tubes were covered with PVC pipes to protect from higher temperature, b) final arrangement of the experiment, c) chlorophyll, rate of transpiration, stomatal conductance and leaf temperature were measured at weekly intervals for 21 days, d) root samples collected from different soil depths, (e) root samples were washed free of soil using a hydropneumatic elutriation system, and f) root samples were analyzed using a flatbed scanner and WinRhizo to quantify root traits (root length, mean root diameter, root volume). Root biomass and specific root length were also determined after drying the root samples in the oven at 70ºC for 2 days.

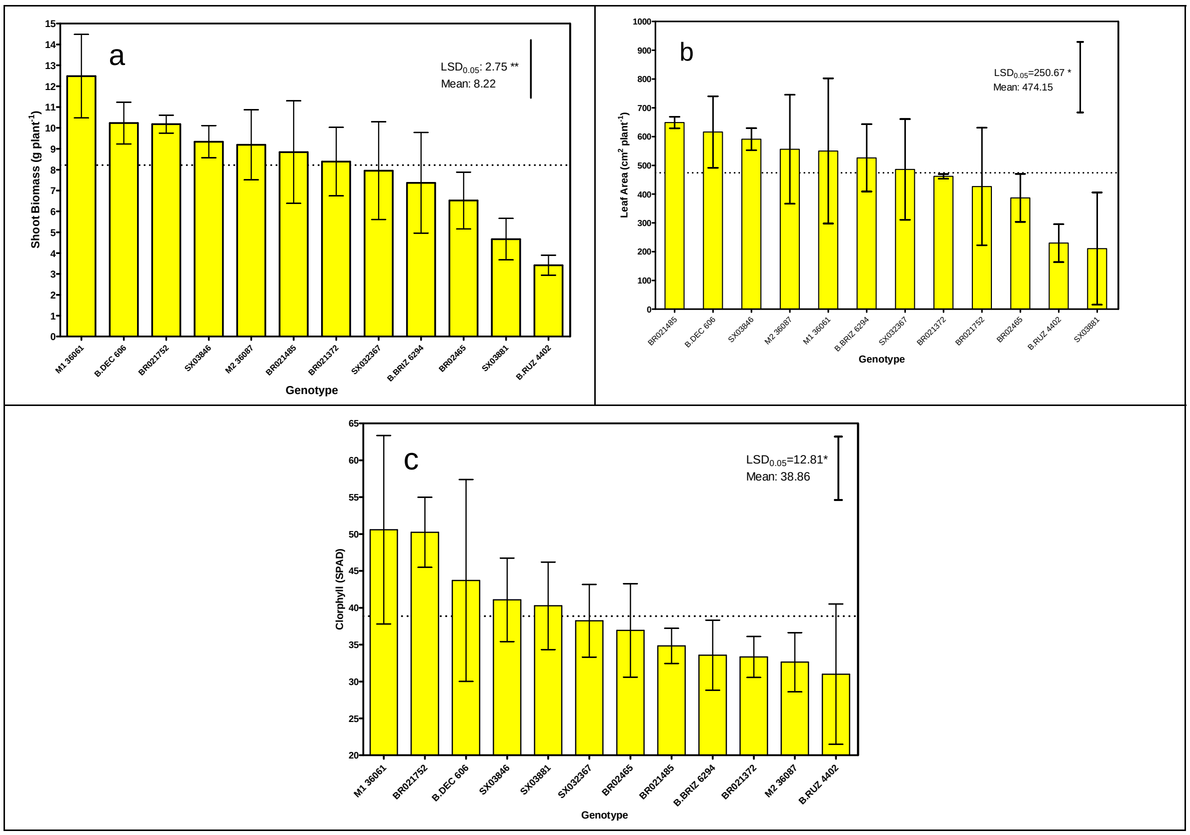
Transparent plastic tubes with soil were covered with PVC tubes to minimize temperature shifts. The soil was fertilized with adequate levels of nutrients (kg/ha: 80 N, 50 P, 100 K, 66 Ca, 28 Mg, 20 S and micronutrients). Plants were kept at 100% field capacity (FC). At harvest (after 3 weeks of treatment), shoot variables such as biomass (stems and leaves, live and dead), leaf area, and total nonstructural carbohydrate (TNC), ash, nitrogen and phosphorous contents in leaves and stems were determined. Physiological traits such as chlorophyll content, rate of transpiration and stomatal conductance were also determined.

For determining the root traits, the cylinders were cut into 0-5, 5-10, 10-20, 20-40, 40-60, 60-80 cm soil depths in order to determine root length, mean root diameter and root volume. Total nonstructural carbohydrate contents of roots were determined for 0-20 and 20-40 cm soil depth. The root samples from different soil depths were washed free of soil using a hydropneumatic elutriation system (Gillison's Variety Fabrication, Benzonia, Michigan, USA). The results were analyzed using the GLM procedure and LSD test of SAS v.9 for Windows, Pearson's correlation coefficients served as a tool to screen variables for higher association with shoot biomass. Also, rooting depth was determined using the cumulative root length fraction with the following model: $Y=1-\beta d$, where Y is the cumulative root fraction from the surface of the soil, d is soil depth in cm and β is the estimated parameter. Since β is the only parameter estimated in the model, it was used to measure vertical root distribution. Higher values of β are associated with a greater proportion of roots at greater depths in relation to lower values of β, which are associated with a greater proportion of roots near the surface of the soil.

Results and Discussion

Shoot biomass presented highly significant differences ($p<0.01$) at the genotype level (Figure 11a). The genotypes with higher levels of shoot biomass production in Al-toxic soil conditions were Mulato CIAT 36061, *B. decumbens* CIAT 606, BR02-1752 and SX03-0846 while BR02-0465, SX03-0881 and *B. ruziziensis* 44-03 showed lower values.

Similar to shoot biomass production, leaf area values also presented significant differences ($p<0.05$) at the genotype level. Genotypes with the highest values were BR02-1485, *Brachiaria decumbens* CIAT 606 and SX03-0846 and those with the lowest values were *Brachiaria ruziziensis* 44-02 and the sexual hybrid SX03-0881 (Figure 11b). Leaf chlorophyll content (SPAD) showed significant genotypic differences (Figure 11c). The genotypes that showed higher amounts of chlorophyll content were Mulato CIAT 36061, BR02-1752 and *Brachiaria decumbens* CIAT 606. Other genotypes such as BR02-1485, *Brachiaria brizantha* CIAT 6294 cv. Marandu, BR02-1372, Mulato 2 CIAT 36087 and *Brachiaria ruziziensis* 44-02 showed lower values.



**Significant at probability level of 0.01, * Significant at probability level of 0.05, N.S. = not significant. The dotted line is the mean value of the 12 genotypes

Figure 11. Differences in (a) shoot biomass, (b) leaf area and (c) chlorphyll content of 12 *Brachiaria* genotypes subjected to Al toxicity conditions for 21 days.

Correlation coefficients (r) between shoot biomass and a number of shoot traits are shown in Table 12. Leaf area, leaf chlorophyll content and TNC contents of leaves and stems showed positive association with shoot biomass indicating that the genotypes that were able to grow were productive under Al toxicity conditions. Leaf and stem nutrient (N and P) contents showed negative association with shoot biomass indicating that high nutrient use efficiency contributed to superior shoot biomass production. Leaf ash content also showed negative association with shoot biomass indicating the contribution of high nutrient use efficiency to leaf growth.

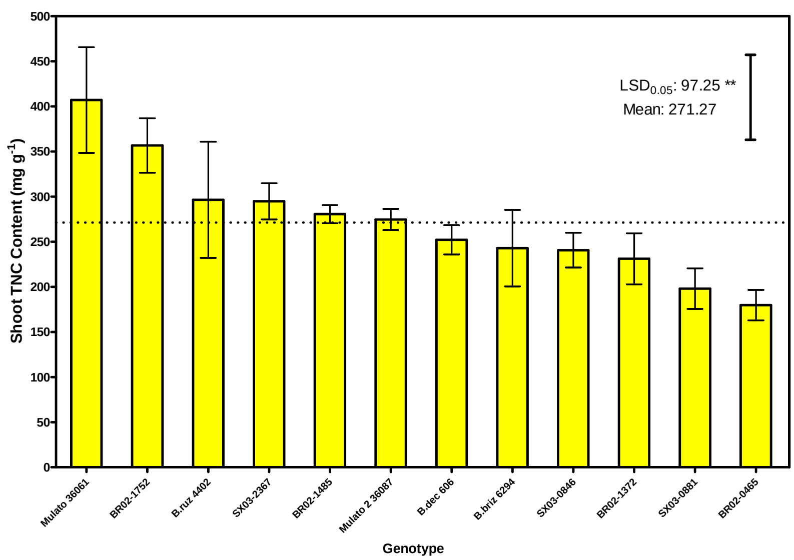
Table 12. Correlation coefficients (r) between shoot biomass and other shoot traits.

Shoot traits	**r**
Leaf area(cm^2)	0.614**
Leaf chlorophyll content (SPAD)	0.391*
Total nonstructural carbohydrates in leaves (mg/g)	0.437**
Total nonstructural carbohydrates in stems (mg/g)	0.599**
Leaf ash content (%)	-0.466**
Stem ash content (%)	-0.088
Leaf N (%)	-0.751**
Stem N (%)	-0.558**
Leaf P (%)	-0.582**
Stem P(%)	-0.792**

(*) Significant at the 0.05 level; (**); Significant at the 0.01 level.

The content of TNC in the shoots presented significant differences between genotypes (Figure 12). Genotypes such as Mulato CIAT 36061 and BR02NO-1752 showed greater values while SX03-0881 and BR02-0465 showed lower values.

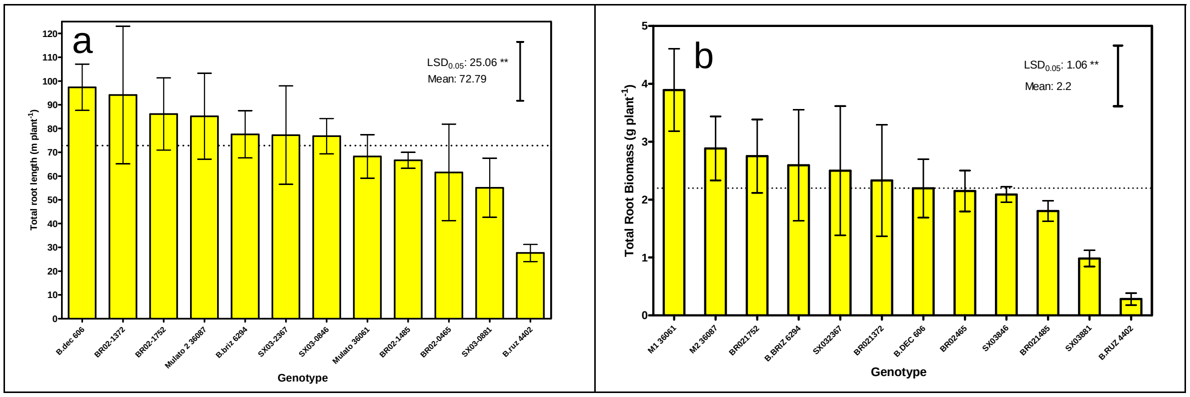
Figure 13a shows differences in total root length production of 12 *Brachiaria* genotypes. This variable showed highly significant differences ($p<0.01$) between genotypes. As expected, *B. decumbens* was outstanding in its root length production while *B. ruziziensis* was least productive in root system development. Root biomass production of cv. Mulato was outstanding while *B. ruziziensis* showed the lowest value (Figure 13b).



**: Significant at the 0.01 probability level, *: Significative at the 0.05 probability level. The straight vertical lines indicate LSD values at the 0.05 probability level. Dotted horizonal line indicates the genotypic mean.

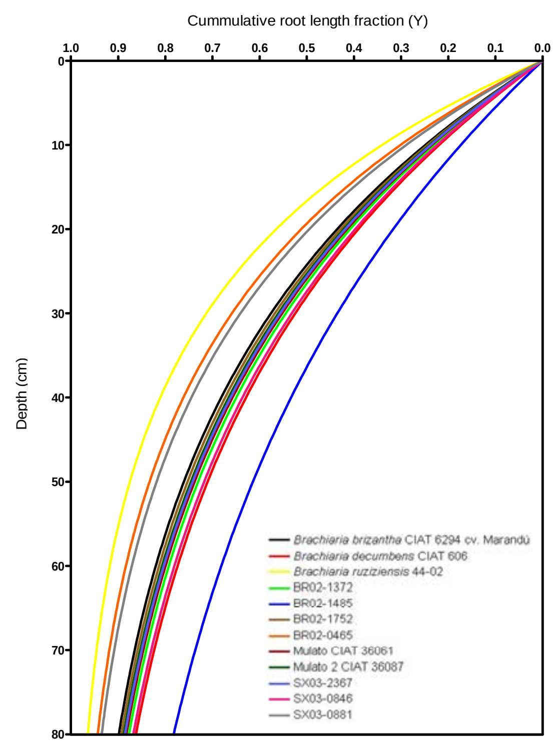
Figure 12. Differences in total nonstructural carbohydrates (TNC) in the shoots of 12 *Brachiaria* genotypes subjected to Al-toxic conditions for 21 days.

Results on root length distribution indicated that genotypes such as BR02-1485, *Brachiaria decumbens* CIAT 606 and SX03-0846, with β values of 0.98, had deeper root systems than genotypes such as BR02-0465 and *Brachiaria ruziziensis* 44-02, with β values of 0.96 (Figure 14).



**Significant at probability level of 0.01, * Significant at probability level of 0.05. The dotted line is the mean value of the 12 genotypes.

Figure 13. Total root length (a) and total root biomass (b) production of 12 *Brachiaria* genotypes that were subjected to Al toxicity conditions in soil for 21 days.



Genotype	β	R^2
BR02-1485	0.98	0.91
B.dec 606	0.98	0.97
SX03-0846	0.98	0.97
BR02-1372	0.97	0.97
Mulato 36061	0.97	0.98
SX03-2367	0.97	0.98
Mulato 2 36087	0.97	0.97
BR02-1752	0.97	0.97
B.briz 6294	0.97	0.98
SX03-0881	0.97	0.99
BR02-0465	0.96	0.97
B.ruz 44-02	0.96	0.97

Figure 14. Cumulative root fraction for 12 *Brachiaria* genotypes grown in Al toxic soil. Genotypes with higher or lower values of β present a deep or shallow root system, respectively

Conclusions

Among the 12 Brachiaria genotypes evaluated for root development under Al toxic soil conditions, *Brachiaria decumbens* was found to be outstanding in developing fine root system while the *Brachiaria* hybrid cv. Mulato was superior in shoot biomass production. The thicker root system of cv. Mulato was associated with its superior ability to produce shoot biomass. This study confirmed the sensitivity of *Brachiaria ruziziensis* to Al toxic soil conditions and this was attributed to its poor root system development.

1.5.1.3 On-farm evaluation of *Brachiaria* grass options in Rwanda

Highlight

- Improved *Brachiaria* grasses were tested with the participation of smallholder farmers under drought and acid soil stress (aluminum toxicity) conditions in two districts of Rwanda. The *Brachiaria* option selected across two districts under either drought or acid soil stress was the *Brachiaria* hybrid cv. Mulato II. It has been selected by farmers under both stress conditions because of its adaptability to these contrasting environments of drought and acid soil stress, producing green forage year round, without any input of fertilizer.

Contributors: M. Mutimura, L. Birasa Adré (ISAR, Rwanda), M. Peters, I. Rao (CIAT), farmers of Bugesera and Nyamagabe districts of Rwanda

Rationale

One of the major limitations of livestock production in Rwanda and tropical Africa in general is scarcity of quality feed year round, in particular in areas constrained by drought and acid soils. Thus, ISAR in collboration with CIAT is evaluating *Brachiraia* grass oprions (both germplasm accessions and hybrids developed by the *Brachiaria* breeding program at CIAT) with farmer particpation in contrsating drought (Bugesera district) and acid soil (Nyamagabe district) environments in Rwanda. This work will directly contribute to the efforts made in Rwanda to increase livestock production by making cattle accessible to smallholder farmers. It is expected that rural benefits are enhanced in the target areas of tropical Africa by involving farmers as decision makers and co-researchers in the *Brachiaria* product development process. We report here the progress made in the last 3 years on participatory evaluation of forage options in Rwanda as part of the work funded by BMZ-GTZ, Germany through a special project on “Fighting drought and aluminum toxicity: Integrating functional genomics, phenotypic screening and participatory evaluation with women and small-scale farmers to develop stress-resistant common bean and *Brachiaria* for the tropics”.

Materials and Methods

An exploratory diagnosis/assessment of current forage use patterns and identification of pilot sites for *Brachiaria* was done. Pilot sites were identified for testing a total of 10 forage grass options (including checks) with farmers, with high potential for improving milk and meat production. Grass-root level participatory research partners and farmer groups were identified to facilitate participatory diagnosis and planning. Actor linkage mapping was used to analyze existing innovation systems in forage production, and to increase the capacity to improve feed systems with *Brachiaria*.

In selected sites the following activities were carried out: a) evaluated forage options via community-based forage trials to explore farmers' decision-making criteria and to understand trade-offs among traits; b) conducted on-farm testing and evaluation, both under researcher design farmer design. Specific end-use and livestock types are addressed, c) conducted follow-up studies of farmer integration of new products into existing farming systems, and d) facilitated initial multiplication and dissemination of farmer-selected varieties via multiple channels (local and regional, public and private).

Results

Participatory evaluation of improved Brachiaria grasses in Rwanda: Improved *Brachiaria* grasses were tested with the participation of smallholder farmers under drought and acid soil stress (aluminum toxicity) conditions. Biomass productivity of *Brachiaria* varieties and hybrids established in on-farm of smallholder farmers of Bugesera (drought stress) and Nyamagabe (acid soil stress with Al toxicity) districts was assessed in both the rainy and dry seasons. Figure 15 shows the dry matter yield (kg ha^{-1}) over time of *Brachiaria* hybrids and accessions for the first rainy and dry seasons in Bugesera district. During the first rainy season, Brachiaria hybrids Mulato, Mulato II and *B. brizantha* cv. Marandu showed higher DM yield whereas in the dry season *B. brizantha* cv. Toledo and *B. decumbens*/local presented the highest DM followed by *B.* hybrid BR02/1485, Mulato, *B. decumbens* cv. Basilisk and Mulato II. Over the two first seasons, *Cenchrus ciliaris* presented the lowest DM yield.

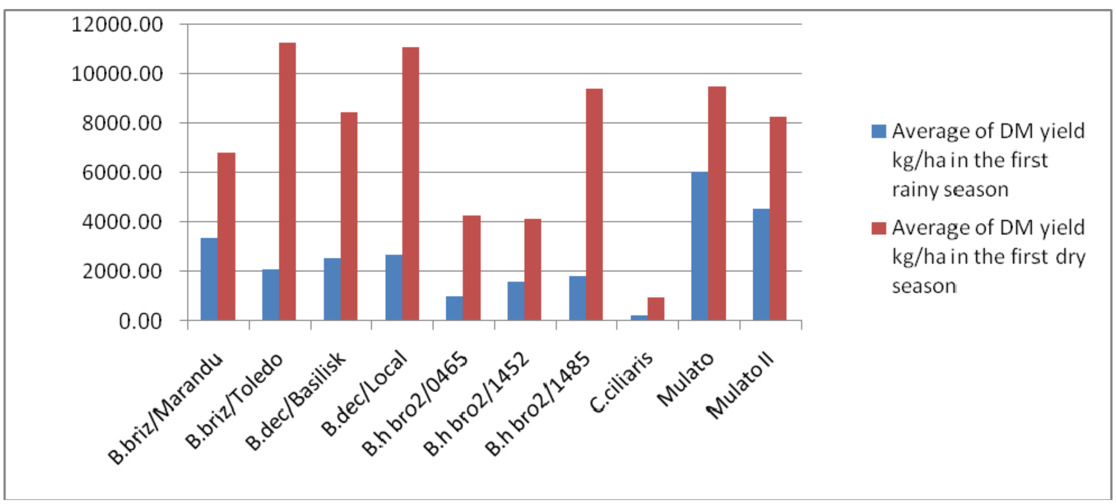


Figure 15. Evaluation of *Brachiaria* hybrids and accessions for the dry matter yield (kg ha^{-1}) for the first rainy and dry season in Bugesera (drought) district, Rwanda.

In Nyamagabe district, in both the rainy and dry seasons *B.* hybrid BR02/1485 presented the highest DM yield (Figure 16) followed by Mulato, cv. Marandu and cv. Basilisk in the rainy season and Mulato II, cv. Basilisk, cv. Marandu and *B. decumbens*/ Local in the dry season.

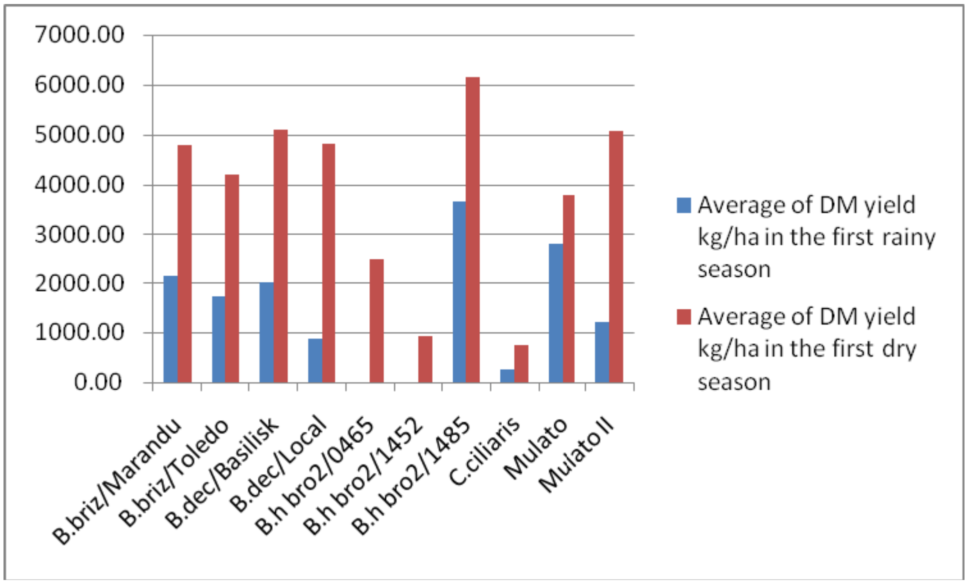


Figure 16. Evaluation of *Brachiaria* hybrids and varities for the dry matter yield (kg ha^{-1}) for the first rainy and dry seasons in Nyamagabe (acid soil) district, Rwanda.

In workshops held in both districts the Bugesera and the Nyamagabe (Photos 3 and 4) farmers ranked and selected accessions and hybrids of *Brachiaria* grass options most suitable to their production system. Among the criteria, drought tolerance is the major criterion mentioned by farmers in Bugesera because of feed scarcity during the dry season. *Brachiaria* hybrid cv Mulato II was preferred as a forage resisting to drought, followed by *Brachiaria brizantha* cv. Marandu, *B*. hybrid cv. Mulato and *B. decumbens* cv Basilisk.. Mulato II was recognized by farmers mainly because of its dry season tolerance since Mulato II remained green up to the end of the dry season.

Photo 3. Farmers in Bugesera participating in ranking of the performance of *Brachiaria* accessions and hybrids compared to the checks.

Photo 4. Farmers in Nyamagabe participating in ranking of the performance of *Brachiaria* accessions and hybrids compared to the checks.

In Nyamagabe district, criteria for farmer's selection were similar to Bugesera. However, in Bugesera farmers stressed the criterion of perenniality (persistence) whereas in Nyamagabe they stressed disease resistance. While in Bugesera drought resistance was the main selection factor, in Nyamagabe acid soil tolerance was the main selection criterion for *Brachiaria*. Contrarily to Bugesera district, in Nyamagabe district, farmers ranked *B.* hybrid BR02/1485, Mulato II, and *B. decumbens* cv local as superior performers, followed by cv. Basilisk and cv. Toledo.

The *Brachiaria* option selected across two districts under either drought or acid soil stress was the *Brachiaria* hybrid cv. Mulato II which took the first place in the low rainfall (Bugesera district) and Al toxicity (Nyamagabe district) prone areas of Rwanda. It has been selected by farmers under both stress conditions because of its adaptability to these contrasting environments of drought and acid soil stress, producing green forage year round, without any input of fertilizer.

Assessment of the acceptability of the new fodder options through gender analysis: Initial observations indicate that women headed households put more efforts on new innovation technologies than men. This is related to the spread of zero grazing system across Rwanda (Photo 5).

Photo 5. A child of the farmer, Karimbanya L., in Bugesera carrying *Brachiaria* grass to feed his dairy cow.

Conclusions

Improved *Brachiaria* grasses were tested with the participation of smallholder farmers under drought and acid soil stress (aluminum toxicity) conditions. The *Brachiaria* option selected across two districts under either drought or acid soil stress was the *Brachiaria* hybrid cv. Mulato II. It has been selected by farmers under both stress conditions because of its adaptability to these contrasting environments of drought and acid soil stress, producing green forage year round, without any input of fertilizer. During farmer visits, farmers acknowledged the palatability of *Brachiaria* and its adaptability to their local climatic and soil conditions. A number of farmers are now commencing to multiply *Brachiaria* on large plots and are providing planting materials to their neighbors. However, dissemination on a larger scale will require further facilitation.

1.5.2 Genotypes of *Brachiaria* with dry season tolerance

Highlight

- Among the 6 *Brachiaria* genotypes that were subjected to a combined stress of drought and Al toxicity in soil, *B. decumbens* CIAT 606 and *B. brizantha* CIAT 26110 cv. Toledo were found to be superior in their ability to tolerate the combined stress conditions of terminal drought and Al toxicity. The superior performance of these two genotypes was attributed to a delay in stomatal closure combined with efficient use of the moisture stored in the soil for plant growth during a dehydration process.

1.5.2.1 Differences in regulation of water use, water use efficiency and growth of six *Brachiaria* genotypes exposed to combined stress conditions of drought and aluminum toxicity

Contributors: V. Hoyos, J. Polania, J. W. Miles and I.M. Rao (CIAT)

Rationale

Adaptation to drought involves complex multigenic components that interact holistically in plant systems and maintaining root growth plays a key role. Soil drying decreases shoot growth rate, plant height, and yield, but affects root growth less. Water loss may be reduced by leaf morphological attributes or due to early stomatal closure in response to abscisic acid (ABA) transported in xylem from root to shoot and perceived at the guard cell apoplast. Al toxicity affects root development, which in turn affects the acquisition of nutrients and water. There is very limited knowledge on the physiological and biochemical bases of brachiariagrass' adaptation to either individual or combined stress factors of drought and Al toxicity. Seasonal drought affects both quantity and quality of forage in tropical savanna environments. *Brachiaria* grasses differ in their level of drought resistance. *B. brizantha* CIAT 6780 and *B. decumbens* CIAT 606 were found to be relatively more adapted to drought stress. One of the physiological mechanisms for improving drought resistance involves developing genotypes with high water use efficiency (WUE, the quantity of forage dry matter accumulated per unit of soil water transpired). Another physiological mechanism that also contributes to drought resistance is the decline in whole plant water use during soil water deficit. During soil water deficit, plants could undergo a transition between the water-replete phase where whole plant water use is not dependent on the soil water content and a second phase where water use is directly related to the availability of soil water. This transition is associated with a reduction in the average stomatal conductance and can occur at different soil water contents for different plant species or cultivars. Our objective was to determine the differences in regulation of water use, water use efficiency and growth among the 4 cultivars and two hybrids of *Brachiaria* that were subjected to combined stress of drought and Al toxicity. This knowledge is needed to develop effective screening method(s) to evaluate *Brachiaria* hybrids generated by the *Brachiaria* breeding program at CIAT for their level of resistance to combined stress of drought and Al toxicity.

Materials and methods

A greenhouse experiment was conducted to determine differences in regulation of water use, WUE (water use efficiency) and shoot growth of *Brachiaria*. Six genotypes (*Brachiaria decumbens* CIAT 606 cv. Basilisk, *Brachiaria ruziziensis* 44-02, *Brachiaria brizantha* CIAT 6294 cv. Marandú, *Brachiaria brizantha* CIAT 26110 cv. Toledo, *Brachiaria* hybrid Mulato (CIAT 36061) and *Brachiaria* hybrid Mulato II (CIAT 36087) that were subjected to a combined stress of drought and Al toxicity in soil. Soil from Matazul farm in the Llanos of Colombia (with 80% Al saturation) with adequate supply of nutrients (kg/ha: 80 N, 50 P, 100 K, 66 Ca, 28 Mg, 20 S and micronutrients) was used to eliminate low nutrient supply effects but maintain Al toxicity effects. The experimental design used was completely randomized arrangement with 2 levels of water supply (well watered and terminal drought) and six genotypes with 4 replications. One stolon was planted per pot (3.5 kg of soil) and was well watered for 3 weeks. At the time of imposing the two treatments (100% field capacity (FC) and terminal drought), the pots were fully irrigated and allowed to drain until reaching a constant weight. The amount of water held at 100% FC is the maximum amount of water held in soil after free drainage. This weight was recorded and used to maintain 100% FC treatment. For inducing terminal drought stress, water supply was simply withheld. The surface of the pot was sealed with plastic in order to avoid evaporative water losses (Figure 17).

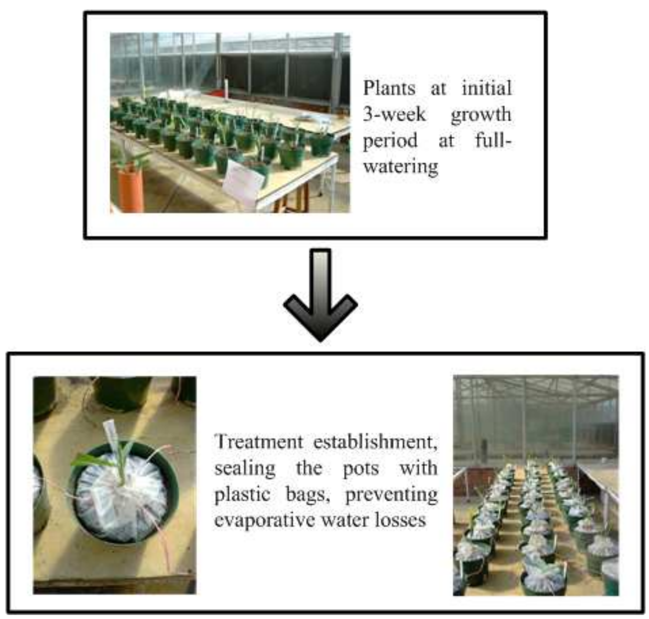


Figure 17. Methodology employed for determining FTSW (fraction of transpirable soil water) response curves.

The weight of each pot was recorded every day in order to determine water loss due to transpiration based on weight difference between the days. At the end of the drying cycle, the transpiration data of the terminal drought pots was normalized by correcting the transpiration of the stressed plant against that of the control pots (100% FC) to obtain a transpiration ratio (TR), which helps to minimize the influence of large variations in transpiration across days, a second normalization was made using the TR of the same drought pot from the first days of the experiment to correct for any differences in plant size, this gives a normalized transpiration ratio (NTR). The experiment was completed when this value reached ~0.1 for each pot, which was defined as the endpoint. This value in terms of experiment duration (days) is variable because of the differential response of the genotypes to applied stress. Nevertheless, the last pot was harvested at 51 days after planting (21 days after establishment and 30 days after stress induction). This was the experimental timeframe.

After reaching the endpoint, the plants were harvested and the total plant (shoot + root) dry weights were recorded. This weight was corrected with the weight of the plant before inducing drought by using an additional set of 4 plants per genotype to record fresh and oven dry weights. To obtain a value for soil moisture, a fraction of transpirable soil water (FTSW) was also calculated from:

$$\text{Daily FTSW} = \frac{\text{daily pot weight - final pot weight}}{\text{initial pot weight - final pot weight}} \qquad (1)$$

The results from these two variables were fitted to the following equation to obtain a curve explaining the behavior of the plant during terminal drought stress:

$$\text{NTR} = \frac{1}{[1 + \text{A} \times \exp(\text{B} \times \text{FTSW})]} \qquad (2)$$

The results were analyzed using the GLM procedure and the LSD test from SAS v.9 for Windows.

Results

Drought response curves: The daily values of normalized transpiration ratio (NTR) were the basis for expressing relative transpiration rate, and the values of the fraction of transpirable soil water (FTSW) expressed the relative soil water content. Results on NTR-FTSW curve for six genotypes of *Brachiaria* during soil drying or terminal drought are shown in Figure 18.

The level of adjustment (based on determination coefficients and 95% confidence intervals) of the transpiration values to the equation mentioned above and the inflection point that occurs in the resulting curve enables to determine the point at which transpiration began to decline for each genotype. This is represented as $FTSW_c$ (critical value for the fraction of transpirable soil water at which transpiration is first reduced during a drying cycle). $FTSW_c$ is the critical soil water content at which each plant began to reduce its water use. Among the 6 genotypes tested *B. brizantha* cv. Toledo and *B. decumbens* CIAT 606 showed lower values of $FTSW_c$ indicating their superior level of adaptation to drought stress in an Al-toxic soil (Table 13).

Table 13. Means for the $FTSW_C$ (critical values for the fraction of transpirable soil water at which transpiration is first reduced during a drying cycle), days to endpoint and FTSW value on endpoint for 6 genotypes during drying of an Al-toxic soil.

