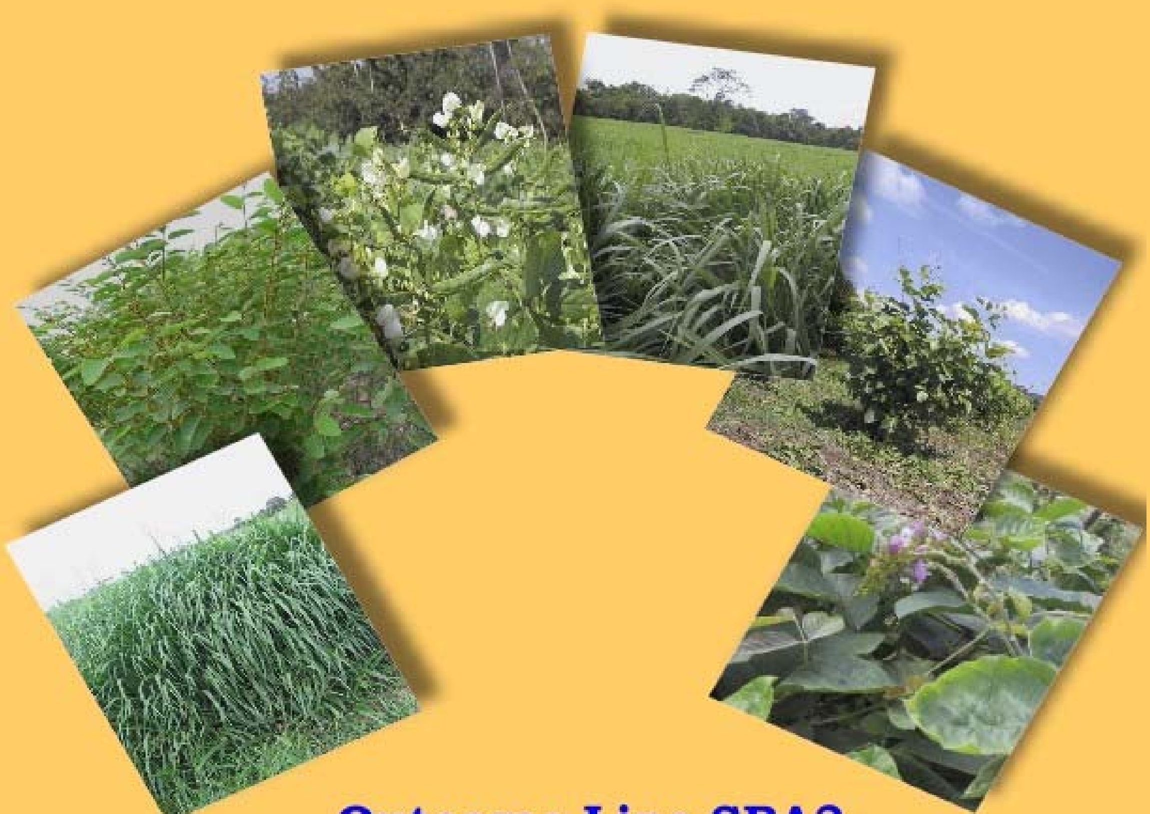
Improved Multipurpose Forages for the Developing Word

Annual Report 2007



Outcome Line SBA3

Centro Internacional de Agricultura Tropical
International Center for Tropical Agriculture

ANNUAL REPORT
2007

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Before

CIAT Project IP5: Tropical Grasses and Legumes: Optimizing Genetic Diversity for Multipurpose Use

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Product Line SBA3

Before
CIAT Project IP5: Tropical Grasses and Legume Optimizing Genetic Diversity For Multipurpose Use

Outcome Line Leader: Michael Peters
Fax: (57-2)-4450073
Email: m.peters-ciat@cgiar.org

Improved Multipurpose Forages for the Developing Word. Product Line SBA3. Annual Report 2007. Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia, 199 p

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Product Line SBA3

Before

CIAT Project IP5: Tropical Grasses and Legume Optimizing Genetic Diversity For Multipurpose Use

Narrative Product Line Description

Rationale & Changes

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 are located in areas with prolonged dry seasons and with land in different stages of degradation, which leads to an inadequate supply of high quality feed for livestock throughout the year. In addition, in many cases smallholders with livestock and limited land (i.e., Southeast Asia) do not have easy access to fodder and have to walk long distances to harvest forages. On the other hand 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 cultivated not only under favorable conditions but also in marginal environments. Improved 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 livestock – crop interface can enable smallholders to be more competitive, with positive effects on poverty alleviation; improved food security and related effects on health are an additional benefit. At the same time forages contribute to nutrient cycling via animal manure, resource conservation and reversing land degradation, with an additional potential in the area of environmental services (e.g., carbon sequestration, biological nitrification inhibition).