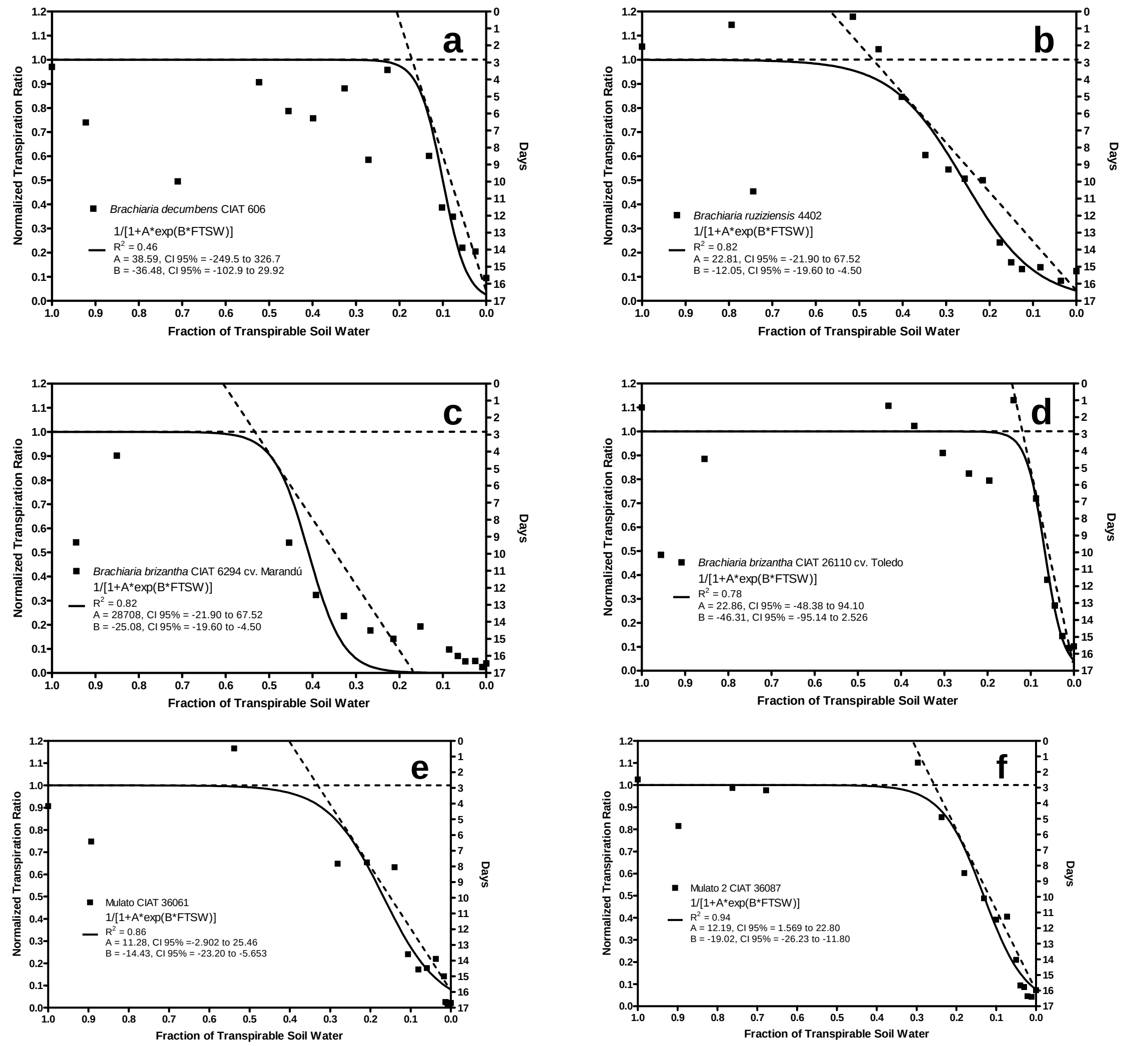
Genotype	$FTSW_c$	Days to endpoint	FTSW on endpoint
Brachiaria brizantha CIAT 26110 cv. Toledo	0.14	14.75	0.02
Brachiaria decumbens CIAT 606	0.17	15.25	0.02
Brachiaria hybrbid cv. Mulato 2 CIAT 36087	0.24	13.00	0.04
Brachiaria hybrbid cv. Mulato CIAT 36061	0.28	11.50	0.07
Brachiaria ruziziensis 44-02	0.46	13.50	0.13
Brachiaria brizantha CIAT 6294 cv. Marandú	0.50	13.25	0.05
Mean	**0.30**	**13.54**	**0.06**
Significance	*	N.S.	N.S.
$LSD_{0.05}$	0.30	3.19	0.15

* Mean is significant at the 0.05 probability level. N.S.= not significant

Full stomatal closure of the genotypes was observed on a mean value of 13.5 days and a FTSW (fraction of transpirable soil water) of 30% (Table 13), with *B. decumbens* (15.25 days, Figure 18a) and *B. brizantha* CIAT 26110 cv. Toledo (14.75 days, Figure 18d) showing higher values and Mulato 2 CIAT 36087 (13 days, Figure 18e) and Mulato CIAT 36061 (11.5 days, Figure 18f) showing lower values. The genotypes that showed lowest values of FTSW were *B. brizantha* CIAT 26110 cv. Toledo (14%, Figure 18d) and *B. decumbens* CIAT 606 (17%, Figure 18a), while the higher values were observed with *B.ruziziensis* 44-02 (46%, Figure 18b) and *B. brizantha* CIAT 6294 cv. Marandu (50%, Figure 18c).

In this sense, the combined stress conditions of terminal drought and Al stress, were physiologically more tolerated by *B.decumbens* CIAT 606 and *B. brizantha* CIAT 26110 cv. Toledo, by showing a delay in stomatal closure through an efficient use of the moisture stored in the soil during dehydration process (Figure 19). Genotypes such as *B. brizantha* CIAT 6294 cv. Marandu and *B. ruziziensis* 44-02 were found to be sensitive to combined stress conditions.

In terms of water use (Figure 20), genotypes such as Mulato CIAT 36061 and Mulato 2 CIAT 36087 were found to be using more amount of water for shoot growth under well watered and drought stress conditions while genotypes such as *B. brizantha* CIAT 6294 cv. Marandú and *B. ruziziensis* 44-02 were using less water due to early stomatal closure. However, genotypes such as *B. decumbens* CIAT 606 and *B. brizantha* CIAT 26110 cv. Toledo showed lower rates of water use with little or no change in their transpiration rates together with a delay in stomatal closure under combined stress.



a. NTR – FTSW response curve for *Brachiaria decumbens* CIAT 606 cv. Basilisk
b. NTR – FTSW response curve for *Brachiaria ruziziensis* 44-02
c. NTR – FTSW response curve for *Brachiaria brizantha* CIAT 6294 cv. Marandú
d. NTR – FTSW response curve for *Brachiaria brizantha* CIAT 26110 cv. Toledo
e. NTR – FTSW response curve for cv. Mulato CIAT 36061
f. NTR – FTSW response curve for cv. Mulato 2 CIAT 36087

Figure 18. NTR (normalized transpiration ratio) – FTSW (fraction of transpirable soil water) response curves of 6 *Brachiaria* genotypes during the water deficit regime. Symbols represent mean daily values (n=4). The solid line represents the fit of the data to equation 2. The intersection of the dashed lines is the point at which stomata begin to close.

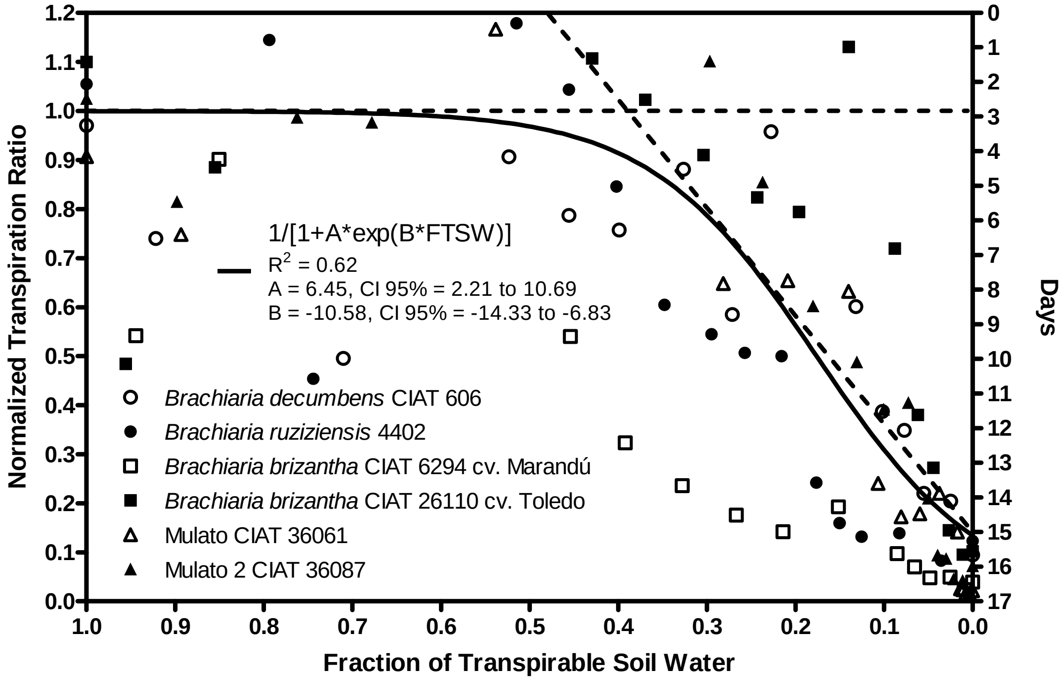


Figure 19. The relationship between the normalized transpiration ratio (NTR) and the daily values of the fraction of transpirable soil water (FTSW) for 6 genotypes of *Brachiaria* during terminal drought stress. The solid line represents the composite fit of all the data to equation 2. The intersection of the dashed lines is the point at which stomata begin to close.

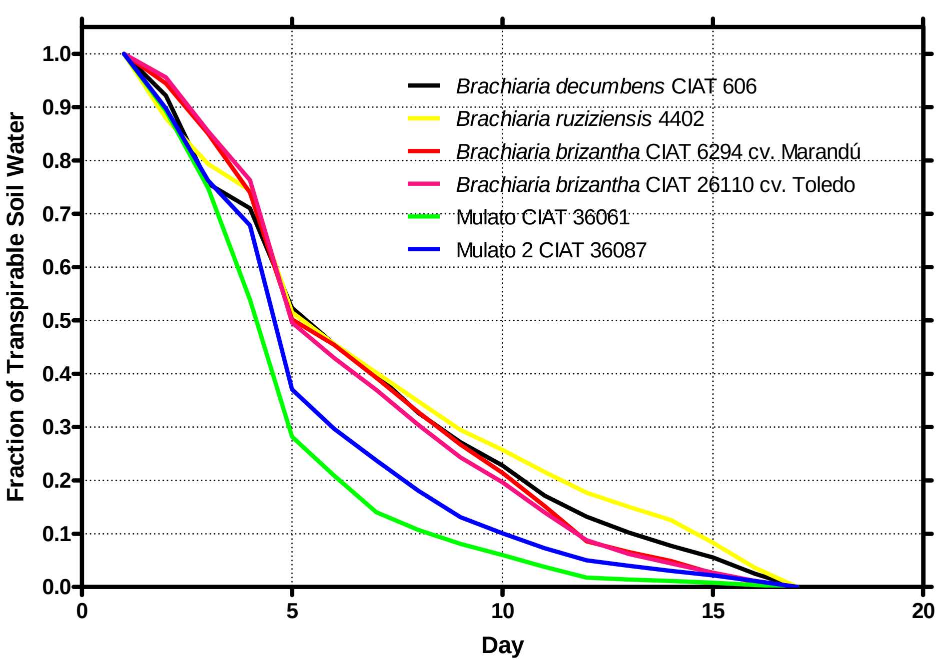


Figure 20. Differences in FTSW values over time for 6 genotypes of *Brachiaria* during soil drying of an Al-toxic soil.

Results from Figure 20 showed that during soil drying, *B. decumbens* CIAT 606 was the most "conservative" genotype in the use of water by regulating stomatal response while Mulato (CIAT 36061) and Mulato 2 (CIAT 36087) were the most demanding genotypes for water to maintain growth. *B. ruziziensis* 44-02 used less water due to its reduced growth due to soil drying and Al toxicity.

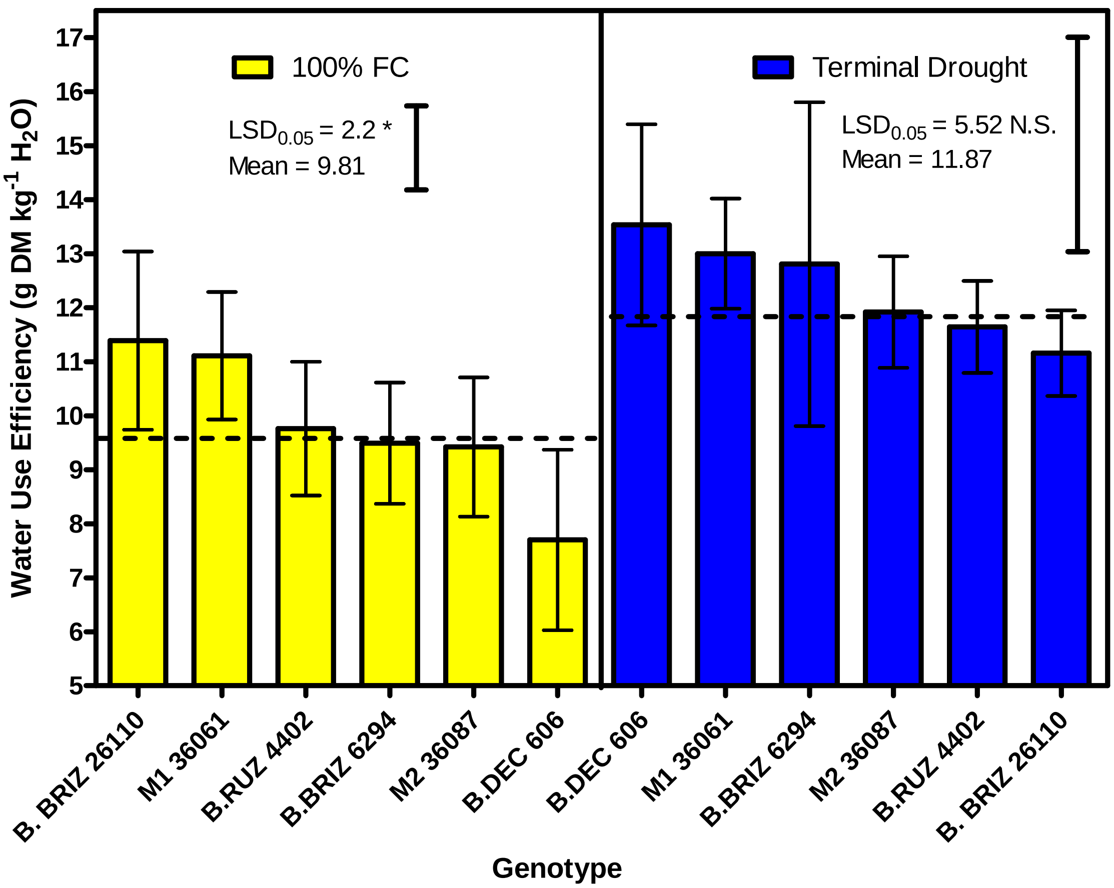


Figure 21. Differences in water use efficiency (unit of dry matter produced per unit of water used) among 6 *Brachiaria* genotypes subjected to 100% FC (well watered) and terminal drought stress to an Al-toxic soil.

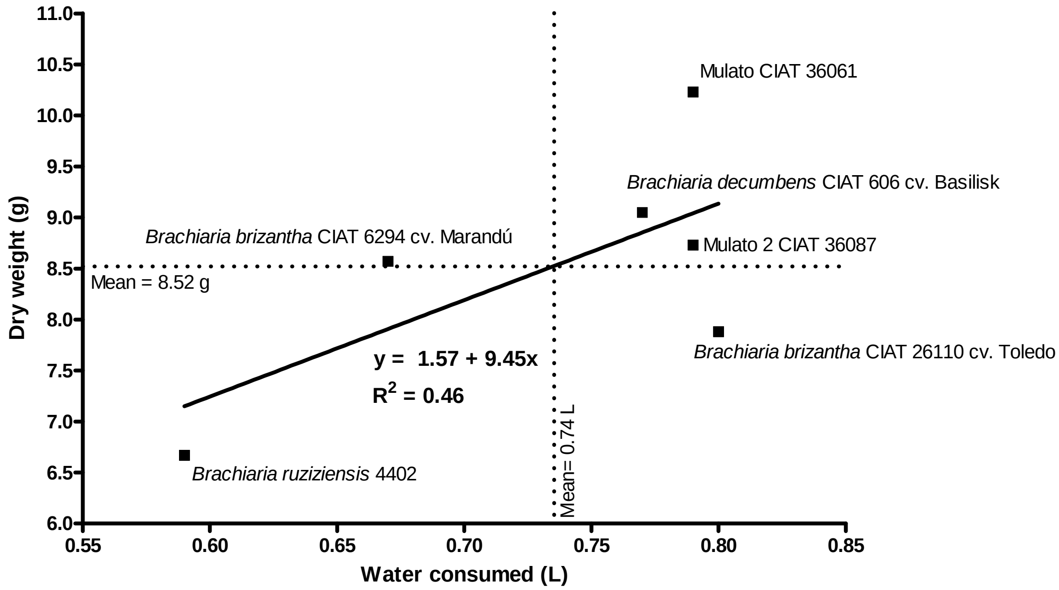


Figure 22. Relationship between total dry matter (shoot + root) production and water use of 6 *Brachiaria* genotypes subjected to combined stress conditions of terminal drought and Al toxicity. The genotypic mean for shoot dry weight = 7.89 and for water use = 0.621.

In terms of water use efficiency (WUE), differences were found between 100% FC and terminal drought stress levels (Figure 21). Even though no significant genotypic differences were found in WUE values under terminal drought, *B.brizantha* CIAT 26110 cv. Toledo and *B. ruziziensis* 44-02 were the genotypes with lower values of WUE (9.85 g DM kg^{-1} H_2O and 10.63 g DM kg^{-1} H_2O, Figure 21) while *B. decumbens* CIAT 606 and Mulato CIAT 36061 showed higher values of WUE (13.65 g DM kg^{-1} H_2O and 12.8 g DM kg^{-1} H_2O, Figure 21). Although physiologically cv. Toledo presented low sensitivity to terminal drought, its final shoot biomass accumulation was lower than the genotypic mean. This is contrary to *B. decumbens* CIAT 606, with its ability to regulate stomatal behavior, transpiration rate and water use it could produce similar shoot biomass under the combined stress conditions compared with well watered conditions. This is because *B. decumbens* could match its growth rate with water availability while the hybrids cv. Mulato and Mulato 2 require more amounts of water to maintain their higher growth rates under drought stress (Figures 22 and 23). Relationship between the total dry matter (shoot + root) production and water consumed showed that cv. Mulato was outstanding in consuming the water and producing the shoot dry weight while. *B. ruziziensis* was least productive (Figure 22). Based on the values of relative reduction in shoot growth under drought stress compared with well watered condition, *B. decumbens* was better adapted to drought stress when combined with Al toxicity in soil (Figure 23). Mean daily transpiration rate was greater with cv. Mulato and *B. brizantha* cv. Marandu under well watered conditions while under drought stress the differences among the six genotpes were small (Figure 23).

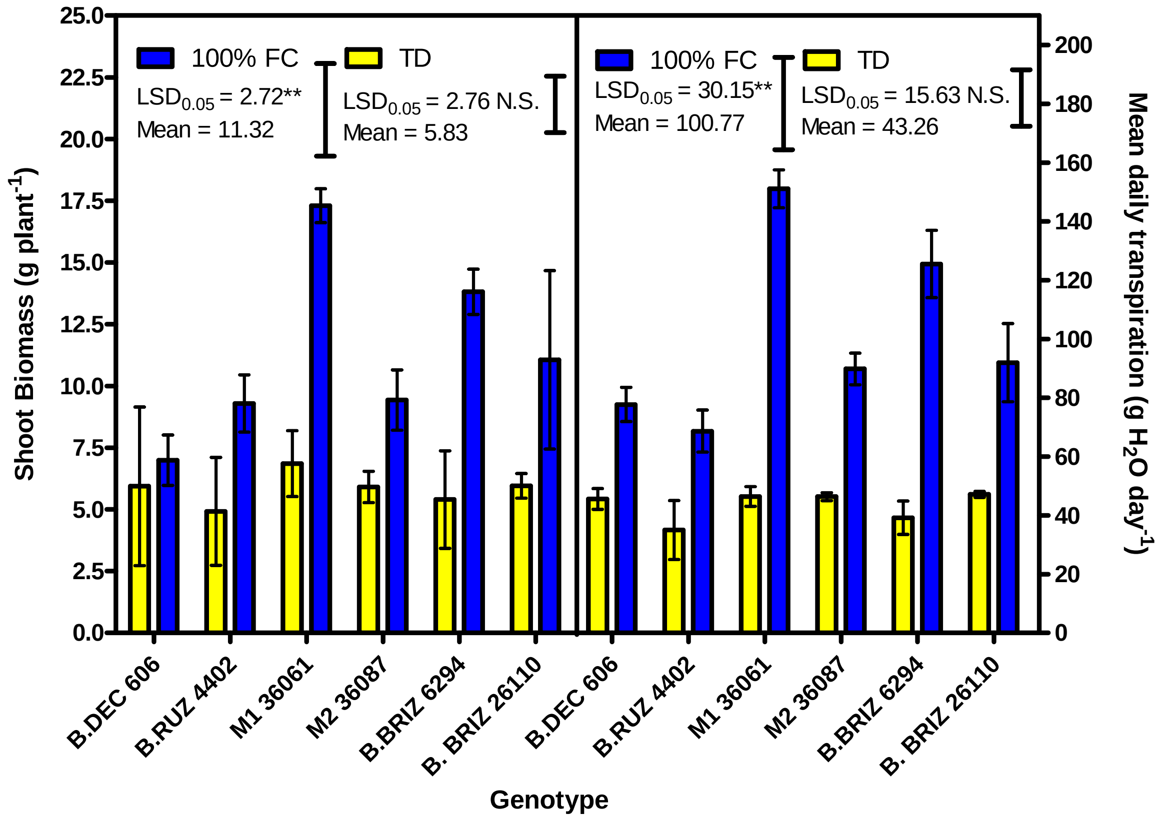


Figure 23. Differences in shoot dry matter and mean daily transpiration among 6 *Brachiaria* genotypes subjected to 100% FC (well watered) and terminal drought stress (TD) when grown in an Al-toxic soil.

Conclusions

Among the six *Brachiaria* genotypes that were subjected to a combined stress of drought and Al toxicity in soil, *B. decumbens* CIAT 606 and *B. brizantha* CIAT 26110 cv. Toledo were found to be superior in their ability to tolerate the combined stress conditions of terminal drought and Al toxicity. The superior performance of these two genotypes was attributed to a delay in stomatal closure combined with efficient use of the moisture stored in the soil during the dehydration process.

Two genotypes, *B. brizantha* CIAT 6294 cv. Marandu and *B. ruziziensis* 44-02 were found to be sensitive to the combined stress conditions due to early stomatal closure that impacted their ability to use water to produce the shoot biomass. Two *Brachiaria* hybrids, cv. Mulato (CIAT 36061) and cv. Mulato 2 (CIAT 36087) showed greater demand for water with their higher growth rate and an intermediate type of response with moderate ability to adjust to the decreasing soil moisture.

1.5.2.2 On-farm evaluation of *Brachiaria* genotypes for adaptation to drought in Nicaragua

Highlight

- Among the 8 *Brachiaria* genotypes evaluated on-farm along with the check (*Andropogon gayanus*) for their adaptation to drought, *Brachiaria* hybrid cv. Mulato 2 (CIAT 36087) and *B. brizantha* cv. Toledo (CIAT 26110) performed well during the second year after establishment based on soil cover and forage biomass production.

Contributors: M. Mena, L. Urbina ((INTA, Nicaragua), R. van der Hoek, A. Schmidt, M. Peters and I. Rao (CIAT)

Rationale

In 2006, the Nicaraguan national agricultural research institute (INTA) started together with CIAT an activity within the framework of the project "Fighting drought and aluminum toxicity: Integrating functional genomics, phenotypic screening and participatory research with women and small-scale farmers to develop stress-resistant common bean and *Brachiaria* for the tropics", financed by BMZ-GTZ, Germany. The objective of the present study was to evaluate the adaptation of new forage grass materials (*Brachiaria*) in comparison with available material in the tropical dry zone in Nicaragua and to develop together with the farmers new forage options for dry season on low fertility acid soils that contribute to improving feed availability as well as feed quality.

Materials and methods

On a farm (Vertisol with a pH of 6.0) in the Carazo department, an area of approx. 625 m^2 was planted with botanical seed of 9 tropical forage grass options including 5 *Brachiaria* hybrids (cv. Mulato CIAT 36061, cv. Mulato 2 CIAT 36087, BR02/1452, BR02/0465, BR02/1485) and 3 accessions (*B. decumbens* CIAT 606, *B. brizantha* CIAT 6294, *B. brizantha* cv. Toledo CIAT 26110) and 1 local check, *Andropogon gayanus*, supplied by CIAT in rows at distances of 0.5 m between rows and 0.2 m between planting spots in three replicates. On a regular basis assessments were made of agronomic characteristics like vigor, pest incidence, soil cover and biomass production. A participatory evaluation with farmers in the area was conducted in October 2008.

Results and discussion

Plant cover and biomass production: Soil cover and biomass production of most accessions increased in the course of the first year (2007). Exceptions were the *Brachiaria* hybrids BR02/1452 (which also showed low vigor) and cv. Mulato (CIAT 36061). Especially cv. Mulato 2 (CIAT 36087) showed a remarkable increase in soil cover from 60% to almost 90%. This was also reflected in an increase in biomass production from 5.5 to 7 t DM/ ha, the latter being superior to all accessions at 15 months after planting. In 2008, general performance was less than in 2007. This was mainly due to a long dry spell and probably the presence of Spittlebug. *Brachiaria* hybrids cv. Mulato (CIAT 36061) and BR02/0465 were performing relatively better than in the previous year, also in comparison with most other accessions (except for cv. Toledo (CIAT 26110) and *A. gayanus*) (Figure 24 and Figure 25).

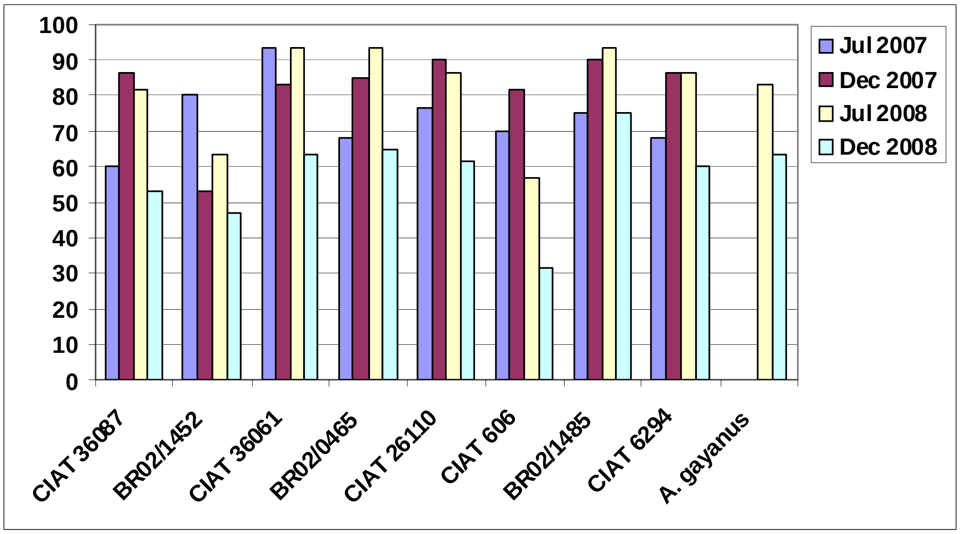


Figure 24. Average cover (%) of 8 *Brachiaria* accessions and *Andropogon gayanus* at 9, 15 (dry season), 21 and 27 (dry season) months after planting at a site in Carazo, Nicaragua, 2007-2008.

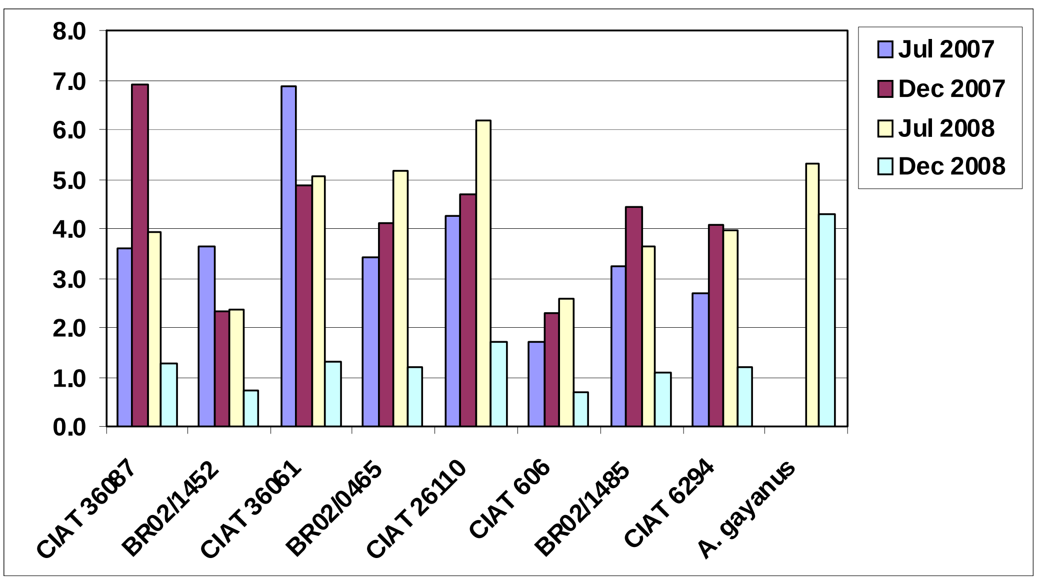


Figure 25. Average forage biomass production (MT/ha) of 8 *Brachiaria* accessions and *Andropogon gayanus* at 9, 15, 21 and 27 months after planting at a site in Carazo, Nicaragua, 2007-2008.

Despite that all plots of the *Brachiaria* hybrid BR02/1452 were replanted during the rainy season in 2007, this hybrid showed a decrease in soil cover to the end of the year leading to the lowest value of all ($p<0.05$). This was due to plant mortality related to excessive soil moisture after heavy rains.

Most findings were confirmed by the participatory evaluation with farmers with highest ranks of preference for cv. Mulato II, *A. gayanus* and the *Brachiaria* hybrid BR02/0465. Most important criteria used by farmers were forage biomass production, drought adaptation and texture of leaves and stems (palatability).

Conclusions

Differences between grasses in soil cover and forage biomass production were significant and generally more pronounced in the dry season. *Brachiaria* hybrid cv. Mulato 2 (CIAT 36087), *B. brizantha* cv. Toledo (CIAT 26110) performed well, within the second year a notable recovery was observed with the hybrid BR02/0465 and good performance of *A. gayanus*. The hybrid BR02/1452 did not demonstrate any obvious advantages compared to the already widely accepted commercial grasses including cv. Toledo (CIAT 26110) and cv. Mulato 2 (CIAT 36087), and the "locally" available grass *Andropogon gayanus*. Participatory evaluation by farmers confirmed the agronomic findings.

1.5.3 Grasses with adaptation to poorly drained soils

Highlights

- We evaluated 31 hybrids of SX05NO series for tolerance to waterlogging and identified three sexual hybrids (SX05NO/1907, SX05NO/2280, SX05NO/2015) that were superior to other sexual hybrids in their tolerance to waterlogging based on greater values of green leaf biomass proportion to total shoot biomass and green leaf biomass production and lower values of dead leaf biomass.

- We evaluated 71 hybrids of BR02NO, BR04NO, BR05NO, BR06NO and MX02NO series for tolerance to waterlogging and identified four hybrids (BR04NO/2069, BR06NO/0850, BR05NO/1609 and BR02NO/1794) that were superior to other hybrids in their tolerance to waterlogging. The superior performance of these hybrids was based on greater values of green leaf biomass proportion to total shoot biomass, green leaf biomass, green leaf area, leaf chlorophyll content and photosynthetic efficiency and lower values of dead leaf biomass.

1.5.3.1 Genotypic variation in waterlogging tolerance of preselected sexual hybrids of *Brachiaria*

Contributors: J. Rincón, R. Garcia, J.W. Miles and I. M. Rao (CIAT)

Rationale

Brachiaria grasses are the most widely planted forages in the tropics. *Brachiaria* pastures during the rainy season occasionally face waterlogging conditions that severely limit pasture productivity and animal performance.

Brachiaria grasses are the most widely planted forages in the tropics. *Brachiaria* pastures during the rainy season occasionally face waterlogging conditions that severely limit pasture productivity and animal performance. Waterlogging drastically reduces oxygen diffusion into the soil causing hypoxia, which is the main limitation that reduces root aerobic respiration and the absorption of minerals and water. In late 2007, we screened 37 clones of SX05 population of *Brachiaria* sexual hybrids along with 3 checks for their tolerance to waterlogging. Among the SX05 series of hybrids tested, three hybrids SX05 1918, SX05 2043, SX05 2411 were identified as superior in their level of tolerance to waterlogging compared to other sexual hybrids. In 2008 we conducted 2 trials to test again 31 clones of a sexual *Brachiaria* population (SX05) to quantify the extent of genetic variability for waterlogging tolerance among sexual hybrids of *Brachiaria*.

Material and methods

Two trials were conducted outside in the Forages patio area of CIAT Palmira during 2008 to determine differences in tolerance to waterlogging among 39 *Brachiaria* genotypes (31 hybrids – SX05NO series; 3 parents - *B. decumbens* CIAT 606; *B. ruziziensis* 44-02; *B. brizantha* CIAT 6294 and 5 checks – *B. brizantha* CIAT 26110; *Brachiaria* hybrid cv. Mulato CIAT 36061; *Brachiaria* hybrid cv. Mulato 2 CIAT 36087; *B. humidicola* CIAT 679; *B. humidicola* CIAT 6133). The two trials were planted using completely randomized block design. Details on each experiment are shown in Table 14. Each experimental unit consisted of one pot filled with 3.5 kg of top soil (0-20 cm) from Santander de Quilichao (Oxisol) and sown with two vegetative propagules (stem cuttings).

Table 14. Experimental design and environmental conditions of two experiments of a sexual *Brachiaria* population.

	Experiment 1	Experiment 2
Experimental design	Randomized complete block	Randomized complete block
	3 replications	5 replication
Date of treatment	9 January 2008	24 April 2008
Temperature	Maximum 22.1 to 33.1 °C	Maximum 29 to 32.5 °C
	Minimum 16.4 to 21 °C	Minimum 17.2 to 20.4 °C
Solar radiation	4.6 to 21.6 MJ m^{-2} d^{-1}	11.8 to 23.5 MJ m^{-2} d^{-1}

An adequate amount of fertilizer was supplied (kg ha^{-1} : 80 N, 50 P, 100 K, 66 Ca, 28 Mg, 20 S, 2 Zn, 2 Cu, 0.1 B and 0.1 Mo) to soil at the time of planting. Plants were grown for 60 days under field capacity conditions before applying waterlogging treatment. Waterlogging treatment was imposed by an excessive water supply (5 cm over soil surface) for 20 days. At the end of the 20 days of treatment, green leaf area (cm^2 $plant^{-1}$), green leaf biomass (g $plant^{-1}$), dead leaf biomass (g $plant^{-1}$) and stem biomass (g $plant^{-1}$) were measured and green leaf biomass proportion was determined.

Results and discussion

Results on shoot attributes measured after 20 days of waterlogging treatment showed that three hybrids (SX05NO/1907, SX05NO/2280, SX05NO/2015) were superior in their ability to produce green leaf biomass, green leaf area and green leaf biomass proportion to total shoot biomass under stress (Table 15). Two other sexual hybrids (SX05NO/2446 and SX05NO/1962) showed moderate level of tolerance to waterlogging based on green leaf biomass proportion to total shoot biomass (Table 15). The tolerant checks *B. humidicola* CIAT 679; *B. humidicola* CIAT 6133 were outstanding in their level of tolerance to waterlogging (Figure 26). Two sexual hybrids (SX05NO/1964 and SX05NO/2480) were highly sensitive to waterlogging stress (Figure 26).

Green leaf biomass proportion to total shoot biomass under waterlogging stress was found to be positively associated with green leaf area, green leaf biomass and stem biomass production and negatively associated with dead leaf biomass (Table 16).

Table 15. Green leaf biomass, green leaf area, dead leaf biomass and green leaf biomass proportion to total shoot biomass of 39 *Brachiaria* genotypes after 20 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia.

Genotype	Green leaf biomass (g plant^{-1})	Green leaf area (cm^2 plant^{-1})	Dead leaf biomass (g plant^{-1})	Green leaf biomass proportion (%)
Parents				
B Ruz. 4402	1.96	209.08	4.30	25
CIAT 606	3.82	441.49	4.83	43
CIAT 6294	1.19	116.06	6.06	23
Checks				
CIAT 26110	2.36	104.65	8.99	19
CIAT 36061	0.54	71.95	5.55	9
CIAT 36087	0.90	111.17	5.91	14
CIAT 6133	**4.99**	**540.53**	**0.66**	**86**
CIAT 679	**5.52**	**527.14**	**1.61**	**82**
Hybrids				
SX05 1905	0.50	69.48	6.86	5
SX05 1907	**1.33**	**151.91**	**7.13**	**11**
SX05 1948	0.35	38.36	8.37	5
SX05 1949	0.81	99.81	5.40	7
SX05 1955	0.54	56.55	5.61	7
SX05 1962	0.55	70.52	5.88	8
SX05 1963	0.29	42.46	5.03	4
SX05 1964	0.01	1.18	7.97	0
SX05 1985	0.26	32.71	5.41	4
SX05 1988	0.14	7.59	6.54	2
SX05 1990	0.64	68.36	7.22	6
SX05 2008	0.36	37.73	7.79	4
SX05 2010	0.29	34.94	5.24	4
SX05 2015	**0.28**	**31.25**	**4.71**	**9**
SX05 2031	0.21	28.63	5.76	5
SX05 2045	0.07	7.09	6.69	1
SX05 2105	0.21	27.71	5.60	2
SX05 2108	0.26	42.50	6.59	3
SX05 2155	0.06	10.19	4.38	2
SX05 2180	0.09	9.62	6.82	2
SX05 2200	0.30	40.83	5.67	4
SX05 2206	0.29	40.48	7.43	3
SX05 2207	0.16	19.41	4.99	4
SX05 2234	0.10	11.44	2.63	3
SX05 2280	**0.92**	**110.43**	**7.43**	**10**
SX05 2343	0.34	29.58	7.01	4
SX05 2421	0.74	75.95	5.34	7
SX05 2440	0.45	55.78	8.97	4
SX05 2446	0.59	83.52	5.74	8
SX05 2480	0.03	3.80	10.37	0
SX05 2560	0.51	68.71	5.25	7
Mean	**0.85**	**90.70**	**5.99**	**11**
LSD $_{0.05}$	**0.97**	**112**	**2.35**	**10**

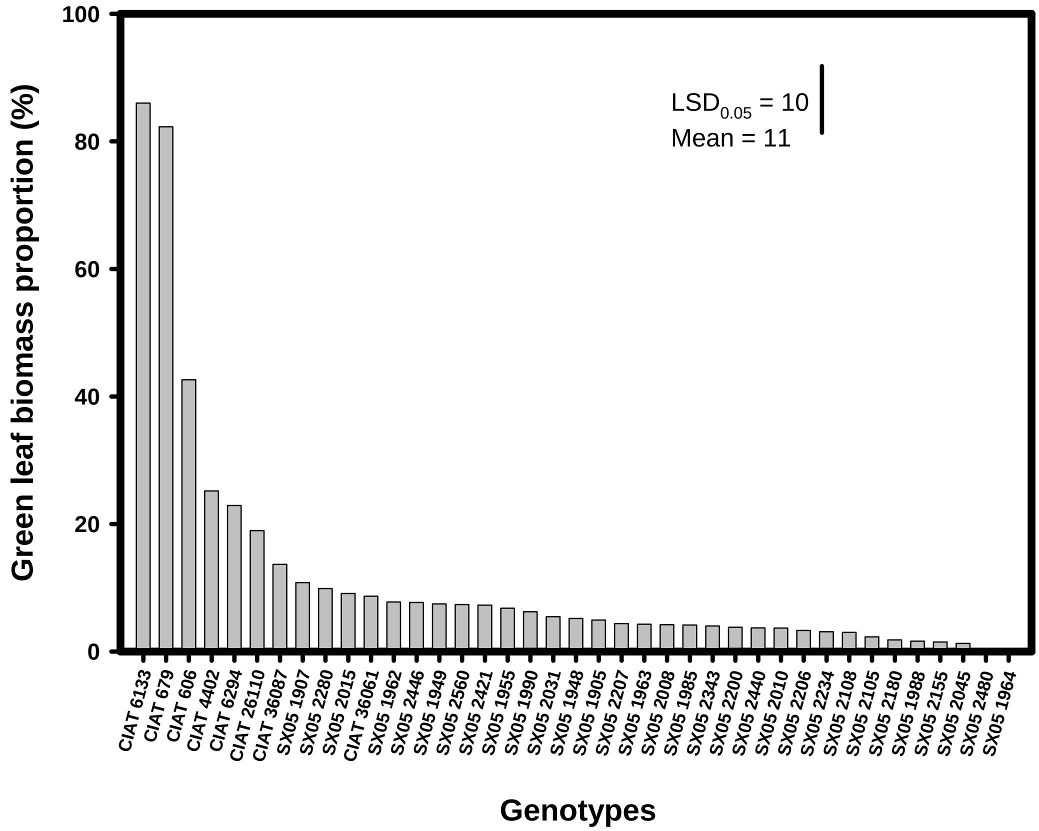


Figure 26. Green leaf biomass proportion to total shoot biomass of 39 *Brachiaria* genotypes after 20 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia.

Table 16. Correlation coefficients (r) between green leaf biomass proportion (%) and other shoot traits of 39 *Brachiaria* genotypes under waterlogging in an Oxisol from Santander de Quilichao, Colombia.

Plant traits	Waterlogging
Green leaf area (cm^2 $plant^{-1}$)	0.82***
Dead leaf biomass (g $plant^{-1}$)	-0.31**
Stem biomass (g $plant^{-1}$)	0.60***
Green leaf biomass (g $plant^{-1}$)	0.87***

*, **, *** Significant at the 0.05, 0.01 and 0.001 probability levels, respectively.

Conclusions

We screened 31 hybrids of SX05NO series for tolerance to waterlogging and identified three sexual hybrids (SX05NO/1907, SX05NO/2280, SX05NO/2015) that were superior to other sexual hybrids in their tolerance to waterlogging based on greater values of green leaf biomass proportion to total shoot biomass and green leaf biomass production and lower values of dead leaf biomass.

1.5.3.2 Genotypic variation in waterlogging tolerance of 71 promising *Brachiaria* hybrids

Contributors: J. Rincón, R. Garcia, J.W. Miles and I. M. Rao (CIAT)

Rationale

Since 2002 some *Brachiaria* hybrid populations (BR02, BR04, BR05 and BR06) have been evaluated for their superior performance and each year a few promising hybrids have been sent to Papalotla seed company for further evaluation. In 2007 Papalotla tested these hybrids together with MX02 population. This evaluation resulted in the selection of a set of 71 promising hybrids based on agronomic vigor, spittlebug resistance and seed set. In 2008 we evaluated this selected hybrids together with 3 parents and 5 checks to quantify genotypic variation in their tolerance to waterlogging.

Material and Methods

Two trials were conducted outside in Forages patio area of CIAT Palmira during 2008 to determine differences in tolerance to waterlogging among 79 *Brachiaria* genotypes (5 hybrids of BR02NO series; 8 hybrids of BR04NO series; 20 hybrids of BR05NO series; 10 hybrids of MX02NO series; 28 hybrids of BR06NO; 3 parents - *B. decumbens* CIAT 606; *B. ruziziensis* 44-02; *B. brizantha* CIAT 6294; and 5 checks - *B. humidicola* CIAT 679; *B. humidicola* CIAT 6133; *B. brizantha* CIAT 26110; *Brachiaria* hybrid cv. Mulato CIAT 36061; *Brachiaria* hybrid cv. Mulato 2 CIAT 36087). Waterlogging treatment was imposed by applying excessive water to the pots (5 cm over soil surface) for 15 days. The trials were planted as randomized complete block design. Details on each experiment are shown in Table 17. Each experimental unit consisted of one pot filled with 3.5 kg of fertilized top soil (0-20 cm) from Santander de Quilichao (Oxisol) and sown with two vegetative propagules (stem cuttings). An adequate amounts of fertilizer were supplied (kg ha^{-1}: 80 N, 50 P, 100 K, 66 Ca, 28 Mg, 20 S, 2 Zn, 2 Cu, 0.1 B and 0.1 Mo) to soil at the time of planting. Plants grew for 60 days under 100% field capacity of soil moisture. Leaf chlorophyll content (in SPAD units), stomatal conductance (mmol $m^{-2}s^{-1}$) and leaf photosynthetic efficiency (Fv′/Fm′: yield of quantum efficiency) were measured at weekly intervals for 2 weeks on a fully expanded young leaf that was marked at the initiation of waterlogging treatment. At the end of the 15 days of treatment, green leaf area (cm^2 $plant^{-1}$), green leaf biomass (g $plant^{-1}$), dead leaf biomass (g $plant^{-1}$) and stem biomass (g $plant^{-1}$) were measured and green leaf biomass proportion was determined.

Table 17. Experimental design and environmental conditions of two experiments of *Brachiaria* genotypes.

	Experiment 1	Experiment 2
Experimental design	Randomized complete block 3 replication	Randomized complete block 4 replication
Date	10 June 2008	23 October 2008
Temperature	Maximum 27.9 to 31.5 °C Minimum 17.7 to 22 °C	Maximum 25.5 to 33 °C Minimum 17.9 to 20.2 °C
Solar radiation	11.5 to 21.1 MJ m^{-2} d^{-1}	12.7 to 23.4 MJ m^{-2} d^{-1}

Results and Discussion

Two checks, *B. humidicola* CIAT 6133 and CIAT 679 were outstanding in green leaf biomass production, leaf area and green leaf biomass proportion to total shoot biomass (Table 18). Among the BR02NO, BR04NO, BR05NO, BR06NO and MX02NO series of hybrids tested, four hybrids BR04NO/2069, BR06NO/0850, BR05NO/1609 and BR02NO/1794 were superior in their production of green leaf biomass proportion to total shoot biomass than the others hybrids (Figure 27, Table 18). These hybrids also showed greater values of leaf chlorophyll content and photosynthetic efficiency (Table 18). Three other hybrids (BR06NO/0584, BR04NO/3207 and BR06NO/1000) showed moderate level of tolerance to waterlogging based on green leaf biomass proportion to total shoot biomass (Figure 27). Among the checks the hybrid cv. Mulato II (CIAT 36087) showed lower level of waterlogging tolerance.

Table 18. Green leaf biomass, green leaf area, leaf chlorophyll content, leaf photosynthetic efficiency, dead leaf biomass and green leaf biomass proportion to total shoot biomass of 79 *Brachiaria* genotypes after 15 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia.

Genotype	Green leaf biomass (g $plant^{-1}$)	Green leaf area (cm^2 $plant^{-1}$)	Total chlorophyll content (SPAD)	Leaf photosynthetic efficiency (Fv′/Fm′)	Dead leaf biomass (g $plant^{-1}$)	Green leaf biomass proportion (%)
Parents						
B Ruz. 4402	1.07	120.95	31.24	0.21	6.27	15
CIAT 606	6.00	793.87	38.16	0.31	4.81	59
CIAT 6294	2.75	279.80	36.26	0.30	8.35	27
Checks						
CIAT 26110	7.89	680.61	40.25	0.30	4.52	61
CIAT 36061	1.37	146.94	35.10	0.26	11.49	12
CIAT 36087	0.56	66.57	35.69	0.29	11.85	5
CIAT 6133	**7.39**	**781.69**	**44.35**	**0.43**	**0.83**	**91**
CIAT 679	**6.67**	**752.48**	**41.98**	**0.44**	**1.34**	**84**
Hybrids						
BR02/0465	0.70	75.16	36.38	0.26	10.28	5
BR02/1372	2.51	326.66	33.50	0.38	7.10	29
BR02/1718	0.54	53.56	33.65	0.26	7.06	7
BR02/1752	2.01	216.10	32.21	0.29	8.65	18
BR02/1794	**3.98**	**466.84**	**34.43**	**0.37**	**8.19**	**31**
BR04/01018	1.25	164.74	31.36	0.30	9.78	12
BR04/01061	1.20	156.40	38.20	0.28	8.46	12
BR04/02069	**4.35**	**532.91**	**40.82**	**0.34**	**5.49**	**45**
BR04/02405	0.29	25.90	34.14	0.20	9.85	3

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Table 18. Green leaf biomass, green leaf area, leaf chlorophyll content, leaf photosynthetic efficiency, dead leaf biomass and green leaf biomass proportion to total shoot biomass of 79 *Brachiaria* genotypes after 15 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia.

Genotype	**Green leaf biomass (g plant^{-1})**	**Green leaf area (cm^2 plant^{-1})**	**Total chlorophyll content (SPAD)**	**Leaf photosynthetic efficiency (Fv′/Fm′)**	**Dead leaf biomass (g plant^{-1})**	**Green leaf biomass proportion (%)**
Parents						
BR04/02515	0.57	79.63	36.55	0.31	8.85	6
BR04/02774	1.19	141.42	33.25	0.26	8.19	13
BR04/03025	0.74	65.32	36.54	0.30	6.61	10
BR04/03207	2.32	176.54	38.82	0.39	4.54	31
BR05/00334	0.35	52.31	27.20	0.23	10.86	3
BR05/00537	1.20	142.32	25.90	0.23	12.54	9
BR05/00549	2.24	281.94	34.60	0.27	10.05	21
BR05/00563	3.27	306.72	31.60	0.28	10.14	24
BR05/00637	2.21	222.39	37.39	0.32	6.38	25
BR05/00743	0.58	63.87	26.16	0.26	9.18	6
BR05/00744	1.14	99.91	33.67	0.31	4.97	20
BR05/00760	2.98	342.31	34.73	0.34	7.47	26
BR05/00931	2.75	314.61	38.10	0.28	7.47	26
BR05/01426	1.02	119.47	34.24	0.28	6.32	14
BR05/01435	0.83	87.78	35.23	0.26	9.99	8
BR05/01449	0.87	89.49	31.09	0.24	9.73	8
BR05/01467	2.36	218.54	34.22	0.27	7.43	24
BR05/01469	0.11	14.81	28.54	0.24	8.11	3
BR05/01520	1.96	241.44	38.29	0.25	7.20	23
BR05/01586	0.55	53.13	27.68	0.24	7.56	7
BR05/01609	**3.94**	**470.07**	**40.96**	**0.34**	**6.71**	**38**
BR05/01702	2.55	339.10	35.39	0.28	7.90	23
BR05/01706	1.57	257.78	31.60	0.24	5.05	21
BR05/01738	2.42	274.68	34.44	0.38	4.90	28
BR06/0012	1.03	182.09	25.41	0.24	10.55	9
BR06/0204	1.19	164.93	29.90	0.24	10.13	11
BR06/0206	2.09	215.08	33.07	0.23	9.15	20
BR06/0387	3.19	469.67	37.36	0.29	8.20	27
BR06/0405	1.52	152.40	34.67	0.29	5.91	22
BR06/0423	1.40	182.48	32.43	0.24	8.67	15
BR06/0531	1.95	249.08	30.04	0.23	9.26	17
BR06/0584	3.16	413.67	34.13	0.26	7.77	31
BR06/0850	**4.35**	**439.57**	**37.57**	**0.28**	**6.96**	**41**
BR06/1000	2.86	392.37	37.50	0.32	6.09	30
BR06/1132	2.75	401.06	39.91	0.31	5.20	31
BR06/1175	2.01	327.61	35.98	0.31	5.66	24
BR06/1254	2.49	276.04	30.40	0.23	8.81	22
BR06/1278	1.78	266.24	34.27	0.26	7.17	18
BR06/1348	2.17	264.47	38.44	0.28	7.11	23
BR06/1366	1.63	206.98	40.18	0.30	7.62	21
BR06/1388	0.97	105.91	32.64	0.25	7.97	14
BR06/1415	1.08	120.93	36.99	0.28	7.33	12
BR06/1433	2.04	282.95	32.98	0.24	7.46	25
BR06/1454	2.03	300.87	35.77	0.26	6.18	29
BR06/1567	1.54	216.76	26.83	0.25	11.18	12
BR06/1696	1.32	172.39	27.19	0.22	7.03	16

Continues…

Table 18. Green leaf biomass, green leaf area, leaf chlorophyll content, leaf photosynthetic efficiency, dead leaf biomass and green leaf biomass proportion to total shoot biomass of 79 *Brachiaria* genotypes after 15 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia.

Genotype	Green leaf biomass (g $plant^{-1}$)	Green leaf area (cm^2 $plant^{-1}$)	Total chlorophyll content (SPAD)	Leaf photosynthetic efficiency (Fv′/Fm′)	Dead leaf biomass (g $plant^{-1}$)	Green leaf biomass proportion (%)
Parents						
BR06/1832	1.43	160.82	35.34	0.31	6.71	18
BR06/1922	1.83	225.53	36.96	0.23	7.78	20
BR06/1932	2.85	337.53	33.50	0.26	7.62	27
BR06/2020	1.17	137.62	33.47	0.26	7.32	14
BR06/2058	1.26	171.95	39.50	0.24	7.01	16
BR06/2204	1.90	199.24	36.18	0.27	7.59	20
MX02/01614	0.94	80.35	35.12	0.28	8.17	11
MX02/01769	1.61	172.73	30.04	0.24	9.10	15
MX02/02090	1.93	223.67	34.13	0.24	9.55	14
MX02/02531	1.59	143.54	37.69	0.28	6.11	18
MX02/02552	0.50	54.96	27.67	0.24	7.10	6
MX02/02775	0.89	145.75	34.05	0.27	8.80	8
MX02/03426	0.82	65.72	36.42	0.27	7.59	9
MX02/03626	0.31	26.39	39.20	0.28	6.16	4
MX02/03641	0.34	43.91	31.62	0.23	9.93	3
MX02/03731	0.82	57.89	37.44	0.27	5.65	19
Mean	**1.96**	**229.53**	**34.52**	**0.28**	**7.68**	**21**
LSD $_{0.05}$	**1.51**	**209**	**5.45**	**0.072**	**2.09**	**14**

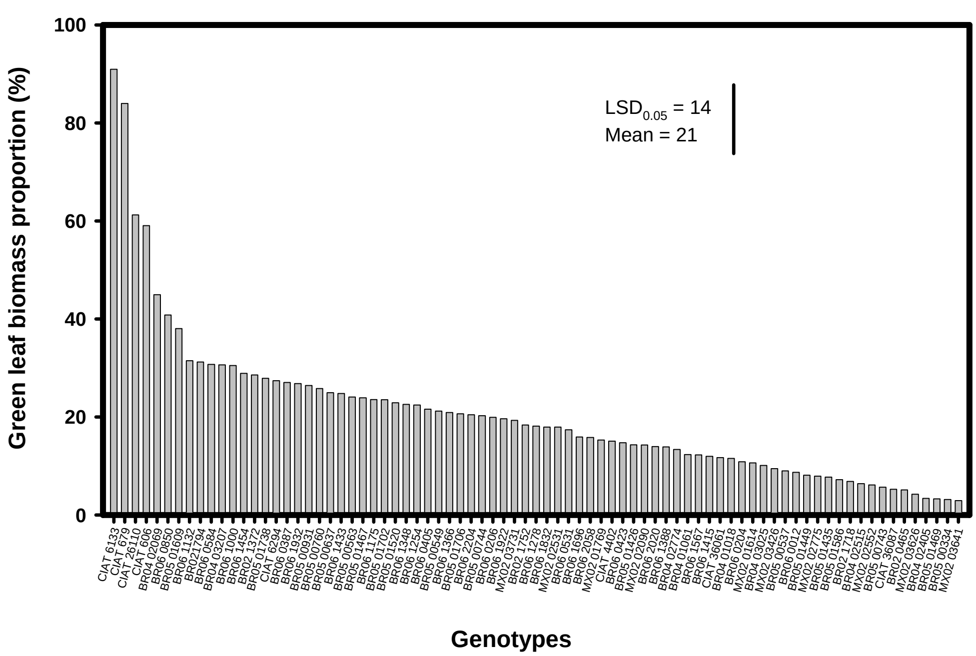

Figure 27. Green leaf biomass proportion to total shoot biomass of 79 Brachiaria genotypes after 15 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia.

Green leaf biomass proportion to total shoot biomass under waterlogging stress was found to be positively associated with green leaf biomass, green leaf area, total chlorophyll content, photosynthetic efficiency and stem biomass production and negatively associated with dead leaf biomass (Table 19). Green leaf biomass proportion has no significant relationship with stomatal conductance indicating that the rate of transpiration was not a major factor affecting tolerance to waterlogging.

Table 19. Correlation coefficients (r) between green leaf biomass proportion (%) and other shoot traits of 79 *Brachiaria* genotypes under waterlogging in an Oxisol from Santander de Quilichao, Colombia.

Plant traits	**Waterlogging**
Green leaf biomass (g plant^{-1})	0.91***
Total chlorophyll content (SPAD)	0.48***
Green leaf area (cm^2 plant^{-1})	0.81***
Dead leaf biomass (g plant^{-1})	-0.66***
Stem biomass (g plant^{-1})	0.36***
Stomatal conductance (mmol m^{-2}s^{-1})	0.008
Leaf photosynthetic efficiency (Fv/Fm)	0.44***

*, **, *** Significant at the 0.05, 0.01 and 0.001 probability levels, respectively.

Conclusions

We screened 71 hybrids of BR02NO, BR04NO, BR05NO, BR06NO and MX02NO series for tolerance to waterlogging and identified four hybrids (BR04NO/2069, BR06NO/0850, BR05NO/1609 and BR02NO/1794) that that were superior to other hybrids in their tolerance to waterlogging. The superior performance of these hybrids was based on greater values of green leaf biomass proportion to total shoot biomass, green leaf biomass, green leaf area, leaf chlorophyll content and photosynthetic efficiency and lower values of dead leaf biomass.

1.5.3.3 Screen synthetic "waterlogging tolerant" sexual population.

Materials and Methods

Two hundred thirty-four SX05 clones were assessed. The six clones with the most green leaf biomass following being subjected to a flooding treatment in pots (Rao et al. 2007) were propagated and recombined by open pollination to form a "waterlogging" synthetic population. Recombined seed was germinated and 500 seedlings established in the greenhouse. A first replication of this population has been assessed for waterlogging tolerance, and a second replication is under evaluation at the time of writing (18 February 2009).

Results and Discussion

It appears that significant genetic variation for plant tolerance to poor soil drainage exists in our synthetic sexual breeding population. We will explore two strategies: i) with intensive, methodical selection, develop a separate "waterlogging" sexual synthetic population, which can be cycled rapidly to build up high levels of resistance, and ii) include waterlogging tolerance among other criteria of selection in the "mainstream" sexual breeding population. If high levels of tolerance can be identified quickly by the first strategy, this tolerance will be introgressed into the main breeding population.

Progress towards output target 2008

- A screening method to assess waterlogging tolerance in *Brachiaria* hybrids streamlined in the breeding program

In the tropics, *Brachiaria* pastures during the rainy season occasionally confront waterlogging conditions that severely limit pasture productivity and animal performance. We developed a screening method to evaluate waterlogging tolerance in *Brachiaria* hybrids. Using this screening method, we showed that waterlogging for 21 days resulted in senescence and death of a great proportion of shoot biomass of the majority of hybrids and also affected development of adventitious roots in some hybrids. In 2006, we implemented the screening method for waterlogging tolerance and screened 48 BR04NO series of hybrids and identified three hybrids (BR04NO/3069, BR04NO/3207 and BR04NO/2774) that were superior in their tolerance to waterlogging based on greater values of green leaf biomass production and leaf chlorophyll content and lower values of dead leaf biomass.

In 2007, we screened 231 clones of SX05 population of *Brachiaria* sexual hybrids along with 3 checks for their tolerance to waterlogging. Among the SX05 series of hybrids tested, three hybrids SX05 1918, SX05 2530, SX05 2103 were identified as superior in their level of tolerance to waterlogging compared to other sexual hybrids. In 2008, we evaluated 31 hybrids of SX05NO series for tolerance to waterlogging and identified three sexual hybrids (SX05NO/1907, SX05NO/2280, SX05NO/2015) that were superior to other sexual hybrids in their tolerance to waterlogging based on greater values of green leaf biomass proportion to total shoot biomass and green leaf biomass production and lower values of dead leaf biomass. We also evaluated 71 most promising hybrids of BR02NO, BR04NO, BR05NO, BR06NO and MX02NO series for tolerance to waterlogging and identified four hybrids (BR04NO/2069, BR06NO/0850, BR05NO/1609 and BR02NO/1794) that were superior to other hybrids in their tolerance to waterlogging.

The superior performance of these hybrids was based on greater values of green leaf biomass proportion to total shoot biomass, green leaf biomass, green leaf area, leaf chlorophyll content and photosynthetic efficiency and lower values of dead leaf biomass. We recommend two plant attributes, green leaf biomass proportion and green leaf biomass that could serve as criteria for selection for waterlogging tolerance in *Brachiaria*. Results from the above studies indicate that it is possible to genetically improve the level of waterlogging tolerance in *Brachiaria* hybrids through breeding and phenotypic evaluation.

1.6 Potential for improving *Brachiaria humidicola* through breeding: Activities preliminary to initiating a plant breeding program in *B. humidicola*

1.6.1 Assess reproductive mode of *B. humidicola* tetraploid germplasm accessions and hybrids

1.6.1.1 Establish field progeny trial of the OP progenies of 14 *B. humidicola* hybrids and 19 tetraploid germplasm accessions

Rationale

Existing cultivars of *B. humidicola* (cvv. Tully and Llanero) have many positive traits, such as their excellent adaptation to low soil fertility, strongly stoloniferous growth habit, tolerance of grazing mis-management, and tolerance of poorly drained soils. However, strong seed dormancy complicates pasture establishment, and low nutritional quality results in only modest animal productivity on *B. humidicola* pastures. These two commercial *B. humidicola* cultivars are hexaploid, and no sexually reproducing hexaploid *B. humidicola* germplasm accession has been identified. However, the species *B. humidicola* also contains tetraploid germplasm, and sexuality has recently been confirmed at this ploidy level, opening the possibility of our gaining reproductive control of this species so as to correct its perceived deficiencies by genetic recombination and selection. Successful hybridization between a sexual and an apomictic, tetraploid *B. humidicola* accessions was achieved several years ago with the production of 14 hybrids from a cross involving two parental accessions. To develop a fully effective *B. humidicola* breeding program, the genetic base of our sexual tetraploid germplasm needs to be broadened and the genetic control of reproductive mode (sexual vs. apomictic) needs to be understood.

Materials and Methods

CIAT's collection of *B. humidicola* germplasm contains 19 accessions identified as having the tetraploid chromosome number (2n=4x=36). Of these 19 accessions, 15 are classed in our Genetic Resources database as apomicts (or facultative apomicts) and four as having sexual reproduction.

A small crossing block was established at CIAT-Popayán in 2007. This crossing block contained single, spaced plants and included several replicates of each of the 19 tetraploid *B. humidicola* germplasm accessions and 14 hybrids. Genotypes were replicated vegetatively. Plants were allowed to flower and mature seed was hand harvested on a single plant basis to produce single-plant progenies. Seed was bulked over replicates of each genotype. Acid-scarified seed was sown in flats and the resulting seedlings transplanted individually to 4-in plastic pots.

A field trial of these progenies was established at CIAT-Quilichao to infer reproductive mode of each of the 33 maternal parents (14 hybrids and 19 germplasm accessions) by the segregation within progenies. A total of 1,848 seedlings were transplanted. Different numbers of individuals per progeny were included, with fewer individuals included in the progenies of germplasm accessions identified as apomicts and more individuals in the progenies of supposedly sexual accessions and in the progenies of the hybrids.

Individual seedlings within progenies were randomly assigned to four hundred sixty-two 4-plant plots. Replicate plots of the same progeny (different sibs) were randomized across the field.

Seedlings were transplanted on 2 x 2 m centers in a square grid; each 4-plant plot was a single row, 8 x 2 m.

Given the strongly stoloniferous growth habit of *B. humidicola*, this field planting had to be managed differently from previous space-planted *Brachiaria* trials. The space between adjacent plants was maintained by periodic application of a non-selective herbicide. Over time, square "micro-paddocks", each a single plant, have been formed (Photo 6).

Photo 6. *Brachiaria humidicola* progeny plots at CIAT-Quilichao, 19 February 2009. Each square "micro-paddock" is a single plant.

Visual assessment of the uniformity of siblings within plots has been conducted several times. A consensus inference of the reproductive mode of the maternal plant is made by comparison among replicate plots of the same progeny.

Results and Discussion

All accessions identified in our Genetic Resources data base as being apomictic or facultatively apomictic behaved, in fact, as apomicts. Three of the four accessions identified as sexual also behaved as apomicts, producing fully uniform progenies. Only a single one of the germplasm accessions behaved as a sexually reproducing plant, producing a segregating progeny.

Progenies of 13 of the 14 hybrids were included in the progeny trial. Of these, five were classified as coming from sexual mothers and six as coming from apomictic mothers. Classification of the remaining two progenies was uncertain and they may be more or less facultative apomicts. These results are not incompatible with a model of inheritance of apomixis as a single, dominant Mendelian factor, as in the other major apomictic tropical forage grasses (Miles 2007). This tentative result has been more convincingly confirmed by embryo sac analysis on a much larger hybrid progeny by C. do Valle and collaborators at Embrapa's Beef Cattle Center (Valle et al. 2008).

1.6.2 Continue to proceed towards synthesis of a broad-based, fully sexual tetraploid *B. humidicola* breeding population

1.6.2.1 Hand-harvest OP seed from several hundred individual plants in segregating progenies in the progeny tests

Rationale

In order to conduct an effective *B. humidicola* breeding program, a genetically broad-based, sexually reproducing breeding population is desirable. The available germplasm base consists of the 19 tetraploid *B. humidicola* germplasm accessions in CIAT's Genetic Resources Unit. All but one of these accessions appears to be apomictic. Before this germplasm resource can be fully exploited, the genetic diversity contained in the 18 apomictic tetraploid accessions need to be made available to recombination and selection by getting it into sexual plants. The basic breeding strategy to be followed has been outlined previously (Miles 2007).

Materials and Methods

Seed resulting from open pollination in this field planting is being hand-harvested from individuals within segregating progenies in the progeny trial. Each of these individuals is a unique hybrid resulting from random open pollination in the previous generation crossing block. As a group, these plants ought to contain genes from the entire tetraploid *B. humidicola* germplasm collection. At least 50% of the individuals in segregating progenies are expected to be sexually reproducing plants.

Results and Discussion

Following a progeny test to identify reproductive mode of the individuals within these segregating progenies, parental clones for the synthesis of a fully sexual breeding population will be identified and recombined, but this will not likely be before 2011.

1.6.2.2 Select on seed set, strength of dormancy, vigor, leafiness, spittlebug reaction, etc

Materials and Methods

Four hundred thirteen individual plants in segregating progenies are being evaluated visually for vigor and leafiness. Seed set and seed dormancy will be assessed on the seed sample harvested from each plant. Reaction to spittlebug nymphs and adults will be assessed under controlled, greenhouse conditions using standard methodologies. Reproductive mode will be assessed by a field progeny test that will be established either in late 2009, or in 2010. From the accumulated information on these 413 hybrid plants, fully sexual individual clones will be selected as parental genotypes from which a synthetic sexual breeding population will be produced by open pollination in an isolated crossing block.

Results and Discussion

Harvest of open-pollinated seed from 413 individual plants in segregating progenies in our current progeny trial is on-going.

1.7. Biological nitrification inhibition (BNI) in tropical grasses

Highlight

- Results from an on-going field study after four years of analyses for BNI activity indicated that total dry shoot biomass and total nitrogen uptake values of *Panicum maximum* and *Brachiaria* hybrid cv. Mulato were higher than those of the two accessions of *Brachiaria humidicola* (CIAT 16888, CIAT 679). However, nitrification rates were lower in both *B. humidicola* accessions and this resulted in lower levels of nitrate in the soil indicating greater biological nitrification inhibition by the two *B. humidicola* accessions.

1.7.1 Field validation of the phenomenon of biological nitrification inhibition from *Brachiaria humidicola*

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Rationale

Genetic variability for Biological Nitrification Inhibition (BNI) has been observed for diverse accessions of *B. humidicola* and other tropical grasses under greenhouse conditions, as part of collaborative research between JIRCAS and CIAT. As a continuation of these research efforts, a long term field experiment was established at CIAT-Palmira with two main objectives: (i) to validate the phenomenon of BNI under field conditions; and (ii) to test the hypothesis that BNI is a cumulative factor in soils with forage grasses that release the BNI activity from root exudates. Given the vast areas that are currently under cultivation with tropical forage grasses, an understanding of the BNI process and the possibility of managing it to: (i) improve N use efficiency, and (ii) reduce nitrate pollution of surface and ground waters as well as reduce net impact on global warming through reduced emissions of nitrous oxide, could have potentially global implications. Different tropical forage grasses with a varying degree of BNI activity were selected for the experiment and a soybean crop and a tropical grass (*P. maximum*) that lacks the BNI activity were also included as controls. Results from the past 4 years are summarized in this report.

Materials and Methods

The field experiment was established in September 2004 at CIAT-HQ at Palmira, Colombia on a fertile clayey Vertisol (pH 6.9), and with an annual rainfall of about 1000 mm and mean temperature of 25^0C. Two accesions of *B. humidicola* were used: the commercial check accession *B. humidicola* CIAT 679, which has been used for most of our previous **studies, and** the high BNI activity *B. humidicola* accesion CIAT 16888. The *Brachiaria* hybrid cv. Mulato was included for having moderate BNI activity and *Panicum maximum* var. common was used as a negative non-inhibiting control. Soybean (var. ICAP34) was used as a negative control due to its known effect on stimulating nitrification. A plot without plants was used as an absolute control.

Treatments were established in plots of 10 m x 10 m with three replications and distributed in a completely randomized block design. Soybean was planted from seeds and the grasses were propagated from vegetative cuttings. Soybean was inoculated with the *Rizhobium* strain CIAT 13232 to favor biological nitrogen fixation. Irrigation was provided to the field as required and two applications of broadcast fertilization were made at 30 and 60 days after planting on each plot, except within two 1 m^2 subplots demarcated in each plot, where the same levels of fertilizer were applied in solution to favor a more homogeneous distribution of the applied nutrients within the soil. Each fertilizer application consisted of an equivalent dose of (kg ha^{-1}): 48N, 24K, 8P, 0.2Zn, 0.2B. The nitrogen source was ammonium sulfate. Weed control was done using Glyphosate in the bare soil plots and in the soybean plots before planting. During the soybean growing cycle manual weeding was done to control weed growth.