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 Product Line entitled 'Multipurpose Forages for Improving Livelihoods of Smallholder Farmers' which is housed in the Sharing the Benefits of Agrobiodiversity Research for Development Challenge Program. The goal of the work on forages is to conserve and exploit the genetic diversity – either through breeding or natural variation - of tropical grasses and legumes to improve the livelihoods of poor rural livestock producers through linkages to traditional and emerging markets and to contribute 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 natural resource base and provide environmental services.

To accomplish the objectives of the Forage Product Line, the research is organized around four major outcomes: 1) Improved *Brachiaria* grasses, 2) Forages as and for high value products developed to capture differentiated markets for smallholders, and 3) Benefits of multipurpose grasses and legumes realized in crop/livestock systems through adaptation, innovation and adoption.

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 crop/livestock and feeding systems using an innovation approach .

As an activity across products 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 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.

CG System 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 having 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 competitivity of swine, poultry and fish in smallholder systems.

To address the priorities of the CGIAR on livestock, the Forage Product Line of CIAT has the global mandate of developing forage-based technologies suitable for extensive and intensive crop/livestock systems in contrasting environments. Selected forages are expected to perform well in infertile soils and to contribute 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 enhanced capacity of grasses with deep root systems to improve physical structure of soils and of legumes to improve soil fertility through their contribution via biological N_2 fixation. Furthermore, improved forages contribute to a) soil improvement through improved soil organic matter quality thereby enhancing soil biological activity and below-ground biodiversity and b) 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 Research for Development Challenge (RDC) dealing with People and Agroecosystems, and with

TSBF (Tropical Soil Biology and Fertility) Institute of CIAT. These strong 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 Forage Product 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 for 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 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 individuals for short term and long term training, group training and knowledge management (SP 5a)

Changes

To capture emerging market and research opportunities targeted to smallholder farmers CIAT has refocused its forage research into the Forage Product Line entitled ‘Multipurpose Forages for Improving Livelihoods of Smallholder Farmers’. As reflected in the attached logframe 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 are maintained. However, they are reorganized under the newly defined products; products and outcomes from 2010 onwards will follow the new product line structure. The most significant change is the inclusion of targeting and delivery of research products, as integral parts across the new products and more concretely addressing emerging market opportunities for forage-based high value and added value products. 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.

Following on changes in the last MTP (2007-2009) more emphasis is placed on livestock other than cattle (such as monogastrics), stronger market orientation addressing the demand for higher value products and other kinds of benefits (such as freeing up labor) that improve poor farmers’ welfare.

With these changes in objectives we will contribute more effectively to income generation and the improvement of livelihoods of poor rural communities that depend on livestock and also to improve access to safe, high quality animal products for poor urban consumers.

The annual budget of the Forage-related work in CIAT has again been cut substantially in 2007. However, with the refocused strategy it is hoped that new funding opportunities can be realized and that through synergies with other CIAT research areas and strengthening partnerships most of the negative effects of the cut can be mitigated. The joint appointment with ILRI on forages for Eastern and Southern Africa has not been renewed. However, as a high priority together with ILRI we are elaborating a research and funding strategy: limited donor funded work in Rwanda is supervised jointly by ILRI and CIAT. This strategy will rely on close collaboration with TSBF Institute and the People and Agroecosystems RDC to integrate forages into production systems and to realize their economic and environmental benefits.

With the departure of our experienced animal nutritionist we are phasing out work on antinutritional factors as a separate strategic research area. However, we were able to secure external funding to contract a junior career animal nutritionist with an initial research emphasis on forages for monogastric animals, contributing to study on trade-offs in the use of forages between feed resource and soil improvement and continuing to support the *Brachiaria* breeding program; delays on delivering our donor commitment on research on the trade-offs between use of forages as feed or green manure have been addressed in a revised research plan which has been consolidated with partners. Stronger linkage with partners in Australia, Laos and Colombia and the People and Agroecosystems RDC within CIAT have allowed us to maintain the research focus on forages for monogastrics but additional partners and funding have been sought through additional proposals for donors . The loss of our in-house capacity in statistical analysis is a concern.