At harvest, soybean plants including roots were removed from the field when they had reached full maturity and the grain was already dry. The plants were separated into roots, shoots and grain, and a representative subsample taken for measuring dry matter content and N analysis. Plants of *P. maximum* were cut at approximately 20 cm height twice during the crop cycle. From each cut a representative subsample collected for dry weight and N analysis. The *Brachiaria* hybrid cv. Mulato and *Panicum maximum* were cut at 20 cm height while the *B. humidicola* accessions were cut at 10 cm height. At harvest time, soil was collected with an auger from the top 10 cm of the soil profile within each subplot of all species and the rhizosphere soil was separated from the bulk soil. Five samples were collected in each subplot and pooled to obtain a composite sample. Samples were carefully managed and only the soil adhered to the roots (rhizosphere soil) was removed and used for soils analysis. Once the rhizosphere soil was collected, it was allowed to air dry and then was finely ground to < 0 – 1 mm mesh. Soil was analyzed for nitrate and ammonium content using KCl extracts and colorimetric determination.

Soil incubation test: Fresh rhizosphere soils at harvest (August 2008) from the field experiment were collected and were incubated with $(NH_4)_2SO_4$ and $NaClO_3$ at 30^0C and at 0, 7 and 9 days after incubation, the samples taken at different intervals were extracted with $CaSO_4$ and analyzed for nitrate and nitrite levels by UV- VIS spectrophotometer. Soil samples were incubated with appropriate levels of ammonium (26 mg N/pot) to favor nitrification and chlorate was added to block the conversion of nitrite to nitrate and to measure rate of nitrite accumulation over time. Rate of nitrite accumulation was easier to measure than nitrate accumulation. Nitrification rates were determined based on nitrite formation per unit time.

Results and Discussion

In this report we present the data collected during the past 4 years on total shoot biomass and shoot N uptake. We also present data on nitrate levels in the top soil (0 – 10 cm) after fertilizer application in August 2008 and soil nitrification rates determined through soil incubation test. *Shoot biomass:* Figure 28 shows the amount of total shoot biomass accumulated from the experimental plots over 4 years (September 2004 to August 2008). Total shoot yields of P. *maximum* and *Brachiaria* hybrid cv. Mulato were significantly higher than those of the 2 accessions of *B. humidicola* (LSD, p<0.001).

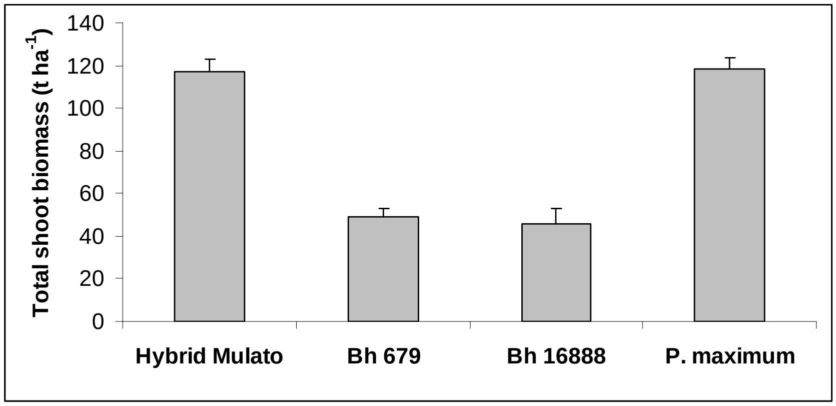

Figure 28. Differences among forage grasses in total shoot biomass production over the period from September 2004 to August 2008.

Shoot N uptake: Total shoot nitrogen uptake by different grasses showed significant differences (LSD, p<0.001) (Figure 29). *Brachiaria* hybrid cv. Mulato and P.*maximum* accumulated considerably more nitrogen than the two accessions of *B. humidicola*. The 2 accessions of B. *humidicola* plots removed less N through shoot growth than what was added as fertilizer N.

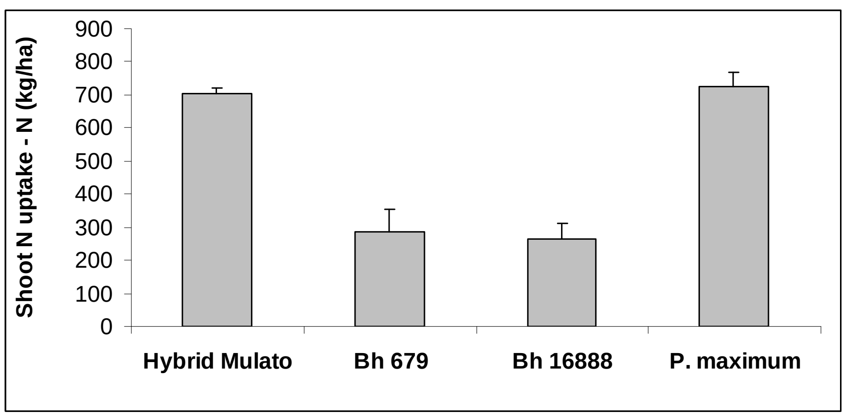

Figure 29. Differences among forage grasses in total shoot N uptake over the period from September 2004 to August 2008.

Soil nitrate level: Results on the nitrate levels in the top soil at harvest time showed significant differences (LSD, p<0.001) (Figure 30). The bare soil and P. *maximum* treatments also had high levels of soil nitrate, while the B.*humidicola* accessions clearly showed lower nitrate levels in soil. The lower N uptake by the two accessions of B. *humidicola* suggests that these grasses had lower growth rates and their demand for N was lower due to their higher BNI activity. It is also possible that the lower demand for N can cause greater leaching losses of N from these plots.

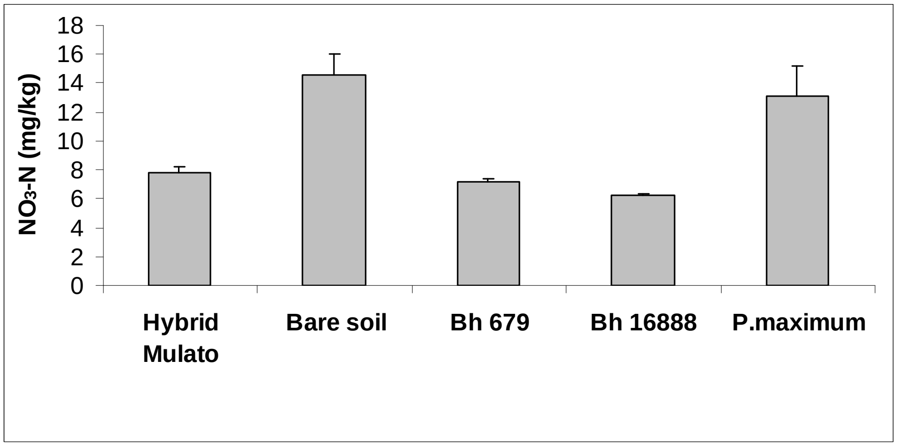

Figure 30. Nitrate levels in the top soil (0-10 cm) after fertilization (August 2008) to different grasses.

Soil nitrification rates (field experiment): Results presented in Figure 30 from the rhizosphere soil incubation test showed significant differences among the grasses (LSD, $p<0.001$) in nitrite formation in the rhizosphere at 12 days after soil incubation. As expected, bare soil showed highest level of accumulation of nitrite during the incubation while *B. humidicola* 679 (high BNI activity) and *B. humidicola* 16888 (highest BNI activity) exhibited markedly lower levels of nitrite than the values from *P. maximum*.

1.8 Field evaluation of a collection of the woody forage legumes *Cratylia s*pp. and *Dioclea* spp.

Contributors: M. Peters, L.H. Franco, R. Schultze-Kraft, B. Hincapié, P. Ávila (CIAT) and statistician G. Ramírez.

Rationale

Following the search for high quality and productive shrub legumes adapted to acid soils a collection of *Cratylia* and *Dioclea* was evaluated in Quilichao. In addition to agronomic characterization, this study is anticipated to identify morphological differences between and in between the species. The evaluation will be finalized in 2009/10.

Materials and Methods

A collection of *Cratylia* spp. and *Dioclea* spp. was sown in the greenhouse, with four Brazilian and two Bolivian accessions of erect *Cratylia argentea*, eleven accessions of a twining *Cratylia* form, possibly a new species, two accessions of erect *C. mollis*, and three accessions each of the closely related, twining species *Dioclea guianensis* and *D. virgata*. After eight weeks leaf samples for identification using molecular markers were taken.

Four months after sowing (October 2007) plants were transferred to the field station in Santander de Quilichao. A Randomized Block design with four replications was used, three for the agronomic evaluation and one for the morphological characterization. Five plants per accessions were sown with 1 m in the row and 1.5 m between rows. Plants were fertilized with P40, K50, Mg20, and S20 (kg/ha); during the first eight weeks irrigation was applied to ensure establishment, and pests were controlled.

Results and Discussion

Plants developed well in the field and no replanting was necessary; no significant diseases and pests were observed (Photo 7).

In Table 20 results from three cuts (one in the dry and two in the wet season, respectively) are presented for the five groups of species and accessions according to their origins: A) *Cratylia argentea* from Brazil (CIAT 18516, 18668, 18674 and 22406)*;* B) *Cratylia argentea* from Bolivia (BOL-01 and -02); C) six accessions of the two *Dioclea* species (CIAT 7799, 8193, 9311, 8008, 8196 and 828); D) eleven accessions of *Cratylia* sp. from Bolivia (CIAT 22397, Bol-03, -04, -05, -06, -07, -08, -09, -10, -11 and -12); and E) two accessions of *C. mollis* (CIAT 7940 and 8034). DM yields/plant showed highly significant ($P<0.01$) differences between groups in both seasons, with the Brazilian *C. argentea* accessions having the highest yields with 287 and 211 g/plant in the dry and wet season, respectively. *C. mollis* had the lowest yields in both seasons. In average, dry season yields were slightly higher than wet season yields, as was the number of regrowing branches (Table 20).

Table 20. Agronomic evaluation of a collection (2006) of *Cratylia* spp. and *Dioclea* spp. in Quilichao. Data of three evaluation cuts (two in the wet season and one in the dry season).

Species	Height	Diameter	Regrowing points	Mean DM yield	Height	Diameter	Regrowing points	Mean DM yield
	Dry				Wet			
	(cm)		(No.)	(g/pl)	(cm)		(No.)	(g/pl)
C. *argentea* - Brazil	118	103	21	287	104	101	21	211
C. *argentea* - Bolivia	113	105	23	233	111	106	22	201
Dioclea spp.	4	83	24	121	45	63	24	110
Cratylia sp.	37	76	26	89	40	67	22	93
C. mollis	89	55	11	39	75	42	9	24
Mean	63	83	26	137	60	72	21	119
LSD (P<0.05)				60.1				43.5

Photo 7. Collection of *Cratylia* spp. and *Dioclea* spp. in Quilichao, and close-up of *Dioclea virgata*

Table 21 shows data for the twining *Cratylia* species. differentiated according to accessions in height, plant diameter, regrowing points and DM yields for two seasons in Quilichao. Highly significant (P<0.01) differences were observed for DM yields although average yields were low compared with other shrubs evaluated under the conditions of Quilichao, with only *Cratylia* sp. CIAT 22397, BOL-05, BOL-10 and BOL-03 reaching DM yields above 100 g/plant in the dry season and BOL-07, BOL-05, CIAT 22397, BOL-10 and BOL-11 in the wet season. Numbers of regrowing points were higher in the dry than in the wet season but this was not reflected in higher DM yield

Table 21. Agronomic evaluation of a collection (2006) of *Cratylia* sp. in Quilichao. Data of three evaluation cuts (two in the wet season and one in the dry season).

Accession	Height	Diameter	Regrowing points	Mean DM yield	Height	Diameter	Regrowing points	Mean DM yield
	Dry				Wet			
	(cm)		(No.)	(g/pl)	(cm)		(No.)	(g/pl)
CIAT 22397	57	71	24	144	57	75	23	115
BOL-05	31	89	32	120	32	77	27	119
BOL-10	39	85	30	111	39	72	23	112
BOL-03	38	84	29	102	39	66	23	96
BOL-11	36	78	25	90	36	68	22	106
BOL-07	51	67	30	85	58	74	30	128
BOL-08	42	79	25	82	44	68	22	81
BOL-04	34	77	25	79	35	65	21	81
BOL-09	33	75	24	72	36	64	18	73
BOL-06	28	57	17	42	26	49	16	42
BOL-12	35	65	22	36	37	53	15	51
Mean	39	76	26	89	40	67	22	93
LSD (P<0.05)				69.8				53.1

For the Brazilian *C. argentea* group (CIAT 18674, 22406, 18516, and 18668) no significant differences between accessions were found for the dry period; however, in the wet season yield differences were highly significant (P<0.01) (Table 22).

Table 22. Agronomic evaluation of a collection (2006) of *Cratylia argentea* from Brazil in Quilichao. Data of three evaluation cuts (two in the wet season and one in the dry season).

Accession	Height	Diameter	Regrowing points	Mean DM yield	Height	Diameter	Regrowing points	Mean DM yield
	Dry				Wet			
	(cm)		(No.)	(g/pl)	(cm)		(No.)	(g/pl)
CIAT 18674	122	106	25	349	114	115	26	343
CIAT 22406	121	109	21	285	104	97	18	151
CIAT 18516*	106	106	21	267	98	99	22	193
CIAT 18668*	121	90	18	247	100	92	19	156
Mean	118	103	21	287	104	101	21	211
LSD (P<0.05)				275.0				132.0

* *C. argentea* CIAT 18516 and 18668 conform the commercial cultivar Veranera.

Average yields in the dry season were higher than in the wet season, with accessions CIAT 18674 being the most stable and having higher yields than accessions CIAT 18516 and 18668 (the mixture known as cv. Veranera), confirming earlier observations. While diameter and number of regrowing points were not different between seasons, in the dry season height was higher resulting in higher DM yields.

Results for *Dioclea virgata* and *D. guianensis* are shown in Table 23. DM yields were slightly higher in the dry season than the wet season, with CIAT 828 having the highest yields with more than 170 g DM/plant. Both species were similar in respect to agronomic performance.

Table 23. Agronomic evaluation of a collection (2006) of *Dioclea* spp. in Quilichao. Data of three evaluation cuts (two in the wet season and one in the dry season).

Species and accession (No. CIAT)	Height	Diameter	Regrowing points	Mean DM yield	Height	Diameter	Regrowing points	Mean DM yield
	Dry				Wet			
	(cm)		(No.)	(g/pl)	(cm)		(No.)	(g/pl)
D. virgata 828	44	90	43	172	45	71	33	170
D. guianensis 7799	41	86	29	129	40	62	23	108
D. virgata 8196	52	85	41	112	55	60	22	102
D. guianensis 9311	45	76	30	110	43	62	22	100
D. virgata 8008	42	79	33	105	43	58	26	86
D. guianensis 8193	41	81	26	100	43	62	19	94
Mean	44	83	34	121	45	63	24	110
LSD (P<0.05)				56.2				65.0

The 2-accession group of *C. argentea* from Bolivia showed no significant differences in DM yield and other parameters (Table 24). Average yields were 233 and 201 g DM/plant in the dry and wet season, respectively.

Table 24. Agronomic evaluation of a collection (2006) of *Cratylia argentea* from Bolivia in Quilichao. Data of three evaluation cuts (two in the wet season and one in the dry season)

Accession	Height	Diameter	Regrowing points	Mean DM yield	Height	Diameter	Regrowing points	Mean DM yield
	Dry				Wet			
	(cm)		(No.)	(g/pl)	(cm)		(No.)	(g/pl)
BOL-01	112	107	24	250	112	111	23	244
BOL-02	115	103	22	216	110	101	21	157
Mean	113	105	23	233	111	106	22	201
LSD (P<0.05)				239.0				141.4

The *C. mollis* accessions CIAT 7940 and 8034 had low yields, below 50 g DM/plant (Table 25.)

Table 25. Agronomic evaluation of a collection (2006) of *Cratylia mollis* in Quilichao. Data of three evaluation cuts (two in the wet season and one in the dry season).

Accession	Height	Diameter	Regrowing points	Mean DM yield	Height	Diameter	Regrowing points	Mean DM yield
	Dry				Wet			
	(cm)		(No.)	(g/pl)	(cm)		(No.)	(g/pl)
CIAT 7940	88	65	12	49	73	38	10	23
CIAT 8034	90	46	9	29	77	46	9	24
Mean	89	45	11	39	75	42	9	24
LSD (P<0.05)				86.8				32.5

Using 8-week regrowth samples collected in the wet season, *in vitro* dry matter digestibility (IVDMD) and crude protein (CP) content differed highly significantly (P<0.01) among accessions (Table 26). *Cratylia argentea* accessions CIAT 18674, 22406, 18668, BOL-01 and -02 as well as *Dioclea virgata* CIAT 8008 showed a digestibility above 65% (Photo 8). High CP concentrations, all above 25%, were measured in *C. argentea* CIAT 18674, 22406, and 18516, and *Cratylia* sp. 22397, BOL-05, -08 and -04. Digestibility of the *Dioclea* spp. accessions CIAT 8196, 828, 9311, 8193 and 7799 was below 45%; CP content was also below the average of the collection.

Photo 8. Regrowth of twining *Cratylia* sp. and young shoots of *Dioclea* spp. in Quilichao.

Table 26. Forage quality of accessions of *Cratylia* spp. and *Dioclea* spp. evaluated in the wet season in Quilichao.

Species* and accession	IVDMD	CP	Species* and accession	IVDMD	CP
	%			%	
Ca CIAT 18674	71	28.6	Csp BOL-09	59	24.3
Ca CIAT 22406	70	27.2	Csp BOL-12	56	23.7
Ca BOL-01	67	22.5	Csp BOL-06	56	23.7
Ca CIAT 18668**	66	24.8	Csp BOL-11	56	23.2
Dv CIAT 8008	65	22.2	Csp BOL-03	56	24.6
Ca BOL-02	65	24.2	Csp BOL-07	55	24.6
Cm CIAT 8034	64	22.8	Csp BOL-10	55	24.2
Csp CIAT 22397	63	25.3	Dv CIAT 8196	44	21.2
Ca CIAT 18516**	63	26.9	Dv CIAT 828	43	22.6
Cm CIAT 7940	61	23.44	Dg CIAT 9311	40	20.5
Csp BOL-05	61	27.9	Dg CIAT 8193	37	20.2
Csp BOL-08	60	25.4	Dg CIAT 7799	36	20.7
Csp BOL-04	59	25.7			
Mean				57	23.9
LSD (P<0.05)				13.472	3.862

* Ca = *Cratylia argentea*; Csp = *Cratylia* sp.; Cm = *Cratylia mollis*; Dv = *Dioclea virgata*; Dg = *Dioclea guianensis*; ** Components of cv. Veranera

1.9 Field evaluation of a collection of the forage legume *Tadehagi triquetrum*

Contributors: L. Cerón (U. Nacional), M. Peters, L.H. Franco, R. Schultze-Kraft, B. Hincapié (CIAT), N. Vivas, S. Morales and C. Martínez (U. del Cauca).

Rationale

There is a scarcity of high quality forage legumes adapted to low fertility (acid) soils). To amplify the available options, a collection of the, as yet, fairly unknown *Tadehagi triquetrum* (L.) H. Ohashi, to be tested for adaptation to acid soils, was planted at CIAT's research station in Quilichao, Cauca, Colombia. In addition, the morphological and phenological diversity of the collection is to be explored. The study is carried out as part of an effort to improve beef production in the Cauca department of Colombia, under the project "Aumento de la Productividad, Competitividad y Sostenibilidad de Pequeños y Medianos Productores de Carne en la Cuenca del Patía y Meseta de Popayán", funded by the Ministry for Agriculture of Colombia.

Materials and Methods

The available collection of *Tadehagi triquetrum*, consisting of 114 accessions, was sown in plastic bags in the greenhouse and after eight weeks, in June 2008, transplanted to the field in Santander de Quilichao (Photo 9).

A Randomized Block design with four replications was utilized, of which three serve for the agronomic evaluation and definition of nutritional quality, and one for the morphological description. For the first three replications, seed of 84 accessions was available whereas for the phenological and morphological studies there was seed of a total of 114 accessions. Each repetition consisted of five plants per accession. Planting distance in the row was 1 m, with 1.5 m between accessions. A basic fertilization with P40, K50, Mg20 y S20 (kg/ha) was given and irrigation based on need applied to ensure establishment; insect pests such as ants and other leaf eaters, and weeds were controlled.

Results

Five months after transplanting, the plants were considered fully established and considerable morphological differences were observed in terms of branching, leaf color, flowering and seed production. Most plants did not reach 1 m in height, with the average height and diameter measured at 0.44 m and 0.77 m, respectively. Three growth habits were distinguished: erect (12 accessions), ascendent (34) and prostrate (38) (Photo 10). Large differences were found in initial development and 50% of the accessions needed replanting; leaf eaters and leaf suckers were observed, in addition to fungal infection, in some cases resulting in death of plants.

The majority of accessions were early in flowering and seed set, in many cases with abundant flower and seed production. Ninety-six percent of accessions flowered by the time of the establishment evaluation and 79% set seed, with the prostrate accessions being the most productive and the erect accessions the least productive ones.

After the establishment evaluation, a standardization cut at 0.25 m height for erect accessions and 0.5 m diameter for the ascendent and prostrate accessions was performed.

Photo 9. *Tadehagi triquetrum* collection established in Quilichao; inflorescense close-up

In Tables 27, 28 and 29, the performance of plants in the establishment phase, separated according to growth habit, is shown.

Table 27. Vigor, height and diameter at the end of the establishment phase (5 months in the field) of erect *Tadehagi triquetrum* accessions in Quilichao, 2008.

Accession	Vigor	Height	Diameter
	Scale 1-5	cm	
CIAT 761	4	81	71
CIAT 880	4	80	72
CIAT 899	4	74	73
CIAT 422	4	73	93
CIAT 23112	4	72	88
CIAT 21912	3	70	43
CIAT 21913	3	70	52
CIAT 23750	3	63	56
CIAT 918	3	51	42
CIAT 13730	2	40	48
CIAT 13269	3	39	48
CIAT 21911	2	37	36
Mean	3.3	64	62
Range	1 -5	3 - 140	4 - 145

Among the erect accessions, a large variation in height was found, partly due to the replanting of a number of accessions. Accessions who reached more than 0.7 m in height were CIAT 761, 880, 899, 422, 23112, 21912 and 21913. In contrast, accessions CIAT 13730, 13269 and 21911 were the least vigorous.

Table 28. Vigor, height and plant diameter at the end of the establishment phase (5 months in the field) of ascendent *Tadehagi triquetrum* accessions in Quilichao, 2008.

Accession	Vigor	Height	Diameter	Accession	Vigor	Height	Diameter
	1-5	cm			1-5	cm	
CIAT 21923	5	39	136	CIAT 23426	3	40	84
CIAT 21921	4	50	112	CIAT 21928	4	51	83
CIAT 23428	4	79	109	CIAT 21914	3	42	81
CIAT 13277	4	91	103	CIAT 13728	3	35	77
CIAT 23236	4	64	102	CIAT 23227	3	38	76
CIAT 23950	4	68	98	CIAT 13544	2	42	76
CIAT 13726	4	55	98	CIAT 33418	3	54	67
CIAT 23749	4	63	97	CIAT 13273	3	62	66
CIAT 23943	4	64	92	CIAT 33110	3	68	65
CIAT 23751	3	62	91	CIAT 23939	3	64	64
CIAT 13270	3	56	90	CIAT 23953	3	48	59
CIAT 23424	4	60	89	CIAT 23114	2	23	57
CIAT 23427	4	49	89	CIAT 13996	3	50	56
CIAT 23753	4	51	86	CIAT 23941	3	31	55
CIAT 21929	3	53	85	CIAT 21916	3	40	44
CIAT 13727	4	57	84	CIAT 465	2	21	40
CIAT 33456	4	49	84	CIAT 13274	2	32	38
Mean					3.3	51	81
Range					1 - 5	1 - 145	1 - 229

There was similar variation among the ascendent accessions. Five accessions, i.e., CIAT 21923, 21921, 23428, 13277 and 23236, reached more than 1 m in diameter and showed vigorous growth.

As for the other growth habits, the development of prostrate accessions was very variable, with accessions CIAT 21925, 13268, 21918, 23945, 33423, 21919, 23952, 13724, 23947 and 33438 extending more than 1 m in diameter.

Table 29. Vigor, height and plant diameter at the end of the establishment phase (5 months in the field) of prostrate *Tadehagi triquetrum* Accessions in Quilichao, 2008.

Accession	Vigor	Height	Diameter	Accession	Vigor	Height	Diameter
	1-5	cm			1-5	cm	
CIAT 21925	4	25	129	CIAT 33393	3	57	78
CIAT 13268	4	33	118	CIAT 21979	3	24	78
CIAT 21918	4	32	117	CIAT 21915	3	25	77
CIAT 23945	4	50	116	CIAT 21927	4	31	75
CIAT 33423	4	55	114	CIAT 33397	3	27	73
CIAT 21919	3	26	104	CIAT 23957	3	27	67
CIAT 23952	4	67	103	CIAT 13542	3	31	67
CIAT 13724	4	33	101	CIAT 21920	3	17	64
CIAT 23947	4	50	100	CIAT 21917	3	25	62
CIAT 33438	3	47	100	CIAT 21940	2	16	57
CIAT 23113	4	55	97	CIAT 23756	3	50	53
CIAT 23956	4	53	88	CIAT 13723	2	11	53
CIAT 23228	3	32	88	CIAT 21958	3	10	53
CIAT 23955	3	32	87	CIAT 21924	2	10	48
CIAT 33384	3	28	85	CIAT 23755	2	12	44
CIAT 33424	4	48	85	CIAT 21922	2	12	40
CIAT 21939	3	18	85	CIAT 13275	2	13	37
CIAT 23954	3	26	83	CIAT 21930	2	6	31
CIAT 13540	3	35	81	CIAT 21926	1	5	19
Mean					3	31	79
Range					1 - 5	1 - 120	1 - 164

After cutting, vigorous regrowth was observed for some of the prostrate and ascendent accessions (Photo 11).

Erect Prostrate Ascendent

Photo 10. *Tadehagi triquetrum* growth habits.

Photo 11. 4-week regrowth of selected *Tadehagi triquetrum accessions* in Quilichao.

1.10 Evaluation of a core collection of *Canavalia brasiliensis* and *Canavalia* sp. for multipurpose uses in Santander de Quilichao, Colombia, 2007.

Contributors: M. Peters, R. Schultze-Kraft, L. H. Franco and B. Hincapié (CIAT)

Rationale

Canavalia brasiliensis Mart. ex Benth. ("Brazilian jack bean") is a weak perennial, prostrate to twining herbaceous legume with a wide natural distribution in the New World tropics and subtropics. In comparison with *C. ensiformis* ("jack bean"), research reports on *C. brasiliensis* are scattered and restricted to studies done in Latin America. The species develops a dense and extensive, deep-reaching root system and subsequently tolerates a 5-month dry period. Based on studies that generally were done with only one genotype, it is adapted to a wide range of soils, including very acid, low-fertility soils. Its main use is as green manure, for fallow improvement and erosion control. Due to medium biomass decomposition, nutrient release of *C. brasiliensis* green manure has the potential to synchronize well with the nutrient demand of the succeeding crop and leads to high N recovery rates. In Central America, the legume is also used to improve the value of stubble grazing in the dry season. Whereas the high concentration, in *Canavalia* seeds, of antinutritive substances such as toxic amino acids (e.g., canavanin), lectins (e.g., concanavalin Br) and trypsin inhibitors are also known for *C. brasiliensis*, there is little information on the nutritive value of the herbage of this species.

Materials and Methods

Accessions *C. brasiliensis* CIAT 7969, 17009, 7648, 17462, 905, 7971, 808, 20303 and 7972 and *Canavalia* sp. CIAT 19038, 21012, 21013 and 21014 were selected, based on an agronomic evaluation of a wider collection in Quilichao in 2004-2005. Selection criteria included adaptation to acid soil, DM yield and nutritive quality. The selected accessions were established in larger plots of 3 x 3 m (Photo 12) for more in-depth agronomic evaluation over several seasons.

Results

The plants established rapidly with little incidence of pests or diseases. Soil cover nine weeks after planting showed highly significant (P<0.01) differences between accessions, with accessions CIAT 905, 19038, 7969, 17462, 17009 and 808 being the fastest to cover the soil reaching a cover above 70%.

At twelve weeks differences between accessions had disappeared, with an average soil cover of above 87 %, including the control accession CIAT 17009 (Photo 13). A detailed description can be found in Table 30. A standardization cut was then performed to measure regrowth after 9 and 12 weeks.

Table 30. Vigor and soil cover (%) during establishment of selected *Canavalia brasiliensis* and *Canavalia* sp. accessions in Quilichao, 2007.

Accession (CIAT No.)	9 Weeks		12 Weeks	
	Vigor 1-5	Soil cover %	Vigor 1-5	Soil cover %
Canavalia sp. 19038	4	83	5	100
C. brasiliensis 7969	4	78	5	100
C. brasiliensis 17009*	4	72	5	97
C. brasiliensis 7648	4	67	5	97
C. brasiliensis 17462	4	77	5	93
C. brasiliensis 905	4	87	4	90
Canavalia sp. 21013	4	67	5	88
C. brasiliensis 7971	3	65	5	88
C. brasiliensis 808	4	70	4	82
Canavalia sp. 21012	3	45	4	80
C. brasiliensis 20303	3	55	4	80
C. brasiliensis 7972	3	53	4	78
Canavalia sp. 21014	2	20	4	63
Mean	3.5	64	4.5	87
LSD (P< 0.05)		21.6		7.3

***** Control

Photo 12. Accessions of *Canavalia* spp. in Quilichao.

Similarly, no significant differences between accessions were found for soil cover in any of the seasonal evaluations. Mean soil cover in the dry season was similar to wet season results (about 70%). Accessions CIAT 17462, 7648, 21012 and 21013 had soil covers above 80% both in the dry and wet season. In contrast, accessions CIAT 17009 and 7971 had much lower soil cover in dry periods (Table 31).

Table 31. Soil cover (%) and DM yield (kg/ha) of selected *Canavalia brasiliensis* and *Canavalia* sp. accessions in the wet (2 cuts) and dry (1 cut) season in Quilichao, 2008.

Accession (CIAT No.)	Wet season				Dry season			
	9 Weeks		12 Weeks		9 Weeks		12 Weeks	
	Soil cover %	DM kg/ha	Soil cover %	DM kg/ha	Soil cover %	DM kg/ha	Soil cover %	DM kg/ha
C. brasiliensis 905	62	2360	64	2220	50	1987	67	3013
C. brasiliensis 17462	78	2180	83	2820	67	1813	85	2987
C. brasiliensis 7971	68	1787	74	2640	40	1693	57	2867
C. brasiliensis 7648	68	1720	80	3280	67	2187	82	2840
Canavalia sp. 21012	74	2727	88	2533	67	2187	85	2773
Canavalia sp. 21014	68	1926	73	2207	50	2040	70	2467
Canavalia sp. 19038	50	2360	63	2467	37	1387	57	2413
Canavalia sp. 21013	75	2300	88	2860	73	1747	88	2387
C. brasiliensis 17009*	71	2080	84	2600	53	1880	68	2307
C. brasiliensis 808	68	2433	75	3353	53	1840	77	2307
C. brasiliensis 20303	63	1907	77	3245	50	1800	72	2267
C. brasiliensis 7969	64	1960	78	2713	70	2227	85	2160
C. brasiliensis 7972	55	1893	78	2680	40	1787	68	2040
Mean	67	2126	77	2740	55	1890	74	2525
LSD ($P < 0.05$)	29.0	1040.4	21.7	1403.9	39.2	1539.2	35.5	1554.1

***** Control

No significant differences were found for DM yield in any of the seasons or regrowth periods. Accessions CIAT 905, 17462, 7971 and 7648 had DM yields of 2.8 t/ha after 12 weeks of regrowth in the dry period. In the wet season, accessions CIAT 808, 7648 and 20303 had DM yields of more than 3.2 t/ha after 12 weeks regrowth (Table 31.)

Interestingly, accessions CIAT 905 and 7971, having had low soil covers (67% and 57%, respectively), yielded more than 2.8 t DM/ha. The control accession CIAT 17009 had yields slightly below the average in both seasons. At present, i.e., after two years of evaluation, a differentiation between biannual and perennial accessions is being observed.

Samples taken in the dry season showed a IVDMD higher than 80% and CP concentrations above 21%, with highly significant differences (P< 0.01) between accessions. Highest nutritive values were measured for CIAT 21014, 21013 and 21012 with IVDMD and CP above 86% and 25%, respectively. In the wet season no significant differences in terms of IVDMD and CP concentrations were observed. However, on average digestibility was lower in the wet than in the dry season, possibly due to the time of sampling (12 weeks after the last cut in contrast to 16 weeks in the dry season) (Table 32).

Table 32. Forage quality of accessions of *Canavalia brasiliensis* and *Canavalia* sp. evaluated in Quilichao.

Accession (CIAT No.)	IVDMD	CP	IVDMD	CP
	Dry season		Wet season	
	%			
Canavalia sp. 21014	88.3	27.5	63.2	23.8
Canavalia sp. 21013	87.9	25.1	65.0	26.2
Canavalia sp. 21012	86.4	27.4	65.2	23.8
Canavalia sp. 19038	84.3	25.2	63-1	24.7
C. brasiliensis 20303	83.3	22.6	63.4	23.7
C. brasiliensis 905	83.0	21.2	66.9	24.8
C. brasiliensis 7972	82.9	21.2	65.3	22.5
C. brasiliensis 808	82.6	22.6	64.5	22.1
C. brasiliensis 17009*	82.2	22.7	67.6	25.5
C. brasiliensis 7969	81.3	25.1	65.3	24.8
C. brasiliensis 7971	80.9	23.9	65.4	22.8
C. brasiliensis 7648	80.8	23.3	67.0	23.0
C. brasiliensis 17462	80.8	22.6	60.8	24.4
Mean	83.5	23.8	64.8	24.0
LSD (P< 0.05)	4.3	4.9	NS	NS

* Control

Photo 13. *Canavalia brasiliensis* CIAT 17009 at Quilichao.

Outcome 2. Forage as high value products developed to capture differentiated markets for smallholders

2.1 Forages for monogastric animals

2.1.1 Legume supplementation of village pigs in Lao PDR

2.1.1.1 Digestible energy value for pigs of the forage legume *Stylosanthes guianensis* CIAT 184 (Stylo 184)

Highlight

- Feeding of Stylo 184 provides nutritive value with increased nitrogen supply and moderate levels of energy. Fibre content increased rapidly with age of material. These results may explain the observed benefits of Stylo supplementation in growing pigs (>25 kg body weight) fattened for sale. The rapidly increasing levels of fibre content with age of Stylo material may explain the observed poor response of supplementing older Stylo material to weaned piglet; young animals are known to be less able to cope with high fibre content in diets.

Contributors: J. S. Kopinski (QDPI&F), S. Keonouchanh (NAFRI), K. Cox (QDPI), W. Stur (CIAT)

Rationale

Rearing pigs is a widespread smallholder livelihood activity in the northern mountainous regions of Lao PDR, contributing substantially to household incomes, especially among upland ethnic groups where rural poverty is endemic. Traditional feed resources for pigs (native tubers, banana stems and leafy vegetables from the forest) are declining from overuse. Labour to collect pig feed and fuel to cook it, mainly provided by women, is also a major constraint. Consequently, village pigs are commonly underfed and chronically protein deficient, resulting in poor productivity.

A promising option for improving these village pig production systems is the planting of forage legumes as a managed crop to provide high protein leaf supplements (Phengsavanh and Stür 2006)[1]. Farmer participants testing the forage legume Stylosanthes guianensis CIAT 184 (Stylo 184) in an ACIAR-funded CIAT project have reported doubling of growth rates, greater survival of suckling piglets and reduced labour requirements to collect and prepare feed. (photo 14).

Objective

This *in-vivo* experiment examined the digestibility and nutritive value of Stylo 184 in exotic pig breeds.

[1] Phengsavanh, P. and Stür, W. (2006). *The use and potential of supplementing village pigs with Stylosanthes guianensis in Lao PDR* Workshop-seminar "Forages for Pigs and Rabbits" MEKARN-CelAgrid, Phnom Penh, Cambodia, 22-24 August, 2006. Article # 14. Retrieved June 16, 2008, from http://www.mekarn.org/proprf/wern.htm

Photo 14. Show mixing Stylo and rice bran for pigs

Materials and Methods

Stylosanthes guianensis was grown from seed at a DPI&F Research Station at Walkamin in northern Queensland, Australia. A half portion of the stylo crop was cut and collected twelve weeks post-planting (early cut) and dried at a low temperature in a fan-forced oven. At 18 weeks post-planting the other half of the original crop was harvested (late cut) and similarly dried. Also at 18 weeks post-planting the section of the crop which had been harvested at 12 weeks (and now having 6 weeks of regrowth) was recut (recut) and dried. The dried material was hammer milled and incorporated in a sorghum basal digestibility diet.

In a pig metabolism study, the digestible energy (DE) value of the dried stylo cut and harvested at different times (early cut, late cut, recut) post-planting were assessed. Sixteen entire male Large White pigs (~22kg) were housed individually in metabolism crates. Total faecal collections were carried out over 5 days following an initial eight day pre-collection diet adaptation period. Ferric oxide was added to the diet as a faecal dye to indicate the start and end of collection. There were four replicates for each experimental diet. Diets were based on 65% sorghum, 25% dried stylo meal and a 10% basal component consisting of casein, vitamins, minerals, lysine and oil.

Results

The preliminary results of chemical analysis results of various stylo cuts are presented in Table 33 and the digestibility results of the four diets in Table 34. It can be seen that the early cut stylo has a higher starch content and lower fibre fraction content than late and recut stylo. As a result the faecal digestible energy content was higher for the early cut stylo than for the subsequent cut stylo material which had become woody, as indicated by the higher NDF and ADF content. The overall energy digestibility coefficient of the diet was observed to be less for the different stylo cuts (0.72-0.78) compared to the basal sorghum diet (0.88).

The nitrogen data indicates that stylo inclusion provided a higher overall nitrogen intake as expected and also an increased faecal excretion of nitrogen. In the case of the early cut stylo the results show an increase in nitrogen digested compared with other diets although there was only a trend for higher retention of N. Overall nitrogen digestibility of diets was reduced with increasing fibre levels of the stylo, although the overall nitrogen retention was less affected.

Table 33. Composition of main dietary ingredients

	sorghum	early cut stylo	late cut stylo	recut stylo
DM	88.5	90.2	90.7	89.9
Ash	1.5	7.6	7.7	8.3
N	1.78	3.41	3.11	3.60
protein	11.13	21.31	19.44	22.50
Fat	3.8	2.2	1.7	1.9
CF	1.2	12.4	21.3	18.0
NDF	5.9	25.6	34.5	29.6
ADF	3.5	16.9	26.8	22.1
Starch	70.5	9.8	3.0	2.5
GE	18.79	18.55	18.53	18.6
Ca	<0.1	1.05	1.18	1.19
P	0.33	0.21	0.2	0.23
Aspartic Acid	7.28	19.89	21.30	22.13
Threonine	3.44	8.53	7.49	8.40
Serine	4.81	8.48	7.66	8.69
Glutamic Acid	23.40	20.89	18.16	19.99
Proline	8.73	9.67	9.62	10.83
Glycine	3.39	9.81	8.71	9.68
Alanine	9.74	10.73	9.33	10.25
Valine	5.08	9.90	8.81	9.86
isoLeucine	4.05	8.42	7.32	8.35
Leucine	13.78	15.44	13.40	15.12
Tyrosine	4.15	6.74	5.72	6.49
Phenylalanine	5.17	9.92	8.80	9.79
Lysine	2.34	10.54	9.45	10.40
Histidine	2.48	4.59	4.11	4.54
Arginine	4.98	12.31	10.37	11.62
Tryptophan	1.38	3.23	2.82	3.38
Cystine	2.17	2.71	1.93	2.69
Methionine	1.82	4.73	3.07	4.01

Table 34. The apparent digestibility of dry matter, energy, nitrogen, and nitrogen retention of stylo experimental diets

	Units	Diet 1 Basal sorghum	Diet 3 Early cut stylo	Diet 2 Late cut stylo	Diet 4 Recut stylo	LSD (P=0.05)
Dry Matter digestibility		0.87a	0.79c	0.75b	0.73d	0.017
Gross energy	MJ/kg DM	18.35	18.26	18.34	18.3	-
Digestible Energy	MJ/kg DM	16.1a	14.2b	13.7c	13.2d	0.37
Digestible Energy	MJ/kg As Is	14.6a	13.0b	12.5c	12.1d	0.34
Energy digestibility		0.88a	0.78b	0.74c	0.72d	0.02
Metabolisable Energy	MJ/kg DM	15.8a	13.9b	13.3c	12.8d	0.38
Intake Nitrogen	g/d	30.6b	35.5a	34.1a	35.9a	1.95
Faeces Nitrogen	g/d	6.8c	9.6b	10.5ab	11.7a	1.62
Urinary Nitrogen	g/d	5.5	5.4	5.4	6.0	1.68
Total N excreted	g/d	12.3b	15.1ab	15.9a	17.7a	2.84
Nitrogen digested	g/d	23.8b	25.9a	23.6b	24.2b	1.44
Nitrogen retained	g/d	18.3	20.5	18.2	18.2	2.13
Nitrogen retention		0.77	0.79	0.77	0.75	0.069
Nitrogen digestibility		0.78a	0.73b	0.69bc	0.67c	0.041

Discussion

The results show that feeding of stylo meal does provide some nutritive value to the pig with increased nitrogen supply and some energy, with a portion of the nitrogen presented being retained by the pig. Further work is being carried out to see what occurs at the ileum and to better gauge the true benefit to the pig from nutrients in stylo.

Additional studies will examine, under controlled conditions, the growth performance response of pigs to stylo feeding. However the digestibility results so far suggest that the field responses reported by Pengsavanh *et al*. (2008)[2] are to some degree a reflection of some nutrient supply from stylo to the pig. Further work is required to assess whether the field observations of a halving of the time to pig market weight with the use of stylo feeding in Lao is a response to either additional energy or protein nutrient supply from stylo alone. Alternatively it could also be partially a response to an increased total feed intake as a result of increased feed supply through the addition of the available stylo.

[2] Phengsavanh, P., Stür, W. and Keonouchanh, S. (2008) *Adoption of the forage legume 'Stylo 184' (Stylosanthes guianensis CIAT 184) in smallholder pig systems in Lao PDR*. Proceedings of the XIIIth Asian-Australasian Association of Animal production Societies, Hanoi in print.

As intensive pig industries move from stall housing of dry sows into group housing, due to legislative changes in response to welfare concerns, the bulkiness and fibre level of stylo could be a viable option to develop new feeding regimes and diets enabling increased sow satiety without over-supplying nutrients to the dry sow.

2.2 Benefits of multipurpose forages in production systems quantified

2.2.1 Enhancing livelihoods of poor livestock keepers through increased use of fodder in South East Asia

2.2.1.1 Feeding fish with improved grasses: A success story in Tuyen Quang, Vietnam

Highlights

- Farmers who adopted improved grasses were able to harvest 63% more fish by weight as well as to obtain 10.7% higher price per kilo of fish harvested because farmers received a "premium" due to the sale of heavier, larger fish.

- Forage adopters earned 2.3 times more income per pond and the return to family labor was five times greater compared to farmers who produced fish in the traditional way.

Contributors: W. Stur (CIAT), W. Khanh (Tay Nguyen University), T. T. L. H. Binh (NIAH), V.H. Yen, S. Phengsavanh (NAFRI), F. Holmann (CIAT)

Rationale

While fishing must surely be one of the oldest recorded sources of livelihood, it is only comparatively recently that fish have become important components of the diets of the majority of the world's people, especially those living in developing countries. Consumption of fish and seafood products reached 14 kg per capita in developing countries in 2001, nearly twice the level recorded in the early 1970s, while population in those countries doubled over the same period. Fish are an important component of the rapid growth of the consumption of animal products in developing countries over the past two decades and into the foreseeable future

Most of the net growth in fish production over the past 20 years has come from the development of fish farming, especially in the developing countries of Asia. The majority of the growth in fish production has come from aquaculture, which ranges from simple ponds utilizing naturally occurring food sources to highly intensive systems with water control, aeration, and supplemental feeding. With global fish supply struggling to keep pace with projected demand over the next 20 years, technology will play a crucial role. Production growth in aquaculture will come from (a) expansion of area; (b) from increased intensity of input use, especially feed; and (c) from technological improvements in both inputs and organisms (Delgado et al., 2003).

In Vietnam, NARS's partners, together with the International Center for Tropical Agriculture (CIAT), begun testing the feeding of improved grasses to increase herbivorous fish production in 1997 in the province of Tuyen Quang, mostly in the districts of Nahang, Son Dung, Ham Yen and Yen Son. Farmers raise complementary fish species in small ponds for household consumption and sale in local markets. Common fish species grown in the same pond are grass carp, silver, mud and common carp, and tilapia. Since 2003, the work has been emphasized only in Ham Yen and Yen Son. In 2005, CIAT and partners were working with about 1700 farmers and 500 of them were using improved grasses to feed fish. (Photo 15). The main grasses employed are *Panicum maximum* ("Simuang"), *Pennisetum purpureum* (Napier) and *Paspalum atratum* ("Terenos"). The fish production in the area is mostly done by smallholders, where farmers own 1 to 2 small ponds.

Photo 15. System of fish production with grasses.

Objective

The objective of this study was to assess the differences in productivity and profitability of fish production in smallholder systems before and after adopting improved grasses in Tuyen Quang, Vietnam.

Materials and Methods

Farmer group meetings and interviews with individual farmers were held using a survey instrument. Two 15-farmer group meetings were organized in August and October of 2005 in the districts of Ham Yen and Yen Son. The survey questions and discussions in the group meetings were centered around feeding management and fish production with emphasis on the kind of forages used to feed fish, management, and yield.

Results

The majority of farmers who raised fish had average wealth status (63%) and a significant proportion were better off (33%) as classified by local Vietnamese authorities. Mean fish pond size was 1540 m^2 and mean forage plot size was 697 m^2 with a few farmers having much larger areas of up to 3700 m^2. In most cases the number of ponds managed by farmers increased from 1 to 2 after they started using forages. Before adoption took place, farmers fed their fish with specific native grasses and vegetation, cassava, rice bran, and banana stem. The main grasses used for fish production were *Panicum maximum* ("Simuang"), *Pennisetum purpureum* (Napier) and *Paspalum atratum* ("Terenos"). Forage adopters harvested almost 63% more fish than non-adopters (122 kg vs. 75 kg / 100 m^2) with a 8% reduction in cycle length (10.6 months vs. 11.5). Moreover, planting improved grasses saved farmers a substantial amount of time in harvesting feed. On average, adopters saved 340 hours per cycle (308 vs. 648 hours/cycle for non-adopters). Most farms (63%) reported that fish farming was an activity where only men participate due mainly to the risk of falling and drowning in the pond.

Farmers who adopted improved grasses were also obtained a 10.7% higher price per kilo of fish harvested because farmers received a "premium" due to the sale of heavier, larger fish (US$0.93/kg vs. $0.84/kg). Thus, combined with the higher fish production, forage adopters produced 2.3 times more income per pond than farmers who produced fish in the traditional way (i.e., US$299 vs $90). The benefit:cost ratio of the forage adopters was 72% higher than the non-adopters (2.56 vs. 1.49). Likewise, the economic return to labor of forage adopters was greater than 5 times the return obtained by non-adopters (i.e., US$1.35/hr vs. $0.26/hr) which means farmers have a lot of incentives to adopt forages because they not only save labor time, but also the economic return to labor is higher. All forage adopters mentioned they invested the extra income from fish in the education of their children and in the acquisition of household needs. About half of them invested in the improvement of their overall standard of living. Twenty-seven percent expanded cattle production, and 17% increased fishpond area. The effort of more than 10 years collaboration between CIAT and NARS in Vietnam testing and validating improved forages is now translated into a more profitable and labour conserving activity compared to the traditional system of fish production.

2.2.3 Cow-calf production: A profitable alternative using improved forages. Case studies from Vietnam and Indonesia

Highlights

- In Vietnam, income from the sale of cattle of forage adopters was 71% higher and the return to family labor was 3.8 times more than for non-adopters.

- In Indonesia, forage adopters received 3.1 times more money from the sale of cattle and the return to family labor was almost 4 times higher than non-adopters.

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Rationale

Cattle production is becoming one of the most important agricultural activities of farmers in South East Asia, especially in locations where soil and weather conditions do not allow farmers to produce other cash crops such as coffee or rubber.

The cow-calf system is defined as a productive activity where farmers keep cows to produce calves for sale. This is the main system found in Daklak in the central highlands of Vietnam and in East Kalimantan in Indonesia. In both sites the system has evolved since the 90's in three distinctive forms: (a) from the use of free grazing to producing feed from improved forages and presented in confinement operations; (b) from using native breeds to cross-breeding; and (c) from cattle keeping as a savings system to a commercial, market-oriented production system.

Vietnam

The evolution of this system in the M'Drak district started in 1995 when farmers, together with NARS's partners and the International Center for Tropical Agriculture (CIAT), begun testing improved forage germplasm for adaptation to local conditions. After five years of testing, the selected grasses and legumes were disseminated to other farmers and adoption took place in three additional districts: Ea Kar, Cu Jut and Buon Don where more than 2,000 farmers begun testing the adapted cultivars.

Indonesia

CIAT, together with the Provincial Livestock Services Office, started working with farmers in 1999 by testing improved forages for adaptation in the village of Tanjung Harapan in the sub-district of Samboja, in the province of East Kalimantan. This is a flat area with very acid soil where coconut is the main crop. Of all forage options tested, farmers selected *Brachiaria humidicola* and established it under coconut plantations for use as cut-and-carry night feed to cattle.

Objective

The objective of this study was to assess the impact of the adoption of improved forages by small farmers on the evolving South East Asian cow-calf production system compared to the traditional system using two case studies: one from the province of Daklak in Vietnam and the second from East Kalimantan in Indonesia.

Materials and Methods

The impact was assessed by way of comparing the production system between farmers who adopted improved forages versus non-adopters through a group discussion and individual survey during July 2005. Farmers who adopted forages in both countries were, in general, larger in both herd and farm size.

Results

In the case study from Vietnam, mean area of planted forages was 2,028 m^2 for an average herd of 6.9 heads equivalent to 405 m^2/AU (where 1 AU was assigned to cattle of >2 years and 0.7 AU to cattle 2 years and younger). Income from the sale of cattle for the forage adopters was 71% higher compared to non-adopters (i.e., US$ 800/yr vs. $467/yr). Farmers who adopted forages spent 26% of the time allocated to feeding management by non-adopters (i.e., 0.44 vs. 1.71 hours/day/head). Therefore, the return to labor for the adopters was US$0.73/hr compared to US$0.19/hr for the non-adopters. Thus, forage adopters in Vietnam made about 3.8 times more money per unit of labor invested than non-adopters.

In the case study from Indonesia, mean area of planted forages was 4,708 m^2 for an average herd of 8.1 heads equivalent to 720 m^2/AU. In terms of income, forage adopters received 3.1 more money from the sale of cattle than non-adopters (i.e., US$900/yr vs. $310/yr). Moreover, forage adopters only allocated 29% of the time spend by non-adopters (i.e., 0.22 vs. 0.76 hours/day/head). Thus, the return to labor by forage adopters was almost 4 times higher than non-adopters (i.e., US$ 3.85/hr vs. US$ 0.97/hr).

In both countries all household members actively participate in most feeding and management practices of the cow-calf operation. The effort of more than 10 years between CIAT and NARS in the region in testing and validating improved forages together with farmers is now translated into a new profitable agricultural activity.

2.2.4 Short-term cattle fattening using improved grasses: A new profitable alternative in Vietnam

Highlight

- Farmers who fattened cattle using planted grasses generated 5.7 times more profit per unit of land than by growing coffee

Contributors: W. Stur (CIAT), T.T. Khanh (TNU), F. Holmann (CIAT)

Rationale

Cattle production is becoming one of the most important agricultural activities of farmers in South East Asia, especially in locations where soil and weather conditions do not allow farmers to produce cash crops such as coffee or rubber. In Vietnam, NARS's partners, together with the International Center for Tropical Agriculture (CIAT), begun testing improved grasses to increase cattle production in 1997. Among the cattle production alternatives is short-term cattle fattening. This activity started in 2002 in the Ea Da Commune, Ea Kar district, Daklak province. All of the farmers fattening cattle were planting improved grasses for cutting and supplying to cattle in pens.

Objective

The objective of the study was to compare the benefits of planting improved forages for short term cattle fattening compared to coffee production in the same area.

Materials and Methods

A survey of thirty farmers, who were randomly selected from about 200 farmers who had fattened cattle using planted grasses during the last 12 months, was conducted at Ea Da commune, Ea Kar district in April 2005. All of these farmers had recently replaced coffee trees with improved forages for feeding to cattle. The surveyed farmers were fattening (or finishing) thin adult cattle before selling them for slaughter.

Results

Ea Kar district is a poor rural district with farmers operating small, mixed crop livestock farms. The main crops grown were upland crops such as maize and cassava, coffee in small pockets of fertile soils, and some paddy rice. Livestock include cattle, pigs, poultry and fish. Farmers who first started finishing cattle for slaughter had an average (33%) or better off (63%) wealth status as defined by local Vietnamese authorities. However, farmers classified as poor were able to also fatten cattle once fattening had been proven as a profitable farm activity and credit was made available to poor and average households by the local government bank.

The main forage species grown for cattle fattening was the grass P*anicum maximum* "Simuang". The average forage area for one cattle fattening/cycle was 561 m^2. Most farmers supplemented the basal diet of fresh improved grasses with a small amount of a mix of cassava meal, rice bran, and maize meal in small amounts (often 1 kg per animal/day). The forage dry matter intake was 6.7 kg/animal/day which represented more than 3% of body weight. The average number of cattle being fattened per cycle was 2 animals per farm with a mean daily weight gain of 670 g/day. About 90% of farmers were fattening their cattle within 90 days with an average of 60 days.

The family spent an average of 110 minutes per day to feed and manage the cattle being fattened. Within family members, women did most of the work, investing about 81 minutes per day whereas men spent 12 minutes and children 7 min/day. The main reason given for this labor division was that fattening cattle was done close to the house which was women's domain while men were responsible for field work with fields often being distant from the house. The benefit:cost ratio for growing coffee was 2.91 and for cattle fattening 1.18. Thus, for every dollar invested in coffee the farmer obtained 2.91 of net profit, or 191% of net margin, and for every dollar invested in finishing cattle, the farmer obtained $1.18, or 18% of net margin. However, even though coffee was more profitable than finishing cattle, in absolute terms of net income it was not because finishing cattle generated 5.7 times more profit per unit of land than coffee (i.e., US$ 541 vs US$ 95 for every 1,200 m^2 of area allocated); therefore, it was economically more attractive to the farmer.

All interviewed farmers stated that in the near future they wanted to increase the cattle fattening enterprise and the majority of farmers (53%) also wanted to acquire cows for reproduction. As a result, 43% of farmers wanted to increase the area planted with forages. None wanted to expand the area allocated to coffee.

2.3 Benefits of adopting forages in Latin America and the Caribbean

2.3.1 Benefits of adopting improved forages in smallholder farms in Central America: An *ex post* analysis

Highlights

- The adoption of improved forages increased milk production, ranging from 9% in Guatemala, 47% in Honduras and Nicaragua, and 53% in Costa Rica. Likewise, milk production costs decreased by 16% in Guatemala, 42% in Honduras, 7% in Nicaragua, and 31% in Costa Rica.

- The increases in production and the reduction in the production costs generated drastic income increases. Family net income increased by 32% in Guatemala in 2007 compared to 2003 when the project started, even with the damage caused by Hurricane Stan, and by extraordinary increases in net income in the other countries: 288% in Honduras, 177% in Nicaragua, and 238% in Costa Rica.

- The use of seed from improved forages has increased significantly throughout Central America and, as a result, pastures are currently being renovated. Seed supply and marketing systems need to be improved so that small producers can easily access information and obtain planting material.

Contriburtors: F. Holmann (CIAT), P. Argel (CORPOICA), E. Pérez (ILRI)

Rationale

Beef production in Central American countries has been characterized by large fluctuations that depend on climatic conditions, the introduction of improved forages, market prices, and international free trade agreements. In the 1970s, intensive milk and beef production systems were mainly based on the use of star grass (*Cynodon* nlemfuensis), which predominated in the main livestock areas of the region. The degradation of this grass because of the lack of proper management practices and the absence of new options as a result of limited forage research caused a dramatic decrease in the livestock herd in the early 1980s.

In 1975, the Tropical Forages Program of the International Center for Tropical Agriculture (CIAT) launched the International Network for Evaluation of Tropical Pastures (RIEPT, its Spanish acronym) with funding from international institutions and support of the national research programs. The network mainly aimed to evaluate new improved forage species that were adapted to the lowlands of tropical America. The RIEPT began operations in Central America in 1985 and, after 11 years of research, identified in 1996 several good-quality grass and legume accessions adapted to different agro-ecological areas. These materials were subsequently released as commercial cultivars by national agricultural research institutes. Among these are the grass cultivars Diamantes (*Brachiaria brizantha* CIAT 6780) and Toledo (*B. brizantha* CIAT 26110) and the *Brachiaria* hybrid cv. Mulato in Costa Rica, as well as the legumes *Arachis pintoi* cv. Porvenir in Costa Rica and cv. Pico Bonito in Honduras, and *Cratylia argentea* cv. Veraniega in Costa Rica. These materials are now widely used in the different livestock areas of Central America.

Of all the cultivars that have been released, *Brachiaria* grasses currently dominate the market, accounting for 84% of all seed sales in Mexico and Honduras, 90% in Nicaragua, 85% in Costa Rica, and 97% in Panama during the first years of the new millennium.

Objective

This study aims to estimate the benefits received by 56 producers who adopted improved forages as part of a project carried out in Guatemala, Honduras, Nicaragua, and Costa Rica in terms of increased productivity, stocking rate, and income due to the additional sale of milk and beef in retribution for family labor.

Materials and Methods

The data used to estimate the benefits received from the adoption of improved forages were obtained from a survey carried out between September and October 2007 that included nine producers in Guatemala, 16 in Honduras, 16 in Nicaragua, and 15 in Costa Rica who had adopted different grass and legume options during the period 2003-2007.

The survey aimed to quantify the changes observed between 2003 and 2007 in terms of land use as a result of the adoption of improved forages, changes in animal inventory by category, milk and beef production, use of family and hired labor, and expenses incurred in feed supplementation during the dry season.

Results

The area planted to improved pastures increased in all countries, ranging from 12% in Guatemala to 105% in Nicaragua. Except for Guatemala (where the animal inventory decreased almost 11%

due to Hurricane Stan), all countries expanded their herds (between 34% and 41%) in practically all animal categories, not only adult cows.

On-farm milk production during the dry season increased 9% in Guatemala, 47% in Honduras and Nicaragua, and 71% in Costa Rica. Milk production during the rainy season remained practically invariable in Guatemala, but increased 48% in Honduras, 19% in Nicaragua, and 53% in Costa Rica. On the other hand, these increases in milk production were also favored by the rise in milk prices in all countries, ranging from 7% in Nicaragua to 36% in Costa Rica during the dry season and from 4% in Nicaragua to 36% in Costa Rica during the rainy season.
Beef production accordingly increased 15% in Nicaragua, 46% in Honduras, and 74% in Costa Rica. Similar to the trend observed in milk production, beef production did not increase in Guatemala because producers had to sell animals to recover from the losses caused by Hurricane Stan. Likewise, at the end of the project, producers in all countries received higher prices as compared with those obtained at the beginning of the project. The price of beef paid to the producer increased 9% in Guatemala, 4% in Honduras, 5% in Nicaragua, and 11% in Costa Rica.

Because of these significant increases ($P>0.05$) in annual milk and meat production, major increases were also observed in the annual net income of farms, reaching 32% in Guatemala, 288% in Honduras, 177% in Nicaragua, and 238% in Costa Rica. These extraordinary increases in net income can be attributed to three factors: (1) the higher milk price in 2007 as compared with that of 2003; (2) higher production due to the better diet; and (3) increased production due to the higher stocking rate allowed because of the adoption of and increase in area sown to improved forages.

The increase in the net income of producers has triggered an increase in the economic returns to family labor, as compared with the commercial value of a day's wages. Therefore, the returns to family labor in Guatemala went from 3.1 times the value of the minimum wage in 2003 to 6.0 times that value in 2007, representing a 97% increase. In Honduras, the returns to family labor went from 2.9 times the minimum wage in 2003 to 9.8 times that value in 2007, representing a 238% increase. Similarly, in Nicaragua these returns represented a 104% increase and in Costa Rica a 200% increase.

2.3.2 Costs and benefits of traditional and improved feeding systems for dairy cattle in two communities in the central highlands of Perú

Highlight

- Improved forages increased stocking rate 3.5 times more in Aramachay and 13% more in Llacuari compared to the traditional feeding system in each site. This increase in stocking rate raised both milk and beef output that generated farm income equivalent to 18% higher than the local wage rates

Contributors: F. Holmann (CIAT), K. Bartl (ETH Zurich), E. Muñoz, C. Gómez (Universidad Agraria de Lima) H.D. Hess (ALP), M. Kreuzer (ETH Zurich)

Rationale

Perú has experienced a fast growth in dairy production, increasing its output by 4.2% annually from 1994 to 2004 (FAOSTAT, 2006). At the same time, dairy imports have increased and currently account for about 50% of all milk used by the industrial sector (citation?). The driving force behind this development has been an increase in domestic demand, originating primarily from fast-growing urban areas (Bernet, 2000). At present, most milk provided to the formal dairy industry is produced by large farms and industrialized enterprises which are mainly located in the lowlands and mid-altitudes. However, there is a great potential to expand and intensify milk production and processing in the Peruvian highlands where currently mainly low-quality cheeses for informal markets are produced, mostly by small-scale farmers (Bernet, 2000).

The slopes in these mountainous regions (3,200 to 4,200 m.a.s.l.) are predominantly covered by native grasslands, and cultivated pastures, whereas the flat lands in the valleys are used for crop production (cereals and potatoes) during the rainy season. The poor quality of native grasslands and cultivated pastures is one of the most important factors limiting productivity of dairy cattle because they are often degraded as a consequence of inappropriate management (e.g. overgrazing).

The history of livestock production in the tropics, which is based on extensive grazing, indicates that one of the main constraints faced by current production systems is the limited forage on offer in terms of quantity and quality, which becomes more critical during the driest periods of the year.

Earlier studies by other authors clearly demonstrated that a special effort is required by smallholders in the Andean highlands of Peru to develop new feeding strategies, especially during the dry season (e.g., forage conservation) to remain or get competitive.

Objectives

The objective of this study is to compare the costs and expected benefits of the traditional feeding system based on forages with low productivity vs. new forage systems based on improved forages of higher productivity and quality in four communities of Perú.

Materials and Methods

Data for this study was gathered in a farm survey conducted in 2005 in the communities of Aramachay, Llacuari, Chalhuas and Sallahuachac, located in the Central Highlands of Perú. The survey was designed to determine herd structure, land use patterns, milk and beef production, and use of inputs for animal feeding, in order to estimate production and reproductive parameters and employment of family/contracted labor. To calculate the economic return to the investment in improved forages, a simulation model that applies optimization techniques through linear programming, implemented as an Excel spreadsheet, was used to perform an *ex ante* evaluation of the costs and benefits of different land use alternatives and of interactions between technological components and biological productivity.

Results

The traditional feeding system was validated by the model based on the survey information and additional information from literature. Under this scenario in Aramachay and Llacuary, current land use maintains a herd size of 1 mature cow (where on average, half a cow is in milk and the other half cow is dry) producing an average of 2.2 kg milk/farm/day during the rainy season and 1.4 kg milk/farm/day in the dry season which generates an annual income of US$ 69/farm/yr. This income translates into an economic return to family labor of US$ 0.58/day which represents only 12% of the local wage rate. In the case of Chalhuas and Sallahuachac, current land use maintains a herd size of 6 mature cows (where four cows are in milk and two are dry) producing an average of 14.7 kg milk/farm/day during the rainy season and 6.5 kg milk/farm/day in the dry season. This production generates an annual income of US$ 1,065/farm/yr. This income translates into an economic return to family labor of US$ 3.32/day which represents about 71% of the local wage rate.

Assuming the current farm areas allocated to irrigated ryegrass production remain the same (i.e., 0.31 ha in Aramachay and Llacuari and 0.37 ha in Chalhuas and Sallahuachac), then the optimal solution of improved feeding systems would be to establish a combination of forage alternatives, which includes ryegrass (fertilized and irrigated) limited to the current planted area, a new fertilized variety of barley (0.26 ha in Aramachay and Llacuari and 0.75 ha in Chalhuas and Sallahuachac), and the remaining farm area under native pastures in both communities. The reason why fertilized barley is part of the optimal solution and not new varieties of improved oats and/or triticale is because fertilized barley produces biomass at a lower cost than fertilized oats or triticale (i.e., $ 7.4 cents/kg DM compared with $ 9.7 and $ 8.3 cents/kg DM, respectively). In addition, fertilized barley produces energy at a lower cost than the other alternatives and a similar cost for protein. Under this option, herd size can be increased up to 3.5 cows (3.5 times more) in Aramachay and Llacuari and up to 6.8 cows (13% more) in Chalhuas and Sallahuachac. This increase in stocking rate raises both milk and beef output that generates farm income that varies between $ 589/farm/yr in Aramachay and Llacuari and $ 1,128/farm/yr in Chalhuas and Sallahuachac. The economic return to family labor is increased to $ 5.55/day in Aramachay and Llacuari equivalent to 18% higher than the local wage rate, and up to $ 4.72/day in Chalhuas and Sallahuachac, equivalent to the existing wage rate.

Results of the sensitivity analysis indicated that two technical parameters (fertility and milk production per cow) and one economic parameter (farmgate price for milk) have the greatest impact on the net income of livestock producers. A 10% increase in herd fertility compared with the current calving rate improves income by 15 - 42% in traditional systems, and by 12 - 13% in improved feeding systems, depending on the community. The second most important parameter in terms of its impact on income is milk productivity. A 10% increase in current milk production per cow results in 13 - 36% more income in traditional systems, and 11 - 12% more in improved feeding systems. Beef and milk prices are decisive if regional producers need to adjust to the new economic framework resulting from the Free Trade Agreement between Perú and the US. A 10% reduction in the farmgate price for milk would imply a decrease in total farm income of 13 - 37% in traditional feeding systems and 13 - 15% in improved feeding systems. A 10% reduction in beef price would lead to a drop in income (3 - 9%), but not as much as when milk prices fall, because dual-purpose production systems depend mostly on the sale of milk or fresh cheese for income and cash flow.

The reduced cost shows the income that is lost by forcing the model to include in the solution a forage technology that has not been considered in the optimal solution. The shadow price, also known as scarcity price, represents the maximum amount of money that a farmer would be willing to pay per additional unit of a given limiting factor that was exhausted in the production process. In this study, the elimination of 1 hectare of ryegrass or improved barley to replace it with 1 hectare of the improved fertilized oat would reduce farm net income between $ 52 in Aramachay and Llacuari to $ 120 in Chalhuas and Sallahuachac. Likewise, the elimination of 1 hectare of ryegrass or improved barley to replace it with 1 hectare of fertilized triticale would reduce farm net income by $ 58 in both communities.

The shadow price of land is about US$ 152. This means that a producer in any community would be willing to pay this amount annually to lease an additional hectare of land for livestock production using the technology alternative based on improved forages. The improved feeding systems discussed in this study can signifficantly improve rural livelihoods in communities of the highlands of Peru.

Outcome 3. Forages integrated into smallholder systems for realizing the benefits of improved grasses and legumes in crop/livestock systems through adaptation, innovation and adoption, aiming at higher livelihood security through higher resource use efficiency.

3.1 Superior and diverse grasses and legumes evaluated in different production systems are disseminated

3.1.1 Scaling out of the forage legume Stylo 184 in Laos

Highlight

- The formation of a pig systems learning alliance with NGOs and other development practitioners proofed to be an effective way of scaling out Stylo 184 supplementation of village pigs

Contriburtors: W. Stur, P. Phengsavanh and S. Keonouchanh (CIAT)

Rationale

An avenue for effective scaling out research results is through partnership with appropriate development stakeholders. Simply offering field days and providing information material on research results to NGOs has not been effective in the past. This project therefore attempted to develop a long-term platform linking research and development by forming and facilitating a Pig Systems Learning Alliance with interested NGOs and development projects.

Objective

Scaling out of Stylo 184 supplementation for village pigs by building capacity of NGOs and other development practitioners to deliver improved pig production technologies in northern Laos.

Materials and Methods

Interested staff of NGOs, development projects and government extension service working in northern Laos were invited to a workshop and field day in villages where farmers were growing and using Stylo 184 as a supplement to local pigs' diets. We discussed the constraints and benefits of legume supplementation, and shared ideas on how to improve village pig production in northern Laos. At this meeting, many participants agreed to form a learning alliance on pig systems. Alliance members met twice a year; early in the year for an annual review and planning workshop, and in the middle of the rainy season for a mid-season review. These workshops provided an opportunity to discuss work plans and implementation issues, review results, share experiences among alliance members, and provide feedback to researchers. Each workshop included a training component covering topics and issues that had been requested by alliance members. Training was thus based on the needs of development partners and linked closely to field implementation. Participation in these meetings and workshops was funded by the respective NGOs. Apart from the 6-monthly meetings, development practitioners were offered linkages with experienced government extension workers in the closest districts or province.