Stability of core resources at the current level will be needed to deliver the products stated in this document and additional resources to expand our contribution to forage-related work in Sub-Saharan Africa.

Impact Pathways

To contribute to the improvement of livelihoods of poor rural livestock owners through high quality forages (outcome 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 where 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, with resistance to major pests and diseases and with adaptation to acid, low fertility soils, to poorly drained soils and to drought are the product targets to be used by different partners engaged in research and development activities. 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.

For its work in Sub-Saharan Africa, Southeast Asia and Latin America and the Caribbean CIAT has developed a joint strategy with ILRI, with complementary research priorities and expertise to include 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 products. 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 there were a number of strong organizations in developed countries (e.g., Australia, USA) involved in development of forages for sub-tropical and tropical environments. However, currently there are only a few suppliers of improved forages with an international mandate as is the case for CIAT, ILRI and ICARDA. The forage work carried out by the CGIAR Centers is complementary. For example, forages developed at ICARDA are mostly for the arid and semi-arid regions, and ILRI is concentrating its work on developing forages for cooler environments and the assessment of food-feed crops, while forages developed by CIAT are for tropical lowlands to mid-altitudes. With ILRI we are discussing a joint strategy. An additional important participant in tropical Forage R&D is EMBRAPA in Brazil, but with a national mandate.

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

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 Al and low levels of P
- Understanding how forages adapt to drought and waterlogging
- Understanding how grasses inhibit biological nitrification in soil

1. 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 grasses 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
2. Developing superior grass and legume genotypes and cultivars (to contribute to increased livestock productivity)
    - Grasses and legumes selected from germplasm collections that have broad adaptation to environmental factors prevailing in target areas and with multiple uses in crop/livestock production systems

- Grasses 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 legumes for soil enhancement or as animal feed

3. 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.
   - Review of taxonomy of selected forage legume genera/species
   - Protocols for indexing diseases of quarantine importance that limit the flows of germplasm between LAC, Africa and South East Asia
   - Decision Support Tools with information on adaptation, uses and management of different forage species

Partners

Through partnerships with different organization from developed and developing countries, the Forage Product 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 four products of the Forage Product Line shown in parenthesis.

1. Colombia – CORPOICA and Universidad Nacional: Conservation, documentation and distribution of forage germplasm

2. Colombia- MADR – IICA- FEDEGAN. (Outcome 3) Desarrollo y uso de recursos forrajeros para mejorar la competitividad y productividad en sistemas sostenibles de producción bovina para el departamento del cauca.

3. Colombia – MADR. (Outcome 3) Implementation and transfer of technologies for restoration of degraded pastures for beef production systems Córdoba, Sucre and Atlantic departments"

4. 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.

5. Costa Rica - SIDE; Guatemala – ICTA and MAGA; Honduras- DICTA; Nicaragua- IDR, IICA and ILRI: (Outcome 3). Analysis of the Beef Chain in Central America. Funds from CFC.

6. Colombia - CORPOICA and Mexico- PAPALOTLA -Seed Company: (Outcome 1) On-farm evaluation of selected *Brachiaria* hybrids. Funds from PAPALOTLA.

7. Colombia - CORPOICA-CVS-CARSUCRE-GANACOR-FEGASUCRE: (Outcome 3). Recuperation of degraded pastures. Funds from MADR.

8. France- ANR. Biodiversity and environmental services at landscape level in the Amazon.

9. Germany – CIM - Forage conservation and Feed Systems for Monogastrics. (Outcome 2).

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

11. Germany -U of Hohenheim; Nicaragua- INTA; Honduras- DICTA: (Outcome 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.