Extension workers provided advice via telephone, occasional visits to the target area of the NGOs, and facilitation of cross visits to villages with good examples of improved pig production systems.[3]

Alliance partners used a range of methods for scaling out supplementary feeding of Stylo 184 and improved pig production technologies. These included the formation of farmer interest groups, farmer-to-farmer exchange, cross visits to successful examples and conducting village learning activities to experiment with Stylo 184 and other pig management improvements.

Results

Interest in joining and remaining with the development alliance was considerable. All four NGOs, three development projects and three district extension offices, who participated in the inception workshop, continued to participate in the development alliance throughout the project. In addition, a further four NGO projects joined the alliance at a later stage. The number of participants at alliance workshops ranged from 30-40 people and the majority of participants attended all workshops.

Development alliance partners reached a large number of villages across the mountainous areas of northern Laos. By the end of 2007, development partners reported that they were working with farmers to improve pig production in more than 100 villages located in 12 districts in 6 provinces in northern Laos. The number of households who were growing and feeding Stylo 184 to pigs, had grown from 200 households in 2005 to 1,400 households by the end of 2007 (Figure 31). 75 % of these households were in NGO and development project target areas. The remaining households were in villages serviced by the three participating government extension offices.

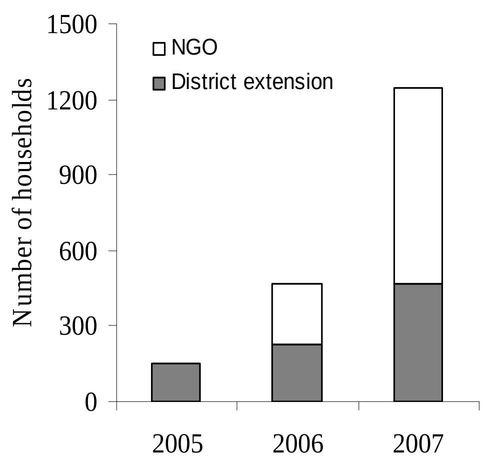

Figure 31. Households growing Stylo 184 as supplementary feed for

[3] Leterme P., Botero M., London A. M., Bindelle J. and Buldgen A. (2006). Nutritive value of tropical tree leaf meals in adult sows. Animal Science 82: 175–182.
Phengsavanh, P. and Stür, W. (2006). *The use and potential of supplementing village pigs with Stylosanthes guianensis in Lao PDR* Workshop-seminar "Forages for Pigs and Rabbits" MEKARN-CelAgrid, Phnom Penh, Cambodia, 22-24 August, 2006. Article # 14. Retrieved June 16, 2008, from http://www.mekarn.org/proprf/wern.htm

The average size of the area of Stylo 184 grown by individual households increased from 150 m^2 in 2005 to 320 m^2 in 2007 (Figure 32), with each area ranging from 100-400 m^2. New farmers tended to start with a smaller area of Stylo 184 and expanded in subsequent years.

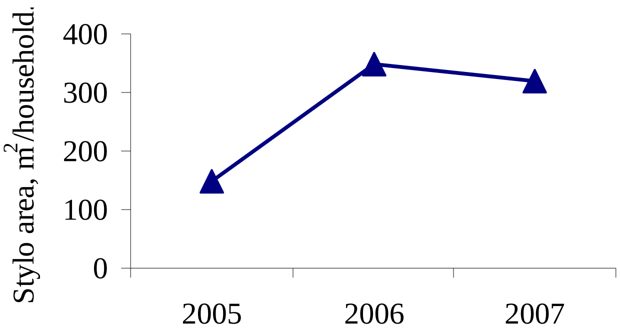

Figure 32. Average size of Stylo plots grown by households (m^2).

Participants at the 2008 annual review and planning meeting were asked to list strength and ideas for improving the alliance model. Cards were used for this activity and these were then grouped into thematic categories. These are presented in Table 35.

Table 35. Strength and weaknesses of the alliance approach

Strengths	How to improve?
▪ Good forum in which to exchange experiences and learn new ways of working with farmers to improve pig production systems.	▪ Need to develop more extension material such as training manuals, posters and leaflets.
▪ Alliance creates a place for discussion and sharing knowledge about problems that occur in different areas and appropriate solutions for overcoming these problems.	▪ Allow more time for discussions and sharing experiences during workshops.
▪ With their new knowledge about working approaches and technical issues, alliance members became more confident in working with farmers.	▪ Need more follow up from mentors.
▪ Working together, helped each team to accomplish tasks and achieve their project targets.	
▪ Alliance members became good friends and formed a network of R&D practitioners.	

Discussion

Research projects working by themselves can only reach a very limited number of end users. This ACIAR-funded project has shown that there were many benefits for researchers, and development practitioners when they worked together and that farmers also benefited from this co-operation. Researchers gained insights into practical issues that emerged during scaling out by NGOs and other development partners. Development practitioners had access to good science, technical information, training, experiences and new ideas. The Lao farmers benefited as Alliance Partners reached many households over a large area of northern Laos in a short time period, and scaling out is set to continue as there are now many development practitioners and organizations with the skills to continue scaling out. Importantly, the development alliance has created an informal network of researchers and development practitioners, who are likely to continue to interact, communicate and support each other.

3.2 Realizing the benefits of cover crop legumes in smallholder crop-livestock systems of the hillsides of Central America

Highlights

- The adoption of the legume *Canavalia brasiliensis* in smallholder mixed crop-livestock systems increases family income when used either as green manure to increase the production of maize and beans or as forage for dry season feeding for milking cows.

- Two field studies were conducted to verify the effect of legume (Canavalia or cowpea) supplementation on milk yield under more controlled conditions of an experimental station. In both studies the low consumption of Canavalia did not result in significantly lower milk yields compared to the cowpea treatments.

- *Canavalia brasiliensis* (Canavalia) showed potential to fix a significant amount of N. Integration of Canavalia increased forage availability and milk production with no negative effect on milk quality. Farmers showed significant interest in integrating Canavalia in their cropping system as a partial substitution to chemical fertilizers, to benefit from increased milk production during the dry season and to recuperate degraded soils.

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Rationale

Soil nutrient depletion is a common problem faced by both subsistence farming and commercial crop production in developing countries and can be attributed to the nutrient removal by agricultural crops, which in general is higher than the amount of nutrients applied to soil. This is a major cause of soil degradation. Research carried out over the past decades has shown significant relationships among soil degradation, food insecurity, and poverty.

The most important animal production system in developing countries is the mixed crop-livestock production system which can be found in Nicaragua as well as other Central American countries, where most farms are small, located in hillside areas undergoing different stages of degradation, and combine livestock production with the planting of subsistence crops such as maize and beans.

Natural pastures are the most important source of feed for livestock but their quality and quantity are seriously limited during the dry season, which lasts from 4 to 6 months, causing shortage of forage leading to under nutrition of animals. Furthermore, because of the problem of forage shortage, producers allow cattle to freely graze the dry vegetation, which leads to the problem of overgrazing—another major source of soil degradation—even worse. On the other hand, milk production significantly decreases during the dry season and, as a result, milk prices increase by 40%-50% as compared with its prices during the rainy season. Improved animal nutrition during the dry season would therefore significantly improve family incomes in these mixed crop-livestock production systems.

In the past, several alternatives have been used to correct forage shortage or deficiencies during the dry season. These have included the use of net energy sources, ranging from forage cane to legumes, the latter contributing protein and complementing energy sources and available forage

grasses. However, the trade-offs in using legumes for animal nutrition versus their use to improve soil quality and, as a result, crop productivity have seldom been analyzed.
This study therefore assesses the economic benefits of: (1) a short-term alternative, which consists of establishing legumes for use as supplement, mixed with crop residues, to increase milk production and farmer incomes during the dry season when milk prices are higher; and (2) a medium-term alternative, which consists of establishing legumes as green manure at the same sites where maize and beans are planted and then incorporate these legumes into the soil to improve its fertility and, accordingly, improve agricultural productivity in subsequent years. This work (Activities 3.5.1 and 3.5.2) is carried out as part of SLP funded project linked to a ZIl-SDC funded project on cover crop legumes.

3.2.1 Legume trade-off analysis: the dilemma of using Canavalia as forage to increase milk production during the dry season or as green manure for soil enhancement to improve the productivity of maize and beans

Contributors: M. Quintero, F. Holmann, R. D. Estrada (CIAT)

Rationale

This study aims to (1) perform an *ex ante* analysis of the expected economic and environmental benefits of using the legume *Canavalia brasiliensis* either as green manure to improve agricultural productivity or as forage to improve milk production during the dry season; and (2) compare these benefits with the subjective perception of producers living in hillside areas of Nicaragua that have mixed maize-beans-livestock production systems regarding these new alternatives.

Material and Methods

Data for this study came from a direct survey interview to 10 smallholder farms using a mixed crop-livestock system in the Pire river watershed in the state of Esteli, in northern Nicaragua. The objective of this survey was to collect information regarding current land use, animal herd inventory, input use, and utilization of family and hired labor, to estimate production costs and and sale of milk, maize, and beans in order to estimate the gross sales and farm net income.

Likewise, the survey also collected information regarding the expectations that farmers had with respect to the use of *Canavalia brasiliensis* in their mixed crop-livestock systems. Expectations were quantified as: (1) the amount of additional milk produced during the dry season required by the farmer to adopt *Canavalia* on his/her farm as dry season fodder; and (2) the amount of fertilizer that farmers could save if they adopt *Canavalia* as green fodder maintaining the current productivity of maize and beans. These expectations are quantified in Table 36.

The *ex ante* trade-off analysis was executed using a simulation model developed by CIAT which uses linear programming to optimize land use under multiple criteria (social, environmental, and economic). Four scenarios were evaluated:

(1) Base line. It is the current farm situation. No adoption of *Canavalia* takes place. The model farm has 17.5 ha of which 14.7 are planted with native pastures and the remaining 2.8 ha planted with maize and beans.

(2) Alternative use 1. *Canavalia* is adopted as green manure to eliminate the use of fertilizer for the production of maize and beans. The simulation model is run assuming the baseline farm adopts *Canavalia* with maize in the same area allocated to maize/bean (i.e., 2.8 ha). Canavalia then is incorporated into the soil.

(3) Alternative use 2. *Canavalia* is adopted as forage for dry season feeding to increase milk production during the dry season. The simulation model is run assuming the baseline farm adopts *Canavalia* and it is planted with maize in the same area allocated to maize/bean (2.8 ha). The difference with Alternative use 1 is that *Canavalia* is not incorporated into the soil but rather, grazed as dry season feeding .

(4) Potential of the system. The simulation model is run without any restrictions. *Canavalia* can be adopted either as green manure or as dry season forage (or both) in any size area of the farm.

Results and discussion

Table 37 contains the main results of the simulation model regarding the four scenarios evaluated.

As shown, Alternative use 1 (*Canavalia* as green manure) increases annual profits by 3%. Income from maize increases by 56%. However, because *Canavalia* is intercroped with beans after the maize harvest, the production of beans is reduced because the planting density has to accommodate the *Canavalia* and therefore, income from beans is reduced by 5% with respect to the baseline farm.

On the contrary, in Alternative 2 (*Canavalia* as forage for milk production), annual profit is increased by 57% eventhough income from maize and beans are reduced by 10% and 22% with respect to the baseline, respectively. The reduction in profits from maize and beans are due because *Canavalia* is intercropped with these two alternatives to produce forage in the same area and therefore, less maize and beans are harvested. The reduction in crop income is compensated by a 273% increase in income from milk. This increase is explained by an increase in milk productivity from 3 to 7 kg/cow/day as well as an increase in stocking rate which allows the farmer to have 3 more additional milking cows (i.e., from 5 to 8 cows). In addition, income from beef is also increased by 92% due to a better feeding of the milking herd during the dry season and therefore, higher weight gains from weaned calves.

In the fourth and last scenario (i.e., potential of the system, Table 37), annual farm income is increased by 200% with respect to the baseline farm. Assuming no restrictions, the optimal solution would be to expand the area planted to maize from 2.8 ha to 6 ha and to beans from 2.8 ha to 8 ha. Because *Canavalia* is intercropped with beans, the area planted to *Canavalia* is also increased, which allows the milking herd inventory to expand from 5 to 11 cows as well as the productivity of milk, which is also increased from 3 kg/cow/day to 7 kg/cow/day.

Conclusions

This is an *ex ante* trade–off analysis where some assumptions had to be made because precise information about some parameters were lacking. Some of these were:

(a) The real contribution of N from Canavalia is still unknown. The authors assumed Canavalia contributed with 278 kg N/ha based on a dry matter biomass production of 4 t/ha with a 20% crude protein content. However, the net use of N by the bean crop or the following maize crop is still unknown or how much of this amount is readily available in the soil. More information is neded to assess the real contribution of Canavalia as a green manure in this system.

(b) The contribution of Canavalia to the productivity of maize or beans assuming there is no application of inorganic fertilizer.

(c) Genetic potential of miking cows. In this study we assumed milking cows could produce 7 kg milk/day, based on the availability of nutrients from Canavalia. However, this may not be the case for cows in the Pire river watershed which have more of a beef producing genotype than milk producing.

Table 36. Reduction in the consumption of fertilizer for the production of maize and beans or increase in the quantity of additional milk during the dry season that producers perceive as necessary for the adoption of the legume *Cannavalia brasiliensis.*

	Amount
Milk production	
• Increase in productivity/cow that justifies the adoption of *Cannavalia* as forage	1.95 (kg/cow/d)
• Value of additional milk productionn	US$ 112.3 (per cow)
Green manure	
• Reduction of fertilizer/ha in maize and beans maintaining the same productivity that justifies the adoption of *Cannavalia*	112 kg NPK 112 kg Urea
• Value of the reduction of fertilizers	US$ 104.2 (per ha)
Preference	
• Producers who prefer to adopt *Canavalia* (%)	
- Only for the production of maize and beans	30
- Only for milk production	20
- For both alternatives	50

Table 37. Annual income, use of labor, and land use obtained in each of the scenarios evaluated.

	Baseline	**Alternative Use 1**	**Alternative Use 2**	**Potential of the system**
Total annual farm income (US$)	5,737	5,909	9,003	17,254
Income from maize	627	979	560	1,171
Income from beans	3,391	3,213	2,638	7,951
Income from milk	1,274	1,274	4,758	6,608
Income from beef	600	600	1,152	1,600
Family labor (days)	150	188	264	399
Hired labor (days)	90	90	90	99
Beans (ha)	3.4	2.8	2.8	8
Maíze	2.8	2.8	2.8	6
C. brasiliensis green manure	----	2.8	----	----
C .brasiliensis animal feed	----	----	3	2
Native pasture	10	10	15	12
Milk production (kg/yr)	4320	4320	16000	22400
Mature cows (#)	5	5	8	11

3.2.2 Evaluate the effects of supplementing legumes on milk yield of cows grazing maize stover under controlled conditions

Contributors: S. Martens (CIAT), C. Lascano (CORPOICA), P. Avila, L. H. Franco, B. Hincapie (CIAT)

Rationale

The aim of this study was to verify the effect of legume supplementation on milk yield under the more controlled conditions of an experimental station and to generate data for conducting trade-off analysis that was described in Activity 3.5.1.

Materials and Methods

Experiments A and B took place in 2008 at the CIAT experimental station Santander de Quilichao, Colombia. Climate data were recorded.

<u>Experiment A:</u>
Three groups of two cows (Holstein x Zebu) with an initial average weight of 429 kg and 182 days of lactation grazed 2 ha of maize stover starting at the end of September 2008. Maize was sown with a seeding rate of 40 kg/ha. Three treatments were applied in a 3x3 latin square design: 1) control with zero supplement, 2) supplemented with cowpea hay, and 3) supplemented with Canavalia hay. The supplementation was at 1 % of liveweight, on DM basis per day and given twice a day at milking time, divided in half. Time of adaptation was 5 days followed by 5 days of measurement.
The animals were weighed at the beginning and at the end of the experiment. The yield of the maize stover, 16.5 weeks old at the beginning of the trial, was estimated for each of the three periods. The nutritional value of the maize stover in terms of crude protein (CP), in-vitro digestibility and fiber (NDF, ADF) was analysed. The amount of hay offered and consumed was recorded to calculate the ratio between the consumption and offer.

<u>Experiment B:</u>
Three groups of two cows (Holstein x Zebu) with an initial average weigth of 424 kg and 153 days of lactation grazed on plots with different forage options in a 3x3 latin square design starting at the end of August 2008: 1) maize stover only (control), 2) maize intercropped with cowpea, 3) maize intercropped with Canavalia. An area of 1 ha each was established at the end of April 2008. The legume-maize fields were sub-divided by 3 for the experiment. Maize was sown at a seeding rate of 40 kg/ha. Canavalia was sown between the maize rows on 13 May, 27 May and 10 June with 20 kg/ha seeding rate, whereas cowpea seeding started on 19 May, followed on 2 June and 16 June with 20 kg/ha. At the beginning of each of the three periods the cowpea was 12 weeks old and Canavalia had 13 weeks. Five days of adaptation were followed by 5 days of measurement. The availability of maize and legumes for each treatment was calculated. Nutritional value of maize stover, cowpea and Canavalia in terms of CP, in-vitro digestibility and fiber (NDF, ADF) was analyzed. In both experiments, the effect of the treatments on the milk yield and milk quality was evaluated by the Ryan-Einot-Gabriel-Welsch Multiple Range test.

Results and discussion

Experiment A:
The final average body weight of the 6 cows was slightly higher than at the beginning of the trial: 435 kg (± 40) vs. 429 kg (± 39). From the offered legume hay, 70% of the cowpea and only 28% of the Canavalia was consumed on average. There was 4583-5988 kg/ha DM maize stover available on the field with a CP content between 5.4-5.9%.

The DM digestibility (in-vitro) ranged from 40-47%. The maize stover had high fiber contents from 81-87% NDF and 51-54% ADF. The cowpea hay had CP contents of 14% on average, the Canavalia hay 16%, while NDF and ADF of cowpea were 60% and 32% and of Canavalia 71% and 47%, respectively. The in-vitro digestibility of cowpea was 72%, of Canavalia 55%. The average milk yield (fat corrected) per cow/day was 6.1 kg in the control, 6.8 kg with cowpea hay supplement and 6.2 kg with Canavalia hay supplement. No statistically significant difference was found (Table 38). The milk fat ranged from 4.0-4.4% and non-fat solids from 7.8-8.1% without significant difference. The milk urea nitrogen, reflecting the protein:energy ratio was from 18.0-19.3 mg/dl still acceptable.

The total rainfall during the trial period was 144 mm.

Experiment B:
The final average body weight of the 6 cows was slightly lower than at the beginning of the trial: 419 kg (± 52) vs. 424 kg (± 54). In the control (1) 3766 kg/ha DM maize stover was available, in 2) 2408 kg/ha DM maize and 667 kg/ha cowpea, in 3) 3026 kg/ha DM maize and 2308 kg/ha DM Canavalia were available. The CP content of the maize stover was similar in all treatments (4.3-4.4%).

However, the in-vitro DM digestibility was lowest in the control (48 %), similar in the maize intercropped with cowpea (52%), and highest in the maize intercropped with Canavalia (71%). The CP content of the legumes was on average 14% of DM in cowpea and 16% of DM in Canavalia. Canavalia had a slightly higher in-vitro digestibility of 71% compared to cowpea with 69%. Fiber contents were 66% NDF in DM in Canavalia and 64% NDF in cowpea, respectively. The field consumption of the legumes was not measured as it was possible in experiment A. However, nearly total consumption of available cowpea was observed in contrast to very little consumption of Canavalia. The milk yields (fat corrected) in kg per cow/day for the treatments were as follows: 6.5 kg control, 8.2 kg with cowpea, 7.5 kg with Canavalia (Table 38).

The milk yields of the legume treatments were significantly higher than the control ($P<0.01$), whereas there was no significant difference between cowpea and Canavalia. The average milk fat content ranged from 4.1-4.6 % and the non-fat solids from 7.7-8.3 % without significant difference. Milk urea nitrogen was lower than in experiment A (16.7-18.5 %). The total rainfall during the trial period was 128 mm.

Table 38. Milk production of the cows grazing maize stover with different supplement

Treatments	Fat corrected milk kg/Cow*day		Fat %	Non-fat solids %	Milk urea nitrogen (MUN) mg/dl
Experiment A	P<0.1904		P<0.3339	P<0.2069	P<0.0414
Maiz Stover	6.09		4.08	7.83	18.02
Stover + Cowpea	6.75		4.02	8.09	19.19
Stover +Canavalia	6.22		4.37	7.88	19.28
Experiment B	P<0.0062		P<0.6789	P<0.3762	P<0.1279
Maiz Stover	6.53	b	4.23	8.25	16.75
Stover + Cowpea	8.24	à	4.10	7.69	16.67
Stover +Canavalia	7.53	à	4.59	7.97	18.50

Conclusions

Even though there was a tendency in the amount of milk yield descending from cowpea > Canavalia > control treatment in experiment A, no significant difference was found. In experiment B the milk yield was significantly higher in the legume treatments compared to the control. The treatments followed the same sequence as in experiment A even though in both cases, crude protein contents of Canavalia were higher than in cowpea. However, in general, the effect was not as pronounced as expected. The consumption of the Canavalia hay in experiment A was very low which might be explained by the low in-vitro digestibility. Low intake was also observed with fresh Canavalia in experiment B, there however the analysed digestibility was even higher than in cowpea. In both experiments the low consumption of Canavalia did not result in significantly lower milk yields compared to the cowpea treatments. The reason for the low consumption of Canavalia is discussed. One assumption is that a longer adaptation period may have increased the intake. The other suggestion is that unkown secondary compounds may have limited higher intake.

3.2.3 Impact of *Canavalia brasiliensis* on biomass availability, milk yield, and milk quality

Contributors: F.L. Humbert (ETH-Zurich), S. Douxchamps (ETH-Zurich), R. Van der Hoek (CIAT), A. Benavidez, M. Mena (INTA-Nicaragua), A. Schmidt, I. Rao (CIAT), S. Bernasconi, E. Frossard and A.Oberson (ETH-Zurich)

Rationale

The objective of this study was to measure the impact of Canavalia into the traditional maize-bean-livestock system either as green manure or as an animal feed in smallholder farms in the watershed of Rio Pire (Condega, Estelí, Nicaragua). This work is carried out as part of ZIL-SDC funded project.

Materials and methods

Four green manure trials and three livestock trials were implemented on smallholder farms in the Rio Pire watershed (Department of Esteli, northern Nicaragua), within a 2 km radius around the community of Santa Teresa (13°18´N, 86°26´W). The altitude ranges from 600 to 900 m.a.s.l. Soils are Udic and Pachic Argiustolls. The climate is classified as tropical wet and dry according to the Köppen-Geiger classification. Annual rainfall is 800 to 1000 mm, primarily during two successive seasons between June and November.

Green manure trials

The main objective was to set up a soil surface N budget at plot level in farmers' fields for the traditional maize/bean (M/B) rotation and compare it to the maize/Canavalia (M/C) rotation. Emphasis was put on the N output through crop harvest and input through N_2 fixation of Canavalia and beans.

Four farmers from Santa Teresa were identified, who were interested in integrating Canavalia in a part of their production area. Their land was distributed at different altitudes across the landscape.

For the first year of cropping (2007-2008), we assessed the soil surface N budget of M/B rotation and compared it with the budget of M/C rotation, with different cutting intensities of above ground biomass of Canavalia to simulate grazing. Nitrogen input variables were mineral fertilizer N, N input with seeds and symbiotic N_2-fixation that was estimated using the natural abundance method. The estimation of N output from the system was based on N removed with harvested parts of maize, bean and Canavalia.

Livestock trials

At three farms two plots of 0.35 ha were planted with maize during the first rainy season and either beans (treatment 1, control) or Canavalia (treatment 2) during the second rainy season. After the maize harvest (Nov/Dec) lactating cows entered the maize fields and grazed first the plots with the maize stover (and weeds/legumes) followed by the maize plots with Canavalia. Each treatment lasted eight days. Biomass, and milk production and quality were measured.

The data were analysed based on a cross-over design (with three groups of 3-5 cows (total 11) rotating between the two treatments). Each treatment had a duration of eight days, of which four days of adaptation and four days of data collection.

Results and discussion

Green manure trials

Canavalia fixed between 15 to 38 kg N ha^{-1} while common bean fixed 10 kg N ha^{-1} on average during crop season. Fixation by common bean was low due to its low biomass production. Farmers applied between 38 and 60 kg N ha^{-1} in the form of mineral fertilizers, while N contained in seed represented only between 1 and 4 kg N ha^{-1}. The highest N outflow occurred with harvest of maize, with an average of 43 kg N ha^{-1}. The nitrogen output by the beans remained under 10 kg ha^{-1} due to low yields. The different proportions of removal of Canavalia biomass had marked impact on the N balance (Figure 33): on average, when 0% of Canavalia was removed from the field, N surplus was 31 kg N ha^{-1}. In contrast, complete removal of Canavalia biomass led to an N deficit of 10 kg ha^{-1}. Under M/B rotation, the N remained more or less balanced with an average N surplus of 10 kg N ha^{-1}.

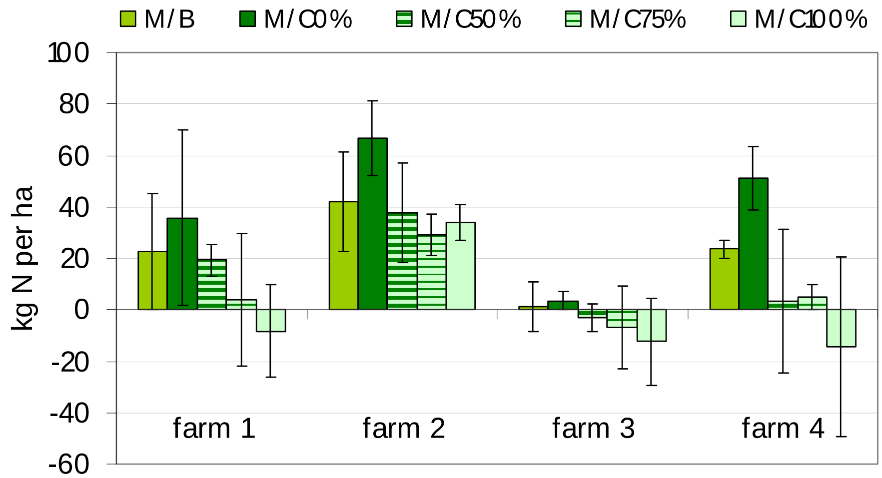

Figure 33. N balance for each crop rotation in farmer's fields. M/B, maize/bean; M/C0%, maize/Canavalia with no removal, M/C50%, maize/Canavalia with 50% removal; M/C75%, maize/Canavalia with 75% removal; M/C100%, maize/Canavalia with 100% removal of biomass during the dry season.

Soil samples from the on-farm trials were analyzed at CIAT headquarters for soil physical measurements including water retention curves, water stable aggregates and saturated hydraulic conductivity. Results showed no significant effect of Canavalia on soil physical properties after one season of cultivation.

An in-depth on-station study is on-going to assess the effects of Canavalia on soil N processes, on the yield of the subsequent maize crop and on the recovery of Canavalia derived N in succeeding crops and the soil using direct and indirect ^{15}N-labelling techniques.

Livestock trials
Planting of *C. brasiliensis* increased average biomass availability with 3 t/ha and resulted in a significantly higher milk production ($p<0.01$). No effect was found on milk quality. Due to differences in lactation stage, differences between farmers (Juan Rodriguez, Felipe Calderon, Marcia Rui) were considerable (Table 39, Figures. 34 and 35).

Table 39. Biomass availability, milk production and milk quality, Santa Teresa, 2008 (data based on three farmers).

	Total DM yield (t/ha)	Milk production (lt/cow/day) (n=11)	Fat (%) (n=11)	Protein (%) (n=11)	Lactose (%) (n=11)	Total non-fat solids (%) (n=11)
Maize residues and weeds (control)	4.8	2.98^{a}	4.00^{a}	3.21^{a}	4.81^{a}	8.77^{a}
Maize residues, weeds and *C. brasiliensis*	8.1	3.83^{b}	4.05^{a}	3.13^{a}	4.66^{a}	8.51^{a}

within columns different superscript letters (ab) denote significant differences ($p<0.01$)

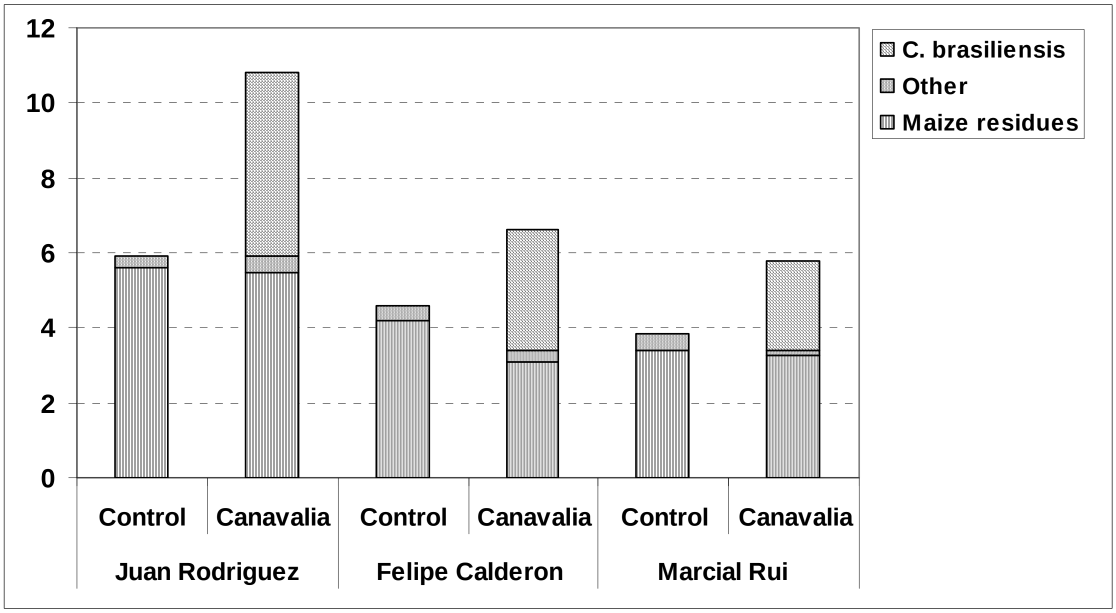

Figure 34. Biomass availability (t DM/ha) of plots without and with *Canavalia brasiliensis* on three farms (Juan Rodriguez, Felipe Calderon, Marcial Ruiz) in Santa Teresa (dry season, 2008).

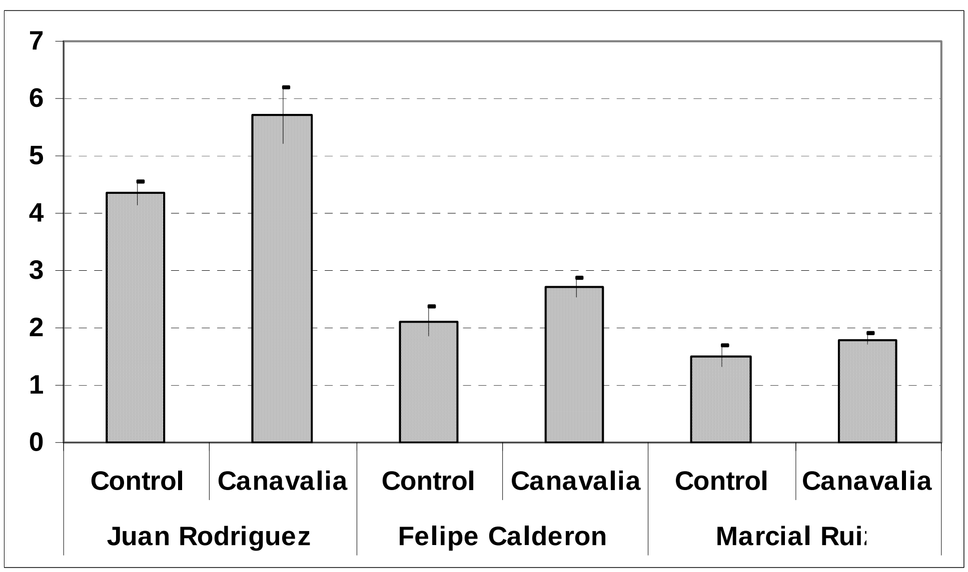

Figure 35. The effect of *Canavalia brasiliensis* on milk production (kg/cow/day) on three farms (Juan Rodriguez, Felipe Calderon, Marcia Ruiz) in Santa Teresa (dry season 2008, error bars indicate standard error of mean)

Conclusions

Canavalia shows potential to fix a significant amount of N. However, when completely removed for utilization as forage, it bears the risk of soil N depletion unless N would be recycled to the plot by animal manure. Without N mineral fertilizer, the N budget would become negative even if Canavalia is left on the field as green manure. Canavalia increased available biomass and augmented milk production in the dry season. This year the effect was even stronger than what was observed last year and farmers showed a clear interest in continuing with this new dry season forage/green manure legume technology. The focus for the coming year will therefore be on validation trials and on seed production with strong farmer involvement in the region, with a leading role for the national agricultural research institute, INTA-Nicaragua.

3.3 On-farm evaluation of forage options in Meseta de Popayán y Cuenca del Valle del Patía, Cauca, Colombia.

Contributors: N. Vivas, S. Morales (U. del Cauca), M. Peters, L. A. Hernández, L. H. Franco, B. Hincapié (CIAT), Fondo Ganadero del Cauca and Farmer groups

Rationale

The watershed of the Valle del Patía and the Meseta de Popayán, Cauca, Colombia is an important livestock area for both beef and milk production. However, forage options available to producers are few, mainly reduced to native or degraded pastures based on Angleton (*Dichanthium aristatum*), Puntero (*Hyparrhenia rufa*), *Brachiaria decumbens* and Guinea (*Panicum maximum*) limiting livestock productivity. Supported by funding from the Ministerio de Agricultura, Colombia and through collaboration under the lead of the Universidad del Cauca, new forage technologies are introduced and evaluated using a participatory approach working with small and medium sized livestock producers.

Materials and Methods

The new forage technologies tested include germplasm options, forage conservation technologies and modules on forage utilization. Using a participatory process adaptation, innovation and adoption is facilitated; capacity building, a farmers, technicians and University level is an integral component to ensure scaling and sustainability. The main collaborators are the livestock producer groups, the Universidad del Cauca, UMATAS and the Fondo Ganadero del Cauca.

The project was commenced in mid 2008 with the socialization of the work to be carried out under the project “Aumento de la Productividad, Competitividad y Sostenibilidad de Pequeños y Medianos Productores de Carne en la Cuenca del Patía y Meseta de Popayán”, with both producers and institutions directly and indirectly involved participating. This was followed by a selection of farm locations for trial and demonstration purposes (Photo 16). The sites in the Meseta de Popayán range from 1700 to 1940 a.s.l, characterized by 1900 mm annual rainfall and a average temperatures of 17.5 º C; the Valle del Patía is located at 600 a 650 a.s.l., with 1318-1960 mm annual rainfall and a temperature of 26 º C; the sites in Mercaderes are located at altitudes between 1150 and 1200 a.s.l., with 1375-1535 mm annual rainfall and average temperatures of 23 º C (Photo 17).