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

13. Lao PDR- National Agriculture and Forestry Research Institute, Australia- Department of Primary Industry and Forestry (DPI & F), Queensland and Canada- Nutrition Prairie Swine Centre, Saskatoon (Outcome 2) – Forage legumes for supplementing village pigs in Lao PDR. Funded by ACIAR

14. Switzerland - ETHZ; and Colombia- CORPOICA, Universidad Nacional de Colombia-Bogotá: (Outcome 2). The forage potential of tannineforus legumes. Funds from ZIL- SDC

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

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

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

Project IP5: (MTP 2007-2009)

Targets	Outputs	Intended User	Outcome	Impact	Achieved 07 (yes or no)	Proof of achievement (list documentation)
Output 1	Grasses and legumes with high forage quality attributes developed	CIAT and NARS researchers and seed companies	New cultivars of *Brachiaria* and legumes with high quality are released and adopted by farmers in LAC, Asia and Africa	Increased production of livestock through feeding high quality grasses and legumes		
Output 1 Targets 2007	Developed at least 5 *Brachiaria* sexual hybrids that combine resistance to 5 species of spittlebug with high leaf digestibility (>60%) and crude protein (>10%) Defined the effect of location and soil fertility on forage quality of 5 shrub legumes	CIAT researchers CIAT and NARS researchers	New genotypes incorporated into the *Brachiaria* breeding program to develop high quality cultivars Environmental niches to grow shrub legumes with tannins in LAC and Africa better defined		Yes Yes	Annual Report Sections 1.1, 1.4 and 1.6 Annual Report Section 3.10 PhD. Thesis Tassilo Tiemann (2008) The forage potential of tanniniferous legumes: Search for sustainable ways to cope with nutritional limitations in smallholder livestock. Swiss Federal Institute of Technology (ETH), Zurich, Switzerland
Output 2	Grasses and legumes with known reaction to pest and diseases and interactions with symbiont organisms developed	CIAT and NARS researchers, and seed companies	New cultivars of *Brachiaria* and legumes with resistance to prevalent pests and diseases are released and adopted by farmers in LAC	Increased profitability and sustainability of livestock production through planting grasses and legumes resistant to major pests and diseases		
Output 2 Targets 2007	Developed at least 5 apomictic *Brachiaria* hybrids that combine resistance to 3 species of spittlebug with tolerance to high levels of Al	NARS researchers	Selected *Brachiaria* hybrid with resistance to spittlebug and adaptation to acid, infertile soils tested in different regions in LAC		Yes	Annual Report Section 1.6
	Grasses and legumes with	CIAT, ARIs and	New cultivars of *Brachiaria*	Increased livestock/crop		

Targets	Outputs	Intended User	Outcome	Impact	Achieved 07 (yes or no)	Proof of achievement (list documentation)
Output 3	adaptation to edaphic and climatic constraints developed	NARS researchers, and seed companies	and legumes with adaptation to low fertility soils, drought and poorly drained soils released by partners and adopted by farmers in LAC, Asia and Africa	production and improved NRM through planting multipurpose forage species adapted to low fertility soils, drought and waterlogged soils		
Output 3 Targets 2007	Developed a screening method for selecting *Brachiaria* hybrids for adaptation to poorly drained soils	CIAT researchers	New genotypes incorporated into the *Brachiaria* breeding program to develop cultivars with adaptation to poor soil drainage		Yes	Annual Report Section 1.8 Rao, I.M.; Rincon, J.; Garcia, R.; Ricaurte, J.; Miles, J. 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.
Output 4	Superior and diverse grasses and legumes evaluated in different production systems are disseminated	NARS researchers, development programs and farmers	New cultivars of grasses and legumes with adaptation to biotic and abiotic stresses are adopted by farmers in LAC, Africa and Asia	Livelihoods of small livestock farmers improved through adoption of forages that result in more efficient use of family labor and higher income from crop and animal products		
Output 4 Targets 2007	Elite accessions (4) of shrub legumes (*Flemingia macrophylla* and *Desmodium velutinum*) selected for high quality and yield in the wet and dry seasons.	NARS researchers and development programs	Researchers in LAC, Asia and Africa select new shrub legume alternatives for on-farm testing		Yes (partly)	Elite accessions defined, Genotype * Environment trials delayed due to adverse environmental conditions, trials re-established in 2008, Progress in Annual Report 2006, Section 3.5.