Photo 16. Socialization of the Project

Photo 17. Livestock production systems in the Meseta de Popayán and the Valle del Patía

Participatory diagnosis

In each of the locations a rapid participatory diagnosis was carried out, to further characterize the production systems and identify opportunities and constraints in the production systems.

Farmer evaluations

To enhance interaction with producers, collaborators in the project were trained in participatory research methodologies for the selection of forages using a "Training to Trainer" model (Photo 18). The training had two functions, to improve skills in participatory evaluation and linked to this, increasing awareness and understanding of farmer's criteria. A total of 20 partners were trained in the following techniques: Collective Construction of Knowledge (CCK), Flowchart-technique for planning, and communication skills for conducting evaluations, criteria definition, and farmer selection using ranking and open ended evaluation techniques. The theoretical training was immediately followed by 'real live' evaluation with farmers, thus initiating the continuous evaluation process (Photos 19).


Photo 18. “Training to Trainer” model at Cauca- University (Facilitator: Luis A Hernández R)

The following forage options are being evaluated

Legumes: *Lablab purpureus* CIAT 22759, *Vigna unguiculata* 9611, *Canavalia brasiliensis* CIAT 17009, *Arachis pintoi* CIAT 22160, *Clitoria ternatea* CIAT 20692, *Desmodium heterocarpon* CIAT 13651, *Centrosema molle* CIAT 15160, *Stylosanthes guianensis* CIAT 11995, *Centrosema brasilianum* CIAT 5234, *Cratylia argentea* CIAT 18516 and *Leucaena leucocephala* 17262

Grasses: *Brachiaria* hybrid cv. Mulato II, *Brachiaria humidicola* CIAT 26159,), *B. humidicola* CIAT 16866, *B. humidicola* CIAT 16888, *Brachiaria brizantha* CIAT 26110 cv. Toledo, *Panicum maximum* CIAT 6962 cv. Mombaza, *Panicum maximum* CIAT 16031 cv. Tanzania, *Panicum maximum* (mix of different materials)


Photos 19. Participatory evaluation of forage options at the “El Limonar”, El Estrecho Patía Valley (December/2009).

To allow overall comparison, evaluations were being combined across the criteria by using a suitable weighted index. The weights were based on the following criteria that at least one farmer had considered to be important, i.e., cover, production, growth, germination, color, pest tolerance and precocity

Table 40 shows the number of farmers spontaneously stating each criterion as being important their evaluations.

Table 40. Farmers' criteria for selecting legumes

Legumes	Frequency of the criteria
Cover	6 (86%)
Production	5 (71%)
Growth	5 (71%)
Germination	4 (57%)
Color	3 (43%)
Pest tolerance	2 (28%)
Precocity	1 (14%)
Total number of farmers	7 (100%)

Thus, results indicate that in the assessment of legumes made by farmers, cover was the most important criterion across the eleven legumes alternative, followed by production and growth. Accordingly, species selection in this phase is defined by indicators for establishment (growth, germination and precocity), stability (pest tolerance) and persistence (production, color as indicator for a healthy plant).

A similar process was carried out for grasses, identifying the following criteria: competitiveness, foliage, cover, color, re-growth capacity and reproduction.

Competitiveness was the most important criterion across the eight grass options, followed by foliage and cover (Table 41).

Table 41. Farmers' criteria for selecting grasses

Grasses	Frequency of the criteria
Competitiveness	7 (100%)
Foliage	6 (86 %)
Cover	5 (71%)
Color	4 (57%)
Re-growth capacity Color	3 (43%)
Reproduction	1 (14%)
Total number of farmers	7 (100%)

Trials

Six nurseries with multipurpose forage options including 19 legumes and grass options were planted, in addition eight multilocational trials for the species *Desmodium velutinum*, *Lablab purpureus*, *Canavalia brasiliensis* and Leucaena *diversifolia* were established in eight locations. These are complemented by agrosilvopastoral trials in the valle del Patía and the la meseta de Popayán (Photo 20).

The trials will be utilized for the participatory evaluations in the way described above, with the aim to facilitate farmer selection for adaptation, innovation and adoption.

Photo 20. Planting of trials en el Valle del Patía

Farmer training

The trials and farmer selection is accompanied by a range of training events (both theoretical and practical) directed at farmers, technicians and University students, addressing establishment, agronomic evaluation, pasture management and forage conservation (Photo 21 and Photo 22).

Photo 21. Training of technicians, students and farmers in agronomic evaluation and pasture establishment

Photo 22. Training in forage conservation technologies for technicians, students and producers

3.4 Restoring degraded grasslands

Highlight

- Restoring degraded pastures allows a progressive increase in soil carbon accumulation which in turn results in significant improvement in several indicators of soil quality. An on-going project in the savannas of the humid Caribbean region of Colombia on restoring degraded pastures contributed to reduce greenhouse gases emissions that in principle could be sold in the markets through clean development mechanisms (CDM) as specified in the Kyoto Protocol.

3.4.1 Restoring degraded grasslands: an option for improving the competitiveness and sustainability of beef production systems in the savannas of the humid Caribbean region of Colombia

Contributors: M. P. Hurtado, J. H. Galvis, A. Alvarez, H. Mina, M. A. Rondón, I. Rao (CIAT); Y. S. Cajas, E. Amézquita, C. Lascano (CORPOICA)

Rationale

In Latin America, beef production in Colombia is only exceeded by Brazil, Argentina and Mexico. In Colombia, milk production represents 26% of national agricultural production, 62% of livestock production and these two systems in conjunction generate about 950,000 direct jobs. In spite of its importance to Colombia, livestock production in the Caribbean region is facing constraints that affect the competitiveness and sustainability of the system. Caribbean livestock activities are being carried out in areas with serious degradation processes in soils and pastures, which decrease carbon sequestration rates, biodiversity and pasture and animal productivity. Although having clear advantages for its geographical position, proximity to ports and reduced transport costs, its exports of meat are affected by pasture degradation. Restoration of degraded grasslands is a strategy that provides opportunities for increasing beef production in the departments of Córdoba, Sucre and Atlántico to improve their profitability and competitive position in foreign markets within the context of new scenarios of international agreements on free trade. At the same time, it also improves environmental services to the region. About 30% of the grassland area is in marginal areas that are not suitable for livestock production due to waterlogging and other constraints and about 70% is used with native pastures or to introduced or adapted forage species of low productivity and quality, especially during the dry season. The degradation of pastures is related to non-sustainable practices, establishment in zones that do not have capacity and/or the suitability, use of poorly adapted species, overgrazing and soil degradation due to compaction and nutrient depletion. Pasture and soil degradation has serious consequences to the producer, reducing the animal production and increasing the costs of livestock production. Therefore, the objective of this study was to estimate the magnitude of pasture degradation and overgrazing and evaluate their impact on beef production to implement technologies that allow the restoration of degraded pastures in the savannas of Córdoba, Sucre and Atlántico. This project is financed by the Colombian Ministry of Agriculture and Rural Development and has the partnership of CORPOICA, CIAT, CARSUCRE, GANACOR, FEGASUCRE and CVS.

Materials and Methods

The study area is located in the Caribbean region in the departments of Córdoba, Sucre and Atlantic with an area of approximately 1.09 million hectares characterized by the dual purpose livestock systems which contribute to 40% of the national beef production. Soil sampling was performed in 4 farms in each department. In each one of the selected farms, an area of well-managed pasture with no signs of degradation was used as a control. Two soil samplings were made: first as the baseline and then one year after implementing new practices of soil management. Depending on the level of compaction in the soil, different tillage treatments were implemented in each farm which included the use of chisel, rake, disc plow, rome and subsoiler. The following improved forage grass options were planted in the farms : *Brachiaria brizantha* cv. Toledo, *Dichanthium annulatum* ('Angleton'), *Panicum maximum* cv. Tanzania and Colosuana (Sucre), *Panicum maximum* cv. Tanzania (Atlántico), *Brachiaria brizantha* cv. Toledo and *Brachiaria decumbens* (Córdoba). Soils were fertilized (kg ha^{-1}) with: 15 N, 15 P, 15 K and ammonium sulfate was used as nitrogen source.

Soil C stocks: In each one of the 12 farms, three soil pits (0.5x0.5x1m) were opened in a baseline study and after one year with change in soil management: pits were located at three positions across each plot, upper part, medium and lower part of the farm. In each pit, soil samples were collected at five depths (0-5, 5-10, 10-20, 20-30 and 30-40 cm) to measure bulk density and determine total carbon stocks in soils. Soils were analyzed using CHN analyzers to measure total carbon.

Soil physical parameters: At the time of soil sampling, soil physical characteristics were evaluated in situ by measuring resistance to penetration in the soil profile using a penetrograph and soil shear strength (torcometer). Samples were collected for bulk and particle density determinations measuring saturated hydraulic conductivity, air permeability, resistance to compaction, and water retention characteristics. As physical conditions determine how water can be stored and move into the soil profile, a good understanding of the behavior of the soil physical characteristics in soil profile in relation to water fluxes will allow to define if there are possibilities of contamination with elements coming from fertilizers or not. Since soil physical characteristics also determine the hydrological response of the soil in relation to rainfall, they will allow to understand the relationship between rainfall and rainfall acceptance capacity of the soils, runoff production as well as the vulnerability of soils to erosion.

Greenhouse gas fluxes: Fluxes of methane (CH_4) and nitrous oxide (N_2O), the two most important greenhouse gases (GHG) related to land use change and agricultural activities were monitored over one year period to follow at least a full cycle of climatic variations using the static chamber technique. Air samplings were done in three farms in each department and in each soil tillage treatment four replicate sampling points were selected and geo-referenced. Four circular

PCV collars were permanently installed at the beginning of the field study in each experimental unit. Prior to each gas sampling, cylindrical PVC chambers (0.03 m^2, 10 cm height) were clamped and air-tightly sealed to the collars. Air samples were then collected from each chamber at 0, 10, 20 and 30 min after chamber installation using 20 mL disposable syringes fitted with plastic stopcocks (Cole Palmer Instruments Co.). Samples were analyzed for N_2O on a gas chromatograph equipped with an electron capture detector (ECD). Nitrous oxide flux was determined from concentration plotted against time. The change in volumetric concentration was converted to a mass flux by using the ideal gas law, taking into account recorded changes in temperature within the chamber over the sampling interval.

Results and Discussion

In Figures 36, 37 and 38, data on total soil carbon (0 to 40 cm) in farms of Córdoba, Atlántico and Sucre are presented for both soil samplings. The results showed a tendency to increase the levels of soil C after one year of the application of different tillage treatments, application of fertilizer and introduction of different types of grass in farms of three departments. Changes in agricultural practices for the purpose of increasing soil organic carbon (SOC) must either increase organic matter inputs to the soil, decrease decomposition of soil organic matter and oxidation of SOC, or a combination thereof. It is widely accepted that substantial amounts of carbon can be sequestered in agricultural soils by changing tillage practices from conventional plowing to less intensive methods, generally known as conservation tillage. Recuperated pastures (soil sampling in 2008) showed that the level of total soil C higher than that of degraded pastures (soil sampling Baseline-2007). Total soil carbon (0 to 40 cm) of recuperated pastures ranged between 52.44 t C ha^{-1} and 157.58 t C ha^{-1}. Also, degraded pastures showed levels from 27.30 t C ha^{-1} to 87.75 t C ha^{-1}. However, the high increase in soil C observed in some farms may be due to spatial variability rather than due to restoration of the degraded pasture.

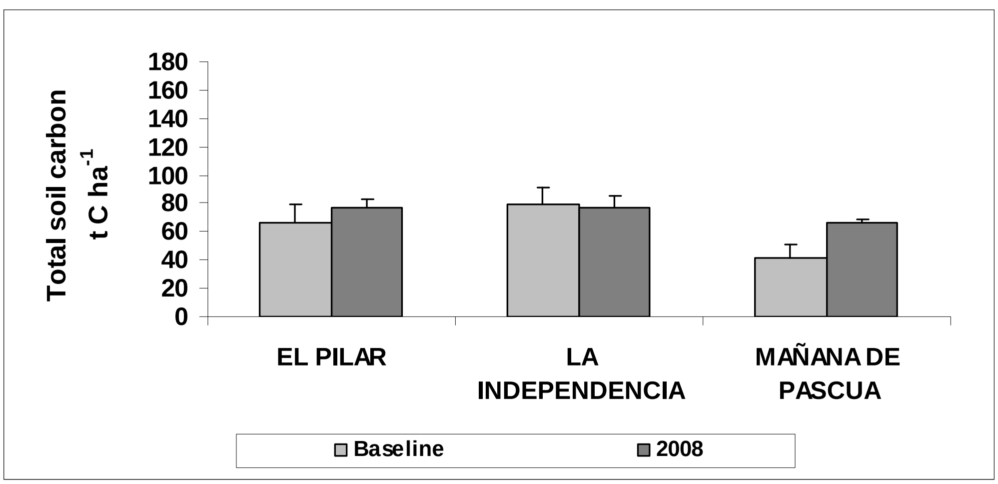

Figure 36. Differences in total soil carbon (0 to 40 cm) in three farms (El Pilar, La Independencia, Mañana de Pascua) of department of Córdoba.

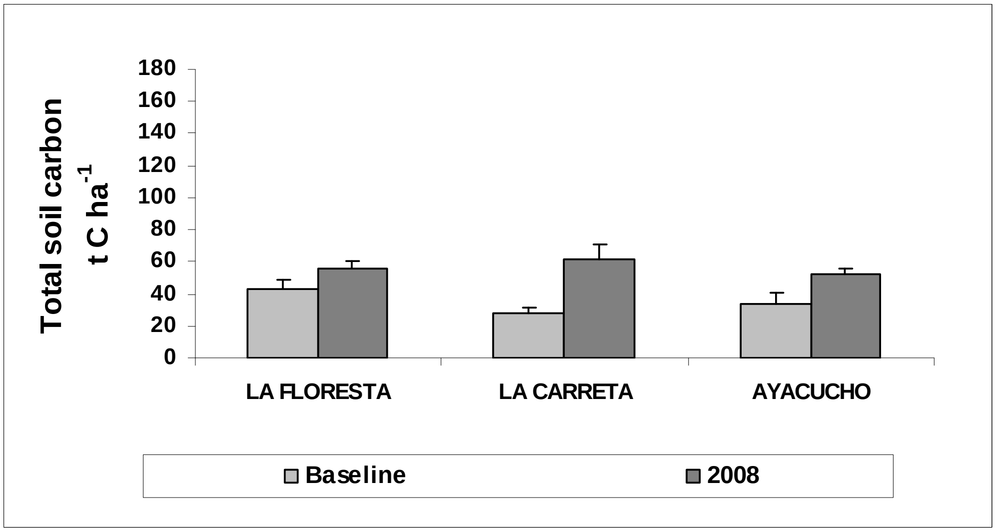

Figure 37. Differences in total soil carbon (0 to 40 cm) in three farms (La Floresta, La Carreta, Ayacucho) of the department of Atlántico.

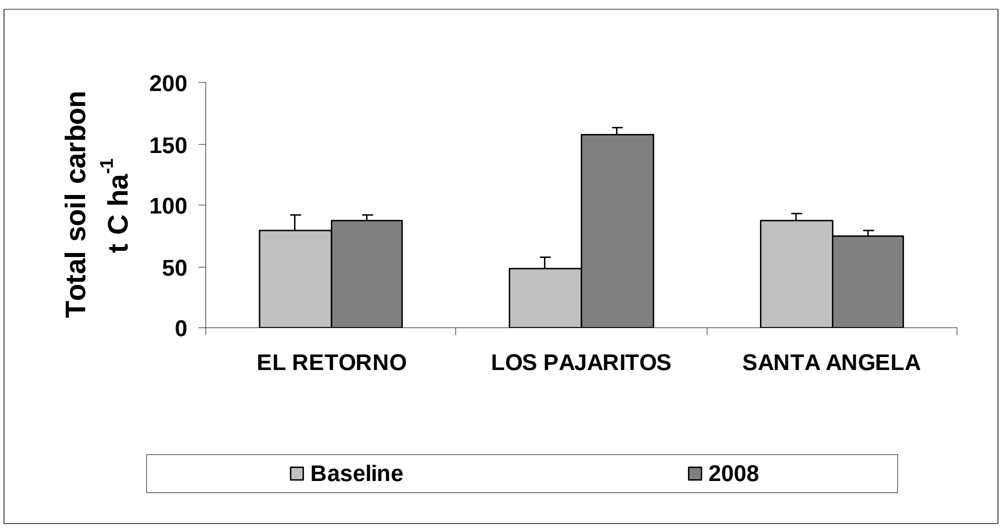

Figure 38. Differences in total soil carbon (0 to 40 cm) in three farms (El Retorno, Los Pajaritos, Santa Angela) of the department of Sucre.

Results presented in Figures 39, 40 and 41 indicate that recuperated pastures of three departments exhibited lower net fluxes of CH_4 than degraded pastures, which were of -23.03 µg CH_4 m^{-2} $h^{-1,}$ and 66.69 µg CH_4 m^{-2} h^{-1} for the Independencia farm (Córdoba) and Ayacucho farm (Atlántico), respectively. These results were obtained from measurements during March 2008.

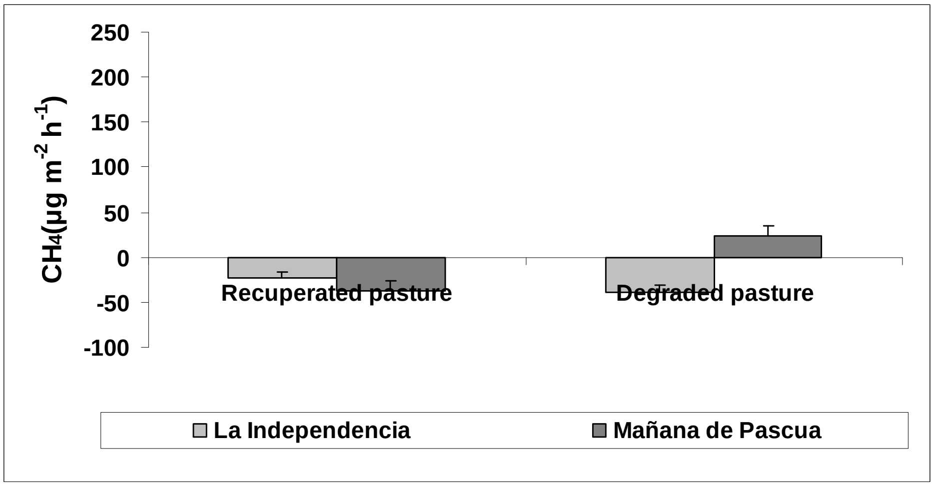

Figure 39. Net fluxes of methane during March 2008 in two farms (La Independencia, Mañana de Pascua) of department of Córdoba.

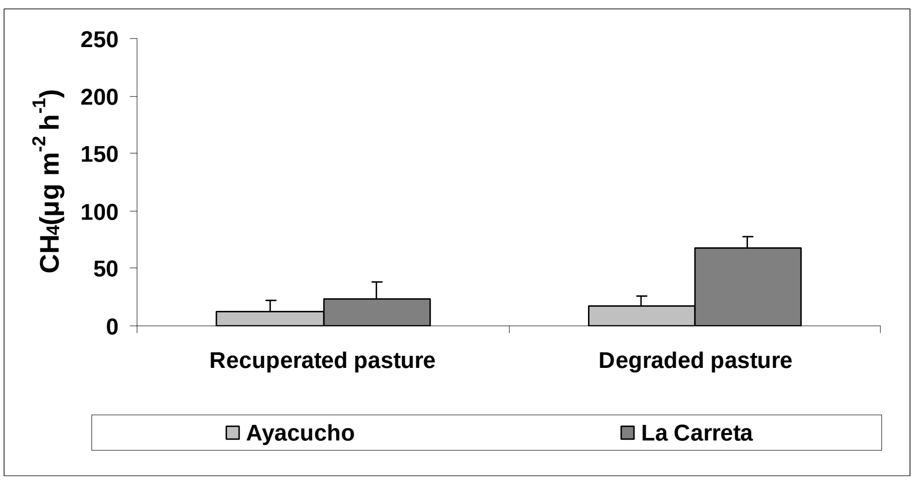

Figure 40. Net fluxes of methane during March 2008 in two farms (Ayacucho, La Carreta) of the department of Atlántico.

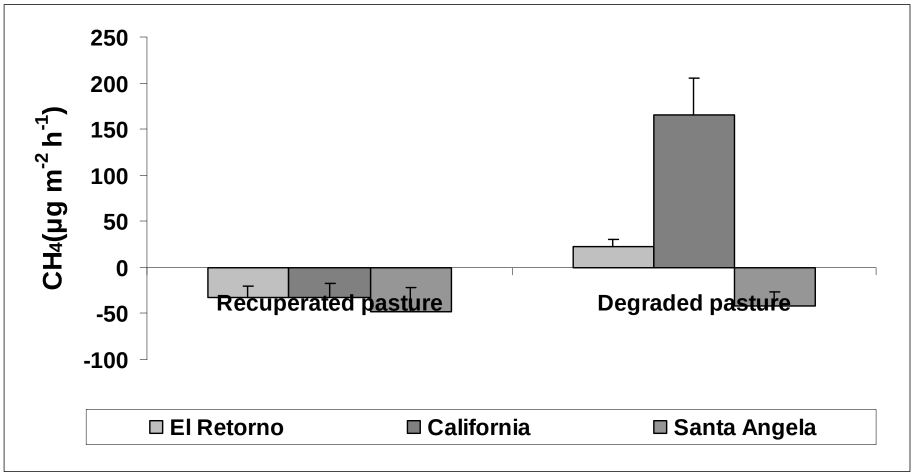

Figure 41. Net fluxes of methane during March 2008 in three farms (El Retorno, California, Santa Angela) of the department of Sucre.

Results presented in Figures 42, 43 and 44 from farms of Córdoba showed greater net fluxes of N_2O (297.04 µg m^{-2} h^{-1}) in contrast to farms of Atlántico (29.15 µg m^{-2} h^{-1}). Fertilization of pastures created favorable conditions for both C storage and N_2O release via nitrification and denitrification by soil microbes, N_2O emissions from these highly managed ecosystems are poorly constrained. Some researchers suggest that the Global Warming Potential (GWP) associated with N_2O emissions approximately offsets the effect of C storage in these ecosystems.

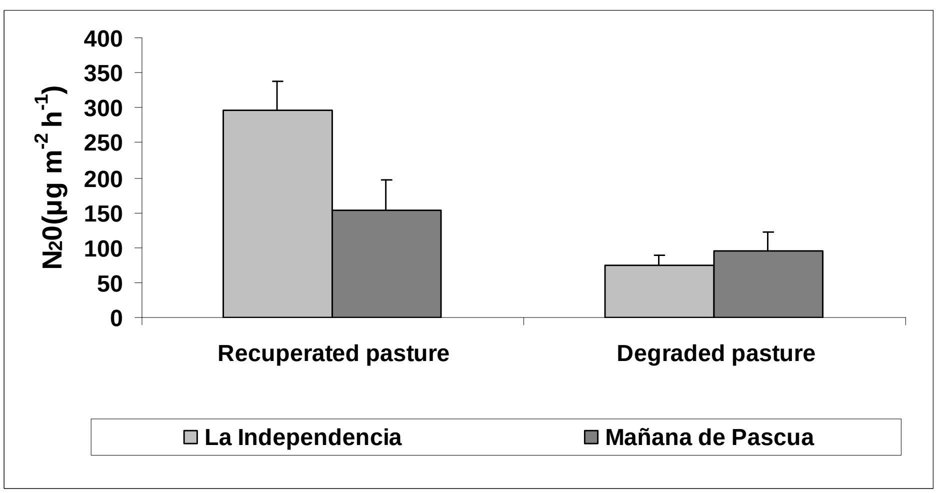

Figure 42. Net fluxes of nitrous oxide during March 2008 in two farms (La Independencia, Mañana de Pascua) of the department of Córdoba.

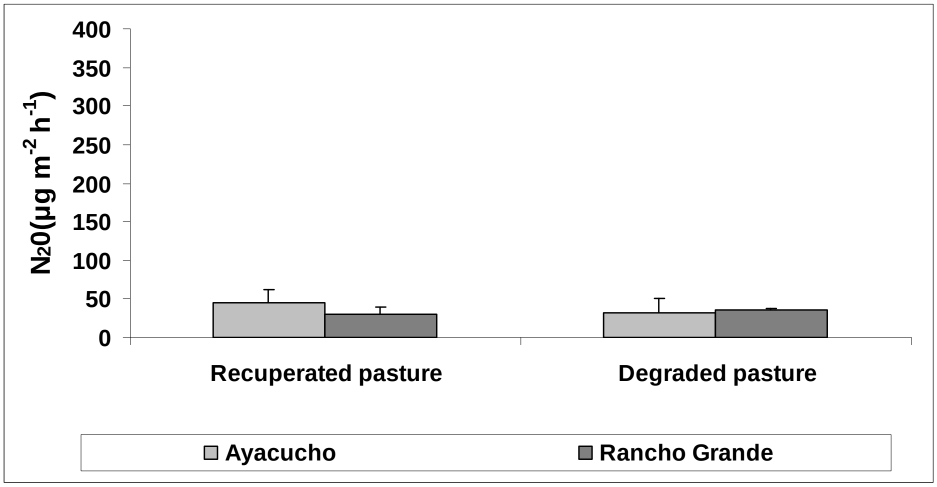

Figure 43. Net fluxes of nitrous oxide during March 2008 in two farms (Ayacucho, Rancho Grande) of department of Atlántico.

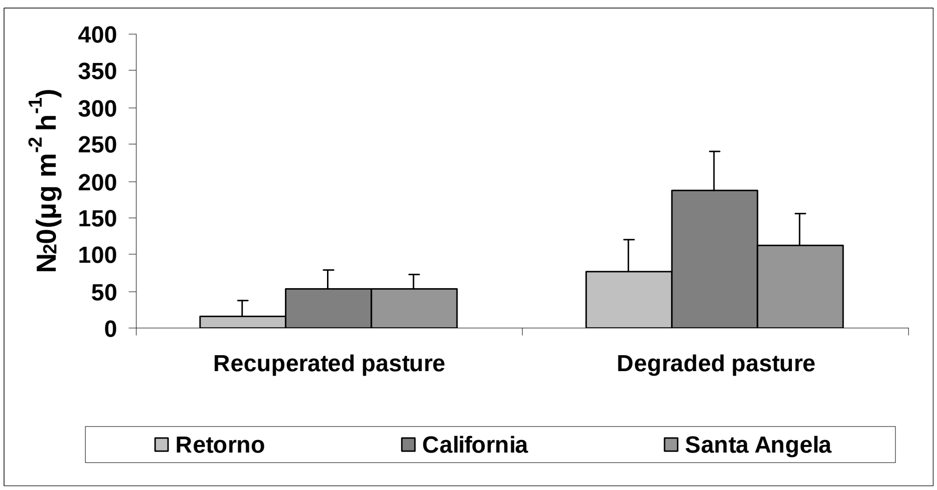

Figure 44. Net fluxes of nitrous oxide during March 2008 in three farms (El Retorno, California, Santa Angela) of the department of Sucre.

Conclusions

Changes in agricultural management can increase or decrease SOC. Optimizing agricultural management for accumulation of SOC can result in the sequestration of atmospheric CO_2, thereby partially mitigating the current increase in atmospheric CO_2. In addition to the environmental benefits of soil C sequestration, consideration has also been given to the implementation of a C credit trading system which may provide economic incentives for C sequestration initiatives. These practices include, but are not limited to, reducing tillage intensity, decreasing or ceasing the fallow period, using a winter cover crop, changing from monoculture to rotation cropping, or altering soil inputs to increase primary production (e.g., fertilizers, pesticides, and irrigation).

Implementing practices that sequester C can reverse the loss of SOC that may have occurred under intensive cultivation thereby increasing SOC to a new equilibrium. Improved pastures are known as accumulators of large amounts of carbon in the soil. Restoring degraded pastures allows a progressive increase in soil carbon accumulation which in turn results in significant improvement in several indicators of soil quality (moisture retention, aeration, and populations of meso and micro-biodiversity, nutrient recycling, reduced soil erosion, etc). Projects on restoring degraded pastures contribute to reduce greenhouse gases emissions that could in principle be sold in the markets through clean development mechanisms (CDM) of the Kyoto Protocol.

3.4.2 Recovering degraded pastures: Cost-benefit analysis from the perspective of livestock producers and technical staff in the Colombian departments of Atlántico, Córdoba, and Sucre

Highlights

- The department presenting the most serious problems of degradation is Atlántico, with the highest proportion of severely degraded pastures (40%) followed by the Department of Sucre, which presents between 33%-38% severely degraded pastures

- Recuperating severely degraded pastures would increase milk production by 57% (i.e., 738 million additional liters of milk per year) with the same number of cows and the same areas under pastures, generating an additional income of US$ 200 million per year.

Contributors: F. Holmann (CIAT), Y.S. Cajas (CORPOICA), Y. Abuabara, W. Barragán, M. Santana, B. Panza, M.M. Muñoz, and G. Ramírez

Rationale

A widespread phenomenon in tropical Latin America is the progressive displacement of livestock production toward marginal areas with lower productive capacity. The low availability of adapted, high-yielding forage materials, together with deficient pasture management, has led to a fast deterioration in livestock productivity and income derived from this activity. This phenomenon has been documented in the cases of Brazil, where livestock production moved from southern states toward the central-west part of the country; Colombia, where it moved from the northern coast region and inter-Andean valleys toward the Orinoquía and Amazon region; and Central America, where it moved from the fertile Pacific region toward the Atlantic coast.

The degradation process

Land degradation is usually defined as the temporary or permanent reduction in the land's productive capacity in a given agro-ecosystem. In the developing world, Latin America ranks highest in extent of degraded areas. In the case of pastures, this degradation process is related to: (1) the establishment of pastures on fragile lands (i.e., hillside areas); (2) the planting of poorly adapted pastures; (3) overgrazing during the rainy season; (4) uncontrolled and frequent burning of pastures; and (5) nutrient depletion. Pasture degradation has serious consequences for the livestock producer: first, it reduces animal production yields and, second, it increases costs.

Once the improved pasture is established, nitrogen deficiency is the first factor that destabilizes the pasture and triggers the beginning of degradation. Once nitrogen deficiency appears, pasture

quality and vigor begin to decline and biological activity falls sharply. Subsequently, deficiencies of other nutrients, such as phosphorus and sulfur, can appear. When the pasture begins to lose vigor, weeds begin to invade the area, making the problem even worse.
After a prolonged period of pasture use, significant changes may occur in the physical structure of the soil, for example in its degree of compaction, which increases soil runoff. Root development may decrease and nutrients are extracted at greater soil depth. Furthermore, soil compaction allows water to run along the surface dragging particles and materials in deposit, thus initiating a process of erosion. As a result, the pasture enters a process of severe degradation.

Subjective perception can be the most viable and perhaps only source of information to estimate the returns or economic losses of complex processes, especially in tropical environments. Producers have the necessary information and make decisions based on their experiences, knowledge, and accessible literature. As a result, it is important to know how livestock producers and the technical staff working with these producers perceive the process of pasture degradation and how it relates to animal productivity to define actions and prepare strategies to recover degraded pastures before they expand considerably.

There are three advantages to using producers' perspective to estimate the level of degradation and its effect on loss of animal productivity: (1) measures are more realistic regarding current degradation processes at the field level; (2) evaluations use an integrated vision of the end user—the livestock producer; and (3) results provide a much more practical viewpoint as compared with the type of interventions accepted by the academic community or consultants.

Objectives

The study covered three departments located along the northern coast of Colombia and aimed to: (a) estimate the milk and meat production of cows grazing pastures suffering different levels of degradation; (b) estimate losses in income as a result of degradation; (c) estimate the proportion of pastures at each level of degradation in the three departments; and (d) identify different strategies to recover degraded pastures and the costs involved.

Materials and methods

Data came from two surveys conducted during three workshops held in August and September of 2008 in the municipalities of Sincelejo (Department of Sucre), Sabana Larga (Department of Atlántico), and Montería (Department of Córdoba). To gather subjective perceptions, in Sucre 15 livestock producers and 7 technical staff members were interviewed; in Atlántico, 9 livestock producers and 6 technical staff members; and in Córdoba, 11 livestock producers and 7 technical staff members. Based on the information gathered, the losses in animal productivity were estimated at the farm level as well as at the departmental level. A 4-level gradient of pasture degradation was defined, where level 1 corresponds to no apparent degradation and level 4 to severe degradation. Regressions were generated based on subjective and descriptive information to better explain the loss in animal productivity at each level of pasture degradation.

Results

The department presenting the most serious problems of degradation is Atlántico, with the highest proportion of severely degraded pastures (level 4, >40%) as well as the lowest area of pastureland with no apparent signs of degradation (level 1, <15%). Atlántico is followed by the Department of Sucre, which presents between 33%-38% severely degraded pastures. Both livestock producers and technical staff agreed with these perceptions.

In the case of the Department of Córdoba, however, replies were highly contrasting. According to livestock producers, Córdoba does not present serious problems of degradation, ranking more than 20% of the pastureland as level 1 and indicating that less than 24% of the pastures were severely degraded. However, according to the technical staff surveyed, Córdoba is the department with highest level of severely degraded pastureland (43%) and the lowest area of pastureland not presenting degradation (level 1, 10.4%).

If the public and private sectors implement a joint strategy that would allow livestock producers to maintain their paddocks at levels 1, 2, and 3 of degradation (in other words, not allowing paddocks to reach level 4 or severe degradation), livestock producers opine that the milk production of the three departments could increase by 57-96% (i.e., 738 million additional liters of milk per year) with the same number of cows and the same areas under pastures, generating an additional income of US$ 200 million per year. According to technicians, this same scenario would allow the three departments to produce 140% more milk and generate an additional income equivalent to US$ 408 million per year. In the case of meat production, these three departments of Colombian's Caribbean region could, according to livestock producers, increase animal weight gains equivalent to 65% slaughter weight in these departments, which would represent an income for producers of US$219 million per year. Technical staff are even more optimistic and consider that these three departments could increase animal weight gains equivalent to 137% slaughter weight in these departments if producers recover the degraded areas that are now level 4, representing an additional income of US$ 464 million per year.

To recover a level-4 pasture to level 1 costs, on average, between US$ 272 and US$ 322/hectare for livestock producers and takes between 3.0 and 4.9 months until it is fully recovered. Technical staff consider that it costs, on average, between US$ 205 and US$240/hectare and between 4.5 and 5.5 months for full recovery.