Output Targets (2008-2010)

Targets	Products	Intended User	Outcome	Impact
OUTCOME 1	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
Outcome 1 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	
Outcome 1 Targets 2009	• At least 2 apomictic *Brachiaria* hybrids that combine high digestibility (>60%) and crude protein (>10%) with spittlebug resistance developed • At least 5 *Brachiaria* hybrids that combine resistance to spittlebugs with adaptation to acid soils released for regional testing • At least 5 *Brachiaria* hybrids with combined resistance to spittlebugs and tolerance to waterlogging developed	NARS researchers, and seed companies NARS researchers, CIAT researchers NARS researchers, CIAT researchers	New cultivars of *Brachiaria* with potential to increase livestock productivity are released and adopted by farmers in LAC and Asia *Brachiaria* hybrids with superior traits available for multilocational testing in LAC *Brachiaria* hybrids with resistance to spittlebug and adaptation to poorly drained soils evaluated in multilocational trials in LAC	
Outcome 1 Targets 2010	• Developed a screening method for selecting *Brachiaria* hybrids for combined adaptation to drought and aluminum toxicity • One apomictic hybrid with phenotype similar to cv. Basilisk (stoloniferous, spreading) with good spittlebug resistance in advanced testing for commercial release.	NARS researchers, CIAT researchers NARS, private seed company	New genotypes incorporated into the *Brachiaria* breeding program to develop cultivars with combined adaptation to drought and aluminum toxicity One "spittlebug-resistant *B. decumbens*" to replace cv. Basilisk on large areas subject to spittlebug attack	

Targets	Products	Intended User	Outcome	Impact
OUTCOME 2	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
Outcome 2 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	
Outcome 2 Targets 2009	• Developed a methodology to correlate *in vitro* and *in vivo* screening of legumes for monogastric utilization	NARS and CIAT researchers	Resource efficient screening of high potential forages for monogastric feeding	
Outcome 2 targets 2010	• At least one forage based feed for monogastric production adopted by smallholders in one country in Southeast Asia and one country in Latin America and the Caribbean	CIAT and NARS researchers	Small-scale monogastric producers adopt forage legumes as supplementary feed	
OUTCOME 3	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
Outcome 3 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	NARS researchers and development programs	Livestock and non-livestock farmers in dry hillsides adopt annual legumes to make high quality hay and silage	

Targets	Products	Intended User	Outcome	Impact
	• Released CaNaSTA for targeting forages (and other crops) to specific environmental and market niches	NARS researchers and development programs	Researchers and development workers are using CaNaSTA to target forages to specific production and market niches	
Outcome 3 Targets 2009	• Released a revised version of SoFT (Selection of Forages for the Tropics) to target forages to different niches	NARS researchers and development programs	Large number of researchers and development workers use SoFT to identify, access and promote best-bet forage species for different environments and uses	
Outcome 3 Targets 2010	• Production vs environmental trade-offs determined between use of 2 cover legumes as feed supplement and for soil fertility improvement in maize-based systems in one hillside region • Production and soil quality improvement benefits from introducing 2 multipurpose forage grass and legume options to restore degraded pastures quantified in one savanna region	CIAT and NARS researchers NARS researchers and development programs	Livestock and non-livestock farmers in dry hillsides adopt at least one cover legume in their production systems Livestock farmers in savannas realize the benefits of the multipurpose forages	

Research Highlights (2007)

Outcome 1: Improved *Brachiaria* grasses

- **Developed a screening method for evaluating *Brachiaria* hybrids for adaptation to poorly drained soils conducted initial screenings**

In the Tropics, pastures often confront waterlogging conditions. We developed a screening method to evaluate waterlogging tolerance in *Brachiaria* hybrids. Using the 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 the development of adventitious roots in some hybrids. We identified three sexual hybrids (SX05/1918, SX05/2043, SX05/2411) that were superior in their tolerance to waterlogging from a group of 37 preselected hybrids. The superiority of these hybrids was due to their greater ability to produce green leaf biomass and green leaf area together with higher proportion of green leaf biomass to total shoot biomass under waterlogging stress. These three attributes could serve as criteria for selection for waterlogging tolerance in *Brachiaria*. The finding of differences in tolerance to waterlogging among sexual clones is a very important result: genetic improvement of waterlogging tolerance in *Brachiaria* hybrids through selection in the sexual breeding population will be possible.