On average, livestock producers perceive that grasses proportionately take the same time going from level 1 to 2 (2.5 years) and from level 2 to 3 (2.5 years), but more time to go from level 3 to 4 (2.9 years). Producers also perceive that the average useful life of grasses is approximately 7.9 years, ranging from 5.3 years for Colosuana (*Botriochloa pertusa*) in Sucre to 10.25 years for Tanzania grass (*Panicum maximum*) in Atlántico. The perception of technical staff about average useful life of grasses is similar to that of livestock producers, but with fewer differences among departments. They perceive the useful life of a pasture to be 7.5 years, 5% less than that perceived by producers, ranging from a useful life of 6.7 years for Colosuana (*B. pertusa*) in Sucre to 8.3 years for Guinea grass (*P. maximum*) in Atlántico.

Both livestock producers and technical staff estimate that an investment of US$ 199 million are required to recover level-4 degraded areas in the three departments. This is a one-time investment that, according to producers, will increase milk production by 2.02 million liters per day and meat production by 454,000 kg live weight per day. According to technical staff these same increases would be 4.14 million liters milk per day and 965,000 kg live weight per day. This amounts to an additional income per year of US$418 (producers) and 873 million (technical staff). As a result, there are enormous economic and productive incentives for the private and public sectors to jointly prepare and implement a strategy to recovery paddocks that are in an advanced level of degradation.

3.5 Process optimization for microbial community analyses of tropical silages by Single Strand Conformation Polymorphism (SSCP)

Contributors: A. Sanabria, J. Torres, J. Abello, S. Martens (CIAT)

Rationale

For livestock production in the tropics, the year round continuity of supply of high quality forage is critical. Conservation of forages at the optimal time might pose an economic option for livestock husbandry. Some authors consider that hay making is difficult in tropical regions because at the time when the forage is of acceptable quality for conservation (early in the wet season), the weather is likely to be too unreliable for sun drying, while artificial drying is expensive and facilities are not widely available. Addition of acids may be beyond the resources of smallholders and can be dangerous.

Fermentation by silage making, which can be done using fresh or, preferably, wilted material, is an option for smallholders, however not yet widely adopted. Silage so far has been mainly fed to ruminants, especially cattle, due to their known capacity to digest large amounts of fiber. There is rising evidence that high quality forages can also be used by non-ruminants such as swine, e.g. as a supplement replacing partly conventional concentrates. For the lack of the enteric microbial system of a rumen, anti-nutritive factors as inherent in many tropical forages and fodder crops have to be overcome before feeding to monogastrics. Fermentation as a cost-effective means is currently being assessed. Lactic acid fermentation which is prevailing in silages is a microbiological process. The knowledge of microbial eco-systems can be related to silage quality. The potential of promising epiphytic bacterial strains for their future use as inoculants is evaluated.

Objective

Microbial communities play a key role in silage processes such as organic matter transformation and nutrient cycling. As knowledge on microbial composition of silages has derived mainly from classical microbiological methods and information on microorganisms in tropical silages is even more limited, adequate molecular techniques are necessary to develop a comprehensive understanding of the microbial ecology of this kind of non-industrial feed.

The objective of this study was to develop a protocol for DNA extraction – Com PCR and digestion until Single strand conformation polymorphism (SSCP) of silage samples to generate genetic profiles of the silage microbial communities with a special emphasis on lactic acid bacteria (LAB).

Materials and Methods

Silage samples (135) and isolates of lactic acid bacteria (LAB) (20) were processed for molecular characterization of their microbial community.

DNA extraction
DNA extraction of silage samples: total genomic DNA was isolated by various methods (using **SDS and proteinase K,** Cetyl Trimethyl Ammonium Bromide (CTAB) and a Commercial Kit). In a second step, the ADN was purified with PEG .

Lactic acid bacterial DNA extraction: 20 LAB isolates from silages were used for this study. Bacterial DNA was extracted using the Promega Wizard DNA Extraction Kit according to the manufacter`s instructions, and purified using the Wizard-DNA purification Kit Promega® (Promega Corp, Mad, WI).
The quality of DNA was checked on 1 % agarose gel, and the DNA concentration was cuantified using DyNA QUANT 200®, aliquot at concentrations of 10 ng/µL, and stored at -80 ºC for further analysis.

PCR of partial 16S rRNA genes for SSCP analysis
The region of the 16S ribosomal RNA gene between positions 519 and 926 of the E. coli 16S rRNA gene sequence was amplified using the primers Com1 and Com1-Ph, where the reverse primer is phosphorylated at the 5`-end (Schwieger and Tebbe, 1998). PCR reactions were conducted in a total volume of 50 µl, containing 10 ng of DNA, 1X PCR reaction buffer, 1.5 mM MgCl2, 0.5 µM of each primer, each deoxynucleoside triphosphate at a concentration of 0.2 mM, 1.25 U of Taq polymerase Promega® (Promega Corp, Mad, WI). Amplifications were carried out in a PTC-100 thermal cycler (MJ Research, Inc, Watertown, MA) beginning with denaturation step by 3 min at 95 ºC, followed by 35 cycles of 1 min at 94 ºC, 1 min at 50 ºC and 90 seconds at 72 ºC, and a final primer extension for 4 min at 72ºC. PCR products were analysed for size and quantity by agarose gel electrophoresis and staining with ethidium bromide

The PCR products were further purified using Wizard® **PCR** Preps DNA Purification Resin (Promega Corp, Mad, WI) according to instructions supplied by the manufacturer. All of the products were digested to obtain single strand DNA: 10U of lambda-exonuclease (Biolabs) at 37 ºC for 45 min according to the single strand community approach described by Schwieger & Tebbe 1998. Different methods to clean digested products were evaluated and compared with samples not purified to select the most adequate one: Phenol Chloroform extraction, PEG and a commercial kit Wizard® Genomic DNA Purification System (Promega Corp, Mad, WI).

Genetic Profile of SSCP Single strand DNA was resuspended in 12.5 µl TE, pH 7.0. Before electrophoretic analysis, 10 µl of denaturing loading buffer (95 % formamide, 10 mM NaOH, 0.025% bromophenol blue, 0.025% xylene cyanol) was added. The mixture was denatured at 95 ºC for 5 min, and immediately cooled on ice. After 5 min, samples were loaded onto the gels. The samples were run in a 0.6 X MDE® gel electrophoresis with 1X TBE buffer in a Sequi-Gen® GT (Biorad, Hercules, Calif., USA) at 700 V for 8 h at 20 ºC. DNA in the gels was visualized by silver staining by Promega® (Promega Corp, Mad, WI).

At the moment the SSCP conditions are evaluated to run all samples.

Results and Discussion

Total DNA extraction of Silage and Bacterial DNA
The DNA extraction procedure delivered high molecular and clean DNA (Figure 45 and Figure 46). The extraction of total DNA was best with CTAB using a modified protocol of Kelemu *et al.*[4] (1999). The DNA extraction of pure LAB cultures worked well with the use of a kit.

[4] Kelemu, S., Skinner, D., Badel, J, L., Moreno, C. X., Rodriguez, C. X., Fernandez, C., Charchar, M. J., Chakraborty, S. 1999. Genetic diversity in South American *Colletotrichum gloeosporioides* isolates from *Stylosanthes guianensis*, a tropical forage legume. European Journal of Plant Pathology 105, 261-272.

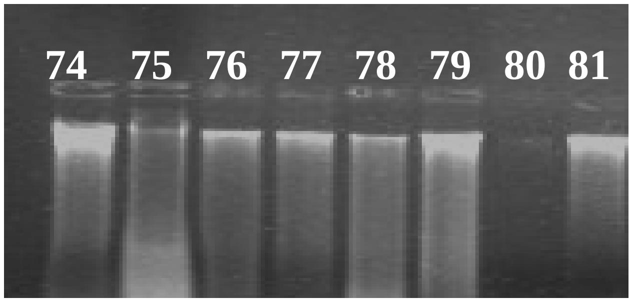

Figure 45. DNA extracted of Silage using CTAB method

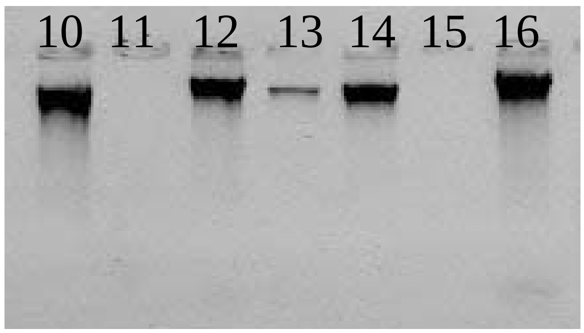

Figure 46. DNA extracted of LAB by kit

PCR amplification of 16S rRNA Genes

For genetic profiling, a region of the 16S rRNA gene, including the variable regions V4 and V5, was amplified by PCR. All samples (silage and LAB DNA) amplified using the universal primers Com1/Com2-Ph. A fragment of approximately 400 pb was amplified (Figure 47 and Figure 48).

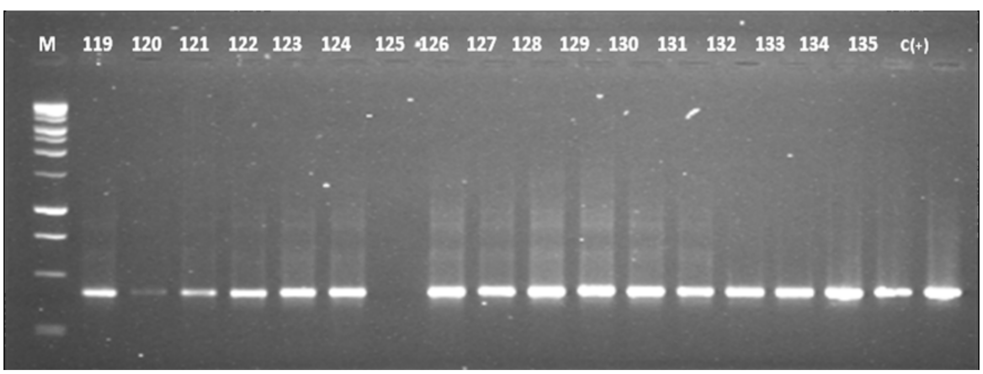

Figure 47. Community amplification using Com1 and Com2-Ph primers of total DNA of silage. The number above the lanes is indicating the code of the samples and (M) stands for the molecular marker 1 KB DNA Ladder Promega®.

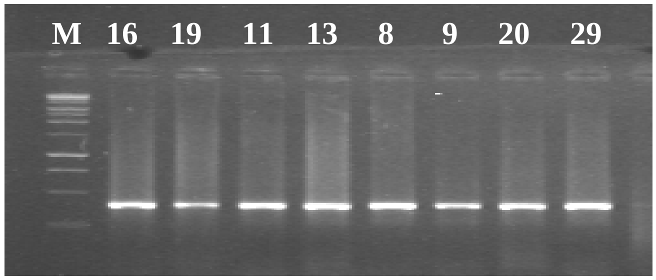

Figure 48. Community amplification using Com1 and Com2-Ph primers of total DNA of LAB. The numbers above the lanes indicate the code of the samples and (M) is the molecular marker 1 KB DNA Ladder Promega®.

The digestion with lambda-exonuclease was necessary to remove one of the complementary DNA strands. Equally important was the posterior cleaning from proteins. Throughout the different methods for purification of digested products that were evaluated and compared to samples not purified, it was shown that purification was necessary and the isoamyl alcohol as well as the PEG method were best.

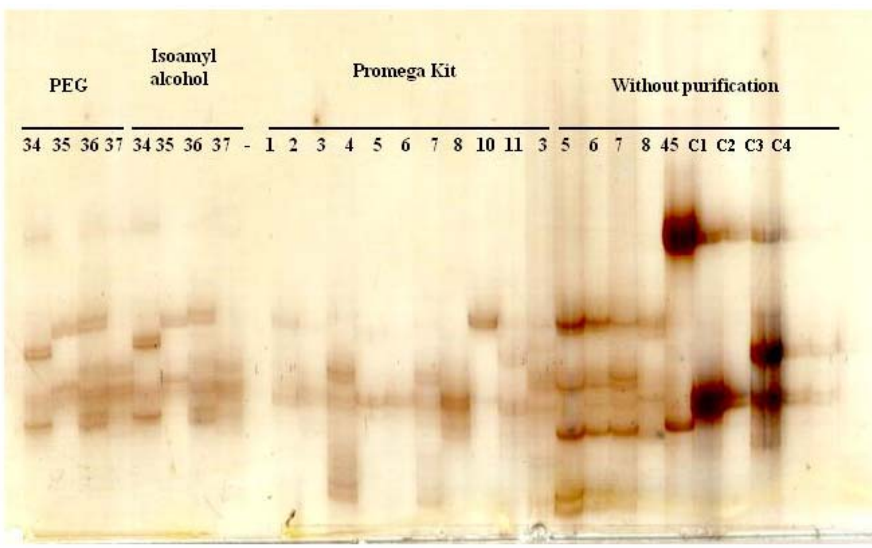

Figure 49. SSCP profiles resulting from different purification methods compared to products of lambda exonuclease without purification

Genetic Profile of SSCP

Some samples derived from total silage DNA extraction were run by vertical electrophoresis for 8 h as a first attempt. After visualising the bands by silver staining they appeared only in the lower part of the gel indicating an extensive running time for this type of samples. In the literature the running times for SSCP gels for microbial community analysis differ widely, which means that a careful approximation to the optimal time for different types of samples is required (Figure 49)

As overall result of the preceding method evaluation described in this article it can be said that the developed protocol is close to allow a routine run for microbial characterization of tropical forage silages.

3.6 Forage seeds: Multiplication and delivery of experimental and basic seed

3.6.1 Multiplication and delivery of selected grasses and legumes in the Forage Seed Unit at CIAT-Palmira: Multiplication and delivery of forage seeds for programs in CIAT, private producer needs, as requested by collaborators and third parties

Highlight

- Nearly one-half ton of seed of 40 accessions of 15 forage species was produced in 2008. A total of 526 kg of seed were distributed. Seed of *Cratylia argentea* accounted for more than 40% of the seed distributed.

Contributors: A. Betancourt; F. Pizarro; J.W. Miles (CIAT)

Rationale

Seed is a crucial, and usually limiting, resource in the evaluation and diffusion of forage germplasm. CIAT maintains a small Forage Seed Unit to meet demand for seed of non-commercial materials for experimental purposes. Excess inventories are available for sale to public and private users outside of CIAT.

Materials and Methods

Seed multiplication areas are maintained at CIAT-Palmira, CIAT-Quilichao, and CIAT-Popayán. Harvested seed is processed at CIAT headquarters (CIAT-Palmira). Seed Unit staff also manage all processes involved in seed dispatches, both within Colombia as well as internationally.

Results and Discussion

A total of 498.33 kg of seed of 40 distinct genetic accessions of 15 forage species was produced in 2008 (Table 42). Over half of the total forage seed produced (278.1 kg) was seed of *Cratylia argentea*.

Table 42. Forage seed produced during 2008, by species.

Genus	Species	No. of acc.	Harvest kg
BRACHIARIA	BRIZANTHA	6	27.000
BRACHIARIA	LACHNANTHA	1	1.000
BRACHIARIA	RUZIZIENSIS	1	5.400
CANAVALIA	BRASILIENSIS	10	27.990
CANAVALIA	SP.	5	10.240
CENTROSEMA	BRASILIANUM	1	.900
CENTROSEMA	MACROCARPUM	1	8.900
CENTROSEMA	MOLLE	1	1.200
CRATYLIA	ARGENTEA	6	278.100
DESMODIUM	HETEROCARPON	1	8.500
LABLAB	PURPUREUS	2	49.100
LEUCAENA	DIVERSIFOLIA	1	1.900
LEUCAENA	LEUCOCEPHALA	2	13.900
MUCUNA	PRURIENS	1	60.000
PUERARIA	PHASEOLOIDES	1	4.200
		Total:	498.330

Over one-half ton of seed of 15 forage genera were distributed in 205 samples to two different countries (Tables 43 and 44). The vast majority of seed dispatched (in excess of 99%) was to destinations within Colombia.

Table 43. Distribution of forage seed during 2007, by genus.

Genus	Samples	Kilos
ARACHIS	3	0.770
BRACHIARIA	40	146.469
CAJANUS	4	2.500
CALLIANDRA	5	5.002
CANAVALIA	25	64.450
CENTROSEMA	15	5.878
CLITORIA	2	0.190
CRATYLIA	22	205.150
DESMODIUM	15	0.548
FLEMINGIA	9	0.765
LABLAB	19	30.800
LEUCAENA	29	46.345
MUCUNA	4	9.006
PUERARIA	5	2.950
STYLOSANTHES	8	5.200
Total: 15	**205**	**526.023**

Table 44. Forage seed distribution during 2008, by recipient country.

País	Samples	Kilos
COLOMBIA	187	522.923
KENYA	18	3.100
Total: 2	205	526.023

3.7 Dissemination and facilitation of communication through the forage web site

Contributors: M. Peters, A. Carvajal, E. Hesse, A. Franco, J.M. Burbano, B. Hincapié (CIAT)
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The CIAT forage web site integrates information from different sources will to allow improved dissemination of forage research to universities, research institutes, partners, donors, development practitioners and farmers.

The general objectives are:

1. The dissemination of research results and
2. Client-orientated information on forages in general

Since August 2002 this web site has been available to a wide range of external and internal users. The web site is the result of a team effort work between all Program members, under the general Web site coordination of the Communications and Capacity Strengthening and with the support of both the Systems and the Information and Documentation Units (Photo 23).

The Web site is accessible in http://www.ciat.cgiar.org/forrajes/index.htm, allows users to:

- Consult general information about the program.
- Provides contacts of different forage experts.
- Consult the forages database.
- Browse the catalog of electronic and printed products.
- Download PDF files containing publications and documents.
- Access additional information, such as staff list, links to partners and donors.

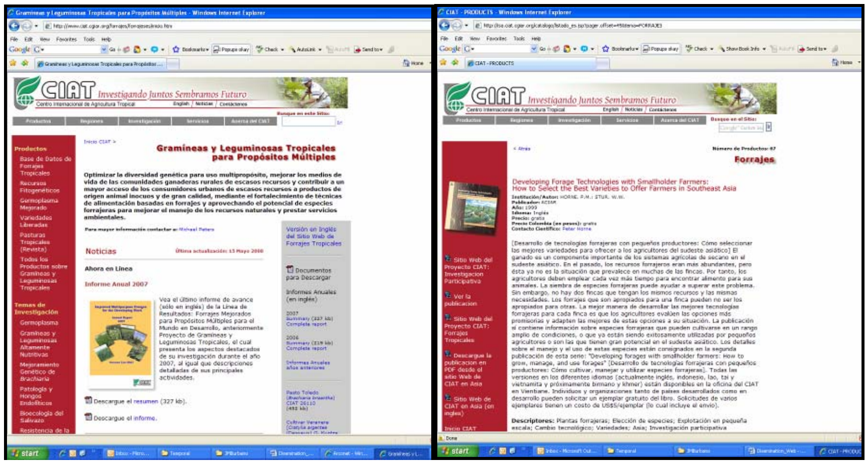

Photo 23. Screen of the forages web site home and page of products.

Figure 50 shows number of visits to the web site between January and December 2008, differentiated for the English and Spanish versions. A total of 248,660 hits were recorded out of which (63,465) were for the Spanish version. An additional 218,243 visits were recorded for the Tropileche website. (18,187/month average).

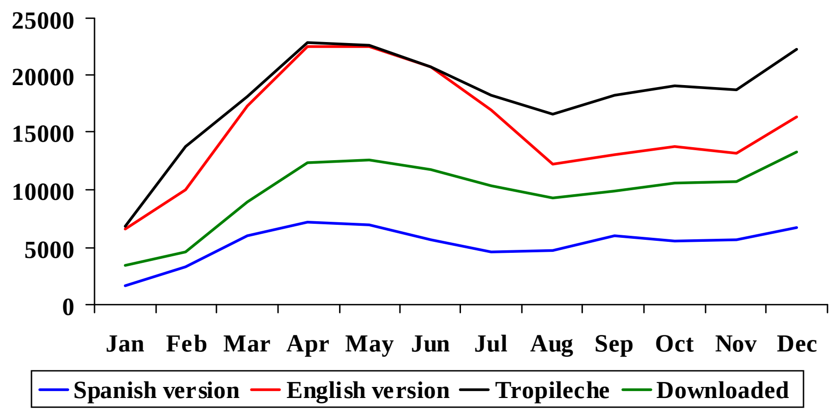

Figure 50. **N**umber of visits to the forage web sites.

In Table 45 downloads of documents placed in the forage web page are shown, with 105,978 documents downloaded in 2008.

Table 45. Download of documents from Tropical Forages Web site (January to December, 2008)

Downloads	Number
Journal: Pasturas Tropicales	46,283
Annual Report	29,614
Technical Bulletin: Cultivar Pasto Toledo	10,811
Technical Bulletin: Brachiaria hibrido cv. Mulato II	5,540
Methods: Evaluación Pasturas con Animales	4,957
Technical Bulletin: Desmodium cv. Maquenque	4,463
Technical Bulletin: Cratylia argentea cv Veranera	4,310
Others	11,955

Forage database in CD-ROM

The Tropical Forage Program in CIAT has generated a great wealth of information on germplasm evaluation, from collection or exchange to the release of cultivars by national institutions. A great part of this information had been entered into a database.

The platform of the Forage Database was developed by CIAT in 2000 using Microsoft Access trough an application in Visual Microsoft InterDev. As a result information contained in the forages Database, was included in a CD-ROM and is available through Internet.

The information incorporated into the database includes information on characterization and adaptation of different forage accessions collected over the past 20 years in CIAT's main research reference sites and through networks (RIEPT). The database contains information on agronomic characterization of 5374 accessions carried in Santander de Quilichao and Carimagua, Colombia and 2209 accession evaluated in 8 evaluation sites in the savannas, forest margins and hillsides. In addition the database includes data from over 230 sites from the RIEPT, RABAOC and *Centrosema* networks as well as data from Genotype x Environment trials of *Arachis pintoi* and *Desmodium ovalifolium*.

It is important to note that there is a continued the frequent demand for this CD-ROM since the launch in 2000, indicating the strong interest for this type of information.

Journal Pasturas Tropicales: United in one single volume in CD-ROM

The Journal Pasturas Tropicales first appeared as a CIAT publication in 1981 as an upgrade of the Informative Bulletin on Tropical Pastures that was first published in 1979. Pasturas Tropicales was CIAT’s response to the need at the time of having a high quality and periodical publication that would allow researchers participating in the International Pasture Evaluation Network (RIEPT) to publish their work. Up to know Pasturas Tropicales is recognized as high quality publication and as a result it is a preferred journal for many researchers in Latin America who are committed to developing improved forages and in seeking better management strategies for pastures to solve livestock production constraints of farmers in tropical regions.

The introduction of new communication technologies and the increasing access to the Internet allows development of novel web based electronic publications, information easily accessible to a large number of users. One of such publications is Pasturas Tropicales: Unidas en un Solo Volumen. This product compiles the complete set of articles published in Pasturas Tropicales from 1979 to 2002 for a total of 474 documents in 2342 pages. The scientific articles and research notes were submitted by 563 authors and collaborators from different national institutions of Brazil, Colombia, Costa Rica, Mexico, Panama, Peru, Venezuela, Paraguay and Argentina where large areas of land are dedicated to pastures/livestock production. The articles can be accessed in an HTML environment. Indexes to consult Pasturas Tropicales based on publication year, authors, species and themes are included. Selected articles can be downloaded as PDF files.

Currently are the being reorganized, and the possibility of publishing Pasturas Tropicales as an e-Journal is being evaluated. The high number of 46,283 downloads in 2008 stresses the continued need for this or a similar publication.

Development of a database and retrieval system for the selection of tropical forages for farming systems in the tropics and subtropics, SoFT.

Farmers depend very heavily on advice from extension specialists, development agencies, researchers and seed companies, but their knowledge is often limited because of inexperience in a region, the difficulty in harnessing the expertise of others, and poor access to information. Much of the important information is fragmented, unpublished or published in media of limited circulation.

In one knowledge system (SoFT – Selection of Forages for the Tropics) much of the accumulated information on species adaptation, its use and management of the last 50 years from across the tropical world is brought together, with information sourced from scientific literature, the plethora of reports, and from unpublished information gleaned directly from agronomists with extensive tropical experience. A comprehensive bibliography and information /fact sheet written for each material of forage in the database is included for an interactive query.

In July 2005 the Selection of forages for the tropics (SoFT) web site was launched in collaboration with CSIRO, QDPI, ILRI and the University of Hohenheim the web site can be accessed under URL http//:www.tropicalforages.info.

Since then, the site has been very well accepted by users around the world, with between 4,557 and 15,828 pages visited per month. Currently the site is most frequented by users from India, Australia, Brazil, Mexico, Russia, Germany, and Malaysia in the descending order. The statistic of the web page show that users include not only research, governmental and non governmental institutions also educational establishments.

Between January 2008 and December 2008 the site was accessed through more than 154,044 visits (figure 51.). At the same time more than 240 CD-ROMs were distributed to diverse institutes, in particular researchers associated with the universities.

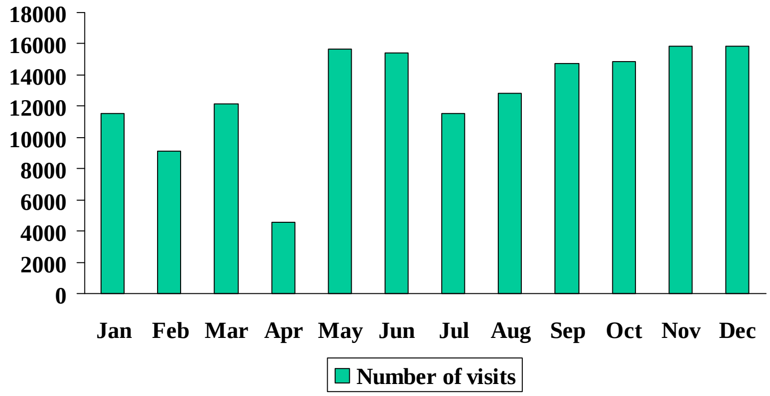

Figure 51. Visits to the SoFT website, January to December 2008.

Annex

List of publications 2008

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Capacity Building (Training)

BS Thesis

Name	Status	University	Title
Aguirre B., Lina María	On-going	Universidad del Valle, Cali, Colombia	Mechanisms of resistance to adult feeding damage in *Brachiaria* spp.
Keller, Fabrizio	Completed	ETH, Zurich, Switzerland	Does the legume *Canavalia brasiliensis* affect soil physical properties in smallholder crop-livestock farms of the Nicaraguan hillsides?
Latorre, Michael	On-going	Universidad del Valle, Cali, Colombia	Morphological, pathogenic and molecular characterization of isolates of *Rhizoctonia* spp. obtained from *Brachiaria* spp. with foliar blight
Martinez M., Carlos Augusto	On-going	Universidad del Cauca, Popayán, Colombia	Evaluación fenológica y caracterización morfológica de *Tadehagi* spp
Uehlinger, Noémi	On-going	ETH, Zurich	Realizing the benefits of cover crop legumes in smallholder crop-livestock systems of the hillsides of Central America
Valencia, Lina	On-going	Universidad de Caldas, Manizales Colombia	Characterization of Xanthomonas spp. isolates causing bacterial wilt on *Brachiaria.*
Zúñiga, Edier	Completed	Universidad Nacional de Colombia, Palmira, Colombia	Correlation between nymph survival and tolerance to adult feeding damage as components of resistance to spittlebug in *Brachiaria* spp.

MS Thesis

Name	Status	University	Title
Ceron F., Claudia Lorena	On-going	Universidad Nacional de Colombia, Palmira, Colombia	Evaluación agronómica y valor nutricional de 8 accesiones de *Tadehagi* spp en suelos ácidos del Norte del Cauca
Mosimann, Anna	On-going	ETH, Zurich	Application of the Structured Mental Model Approach (SMMA) to analyze the sustainability of a new cultivation and livestock feeding method in Nicaragua
Sanabria, Adriana	Completed	Universidad Nacional de Colombia, Bogotá, Colombia	Genetic diversity among casual agents of anthracnosis in tropical fruits
Torres Jaramillo, Julieta	On-going	Universidad Nacional de Colombia, Sede Palmira, Colombia	Tropical grain legumes as alternatives to soybean meal for small producers of monogastric animals in the tropic
Mutimura, Mupenzi	On going	University of KwaZulu-Natal/ Pietermaritzburg Campus/ South Africa	On-farm evaluation of *Brachiaria* grass options in Rwanda

PhD Thesis

Name	Status	University	Title
Cardoso Arango, Juan Andrés	On-going	Universidad de Granada, Spain	Adaptación abiótica a estrés en pastos y leguminosas
Castro, Aracely	On-going	Universidad Nacional de Colombia, Palmira, Colombia	Nutrient dynamics in the Quesungual slash and much agroforestry system
Douxchamps, Sabine	On-going	ETH-Zurich, Switzerland	Effect of *Canabalia brasiliensis* on the nitrogen supply to the traditional maize-bean system in Nicaragua
Ipaz, Sandro	On-going	Universidad Nacional de Colombia	Diagnostico y caracterización del sellamiento y encostramiento en molisoles y vertisoles bajo sistemas de producción tradicional y agricultura agrosostenible en el Valle del Cauca
Louw-Gaume, Annabé	Completed	ETH, Zurich, Switzerland	Adaptation of *Brachiaria* grasses to low P soils
Noguera, Diana Cristina	On-going	Universite Paris VI Pierre et Marie Curie	Interacciones de la tierra y los lombrices y análisis de sus efectos sobre el crecimiento y la fisiología de las plantas
Reiber, Christoph	On going	University of Hohenheim, Germany	Encouraging adoption of research-based offerings with contrasting extension approaches
Sanchez, Elsa	On-going	University of Hohenheim, Germany	From subsistence to market oriented livestock smallholder development in Nicaragua and Honduras

List of Donors

Australia - ACIAR

Forage legumes for supplementing village pigs in Lao PDR. 2008. Asia.

Austria- BOKU

Development of Low Input Systems Such as Organic Farming by Optimising the Use of Legumes in a Dry Region of Nicaragua to Strengthen Soil Fertility, Yield, Human Nutrition and Farm Income. 2008. Use of legumes in low input systems (ULLIS), KEF Commission for Development Studies at the Austrian Academy of Sciences. (NARS: INTA; University UNA, ARI: BOKU)

Africa - IWMI

Payment for Environmental Services as a Mechanism for Promoting Rural Development in the Upper Watersheds of the Tropics

Quesungual Slash and Mulch Agroforestry System(QSMAS): Improving Crop Water Productivity, Food Security and Resource Quality in the Sub-Humid Tropics

Brasil, EMBRAPA -CGIAR

Soil quality monitoring system

Colombia - CVS - CORPOICA -CIAT

Rehabilitación de Tierras Degradadas Mediante Sistemas Silvopastoriles y Reforestación en las Sabanas de Córdoba, Colombia

Colombia - CRC

Estudio de las limitantes físicas, químicas y biológicas de los suelos de la meseta de Popayán con miras a mejorar la productividad.

Ubicación y medida de control de procesos erosivos de la cuenca del río Cauca.

Colombia – FONTAGRO

Desarrollo de Genotipos de Brachiaria spp. Adaptados a Suelos con Drenaje Deficiente para Aumentar Producción Bovina y Adaptar Sistemas de Pastoreo al Cambio Climático en América Latina

Colombia – MADR – IICA -FEDEGAN

Aumento de la productividad, competitividad y sostenibilidad de sistemas de pequeños y medianos productores de carne en la cuenca del Patía y meseta de Popayán.

Colombia – MADR

Implementación y difusión de tecnologías para rehabilitación de praderas degradadas en el Sistema de Producción de Carne en los departamentos de Córdoba, Sucre y Atlántico. Collaborative work with CORPOICA. 2007-2009

Aumento de la productividad, competitividad y sostenibilidad de sistemas de pequeños y medianos productores de carne en la cuenca del Patía y meseta de Popayán.

Colombia - SAP

Development of agricultural production in the Valle de Cauca (University; Universidad Nacional, Government).

France - ANR

Biodiversity and environmental services at landscape level in the Amazon. ANR-France grant for Euros 843,180 for 3 years.

Germany - BMZ

Demand-Driven Use of Forages in Fragile, Long Dry Season Environments of Central America to Improve Livelihoods of Smallholders.
PostDoc proposal Understanding and Catalyzing Learning Selection processes, BMZ, (NARS: DICTA; ARI: University of Hohenheim, CG: ILRI).

Fighting drought and aluminum toxicity: Integrating functional genomics, phenotypic screening and participatory evaluation with farmers to develop stress resistant common bean and *Brachiaria* for the tropics.

More chicken and pork in the pot, and money in pocket: Improving forages for monogastric animals with low-income farmers

Germany – CIM

Forage Conservation and Feed Systems for Monogastrics.

Germany - GTZ

Understanding and Catalyzing Learning-Selection Processes of Multi-Purpose Forage Based Technologies in Central-America with Focus on Dry and Farmer-L. 2008

Germany - VOLKSWAGEN FOUNDATION

Research and development of multipurpose forage legumes for smallholders crop-livestock systems in the hillsides of Latin America (with the U. of Hohenheim and CORPOICA).
Evaluación Abonos verdes - Arbustuvas - Investigación Participativa – Cauca

Italy - FAO

Translation of Soft into Spanish.

Italy - IFAD

Enhancing livelihoods of poor livestock keepers through increasing use of fodder.SLP Project led by ILRI,CIAT responsible for implementing activities in Vietnam. Asia

Kenya - ILRI

Realizing the benefits of cover crop legumes in smallholder crop-livestock systems of the hillsides of Central America: Trade-off analysis of using legumes for soil enhancing or as animal feed resource (Co-financiation with ZIL 2007-2009)
Tradeoff analysis

Trade-off analysis of using legumes for soil enhancing or as animal feed resource. Collaborative work with ILRI and INTA-Nicaragua. Proposal approved by ILRI led SLP. 2007 – 2009

Mexico - Semillas Papalotla, S.A. de C.V.

Brachiaria Improvement Program

Nicaragua, MARENA

Propuesta de Transversalización del Manejo Sostenible de la Tierra en las Políticas, Estrategias e Instrumentos de Planificación y Operativos del IDR, PRODESEC, FUNICA y PESA-FAO que Operan en las Zonas del Proyecto MST.

Netherlands - CFC

Enhancing beef productivity, quality, safety, and trade in Central America (Guatemala, Nicaragua, Honduras)

Switzerland ZIL - ETH

Adaptation of *Brachiaria* grasses to low P soils - funded by ZIL-SDC of Switzerland in collaboration with ETH, Zurich, Switzerland. Swiss Franks.

Improved Feeding Systems for Smallholder Dairy Cattle with Emphasis on Dry Season Feeding and its Effect on Milk Production and Quality. 2007

Realizing the benefits of cover crop legumes in smallholder crop-livestock systems of the hillsides of Central America. Collaborative work with ETH and INTA-Nicaragua. Proposal approved by **ZIL-SDC**.

Switzerland – SDC- ZIL

Adaptation of Brachiaria to low P (with ETHZ) 2003-2005

The forage potential of tanniniferous legumes: The search for sustainable ways to cope with nutritional limitations in smallholder systems (with ETHZ)

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