Outcome 2: Forages as and for high value products developed to capture differentiated markets for smallholders

- **Impact of the adoption of improved grasses in Central America**

During 2003 to 2007, CIAT monitored 56 smallholder dual purpose farms in Central America. These producers adopted 6 and 3 species of improved grasses and legumes, respectively. The adoption of new forages increased stocking rate by 15% in Honduras, 21% in Nicaragua, and 38% in Costa Rica, resulting in an increase in the number of milking cows by 24% in Honduras, 41% in Nicaragua, and 36% in Costa Rica.; milk production increased by 47% in Honduras and Nicaragua, and 53% in Costa Rica while beef production increased by 15% in Nicaragua, 46% in Honduras, and 74% in Costa Rica, respectively.

At the same time, milk price increased from 7% in Nicaragua up to 36% in Costa Rica, while beef prices increased between 4% and 11%, The increase in herd size and milk and beef production, coupled with higher product prices allowed family income to drastically increase by 288% in Honduras, 177% in Nicaragua, and 238% in Costa Rica. Seed sales of improved forages has increased significantly throughout Central America and, as a result, (degraded) pastures are currently being renovated. Current national policies to liberalize grass seed imports have favored the dissemination of CIAT’s forage products in the region.

Outcome 3: Benefits of multipurpose grasses and legumes realized in crop/livestock systems through adaptation, innovation and adoption

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

  Livestock trials were established on three smallholder farms in the watershed of Rio Pire (Condega, Estelí, Nicaragua) to test whether the introduction of the drought tolerant cover legume *Canavalia brasiliensis* (Canavalia) into the traditional maize-bean-livestock system can produce more dry season feed of better quality and can overcome soil fertility decline. At each farmer two plots of 0.35 ha were planted with maize during the first rainy season and either beans or Canavalia during the second rainy season. After the maize harvest, three groups of 3-5 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 had a duration of eight days, of which four days of adaptation and four days of data collection.

  Planting of *C. brasiliensis* increased average biomass availability with almost a tonne per hectare and resulted in a significantly higher milk production of 0.5 kg/animal/day ($p<0.05$). No effect was found on milk quality. The positive effect on milk production is recognized by the farmers and they show a clear interest in continuing with this technology to increase milk production during the dry season and recuperate degraded soils.

PROJECT OUTCOME: Adoption of forages in Southeast Asia (MTP 2005 to 2007)

Since the mid-1990s, CIAT and partners have worked together with smallholder farmers to develop forage technologies in Southeast Asia. By the end of 2005, more than 10,000 smallholder farmers had adopted intensively managed forage plots for improved livestock production. This outcome relates to Output 4 of the 2005-2007 MTP, stating ‘A forage production systems established with >5000 farmers in 4 countries of SE Asia by 2006’.

A surveyed of the adoption of planted forages by smallholders at project sites of the ‘Livelihood and Livestock Systems Project (ADB funded, 2003-2005), was conducted in 2005. More than 500 households were interviewed. In addition, several case studies documented the impact of adoption of forages in defined livestock production systems; cattle fattening, cow-calf production and herbivorous fish production. Adoption of forages was 172 households (hh) in Cambodia, 157 hh in PR China, 2632 hh in Indonesia, 32 hh in Laos, 491 hh in the Philippines, and 4091 in Vietnam. Additional forage adoption was recorded in non-project sites; mainly Laos, adding another 2700 hh.

Planting forages on their own land was the key factor that enabled smallholders to improve livestock production. The initial benefit from planted forages was, almost invariably, labor savings from easy access to feed. Subsequently, improved growth of animals receiving planted forages emerged and farmers started to intensify livestock production based on the additional new feed resource. This led to improved feeding and management systems, and a shift from extensive to more market-oriented livestock production. Relative small areas of forages (500 – 2000 m^2) were needed to achieve these benefits. Participatory approaches to working with farmers were an essential component of success. Partnerships varied and changed from more research-oriented partners to development-oriented partners as the project moved from developing forage technologies to scaling out, by end of 2006 reaching >5000 additional adopters.

Outcome 1: Improved *Brachiaria* grasses

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

Highlight

- The new *Brachiaria* hybrids have a good potential to accumulate high nitrogen rates and thus give a high nutritional value in terms of crude protein.

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

1.1.1.1 Assess 168 BR06 hybrids for digestibility and crude protein

Contributors: P. Avila; C.E. Lascano, S. Martens; J.W. Miles (CIAT)

Rationale

After selecting *Brachiaria* hybrids for best adaptation to biotic and abiotic stresses such as for aluminum tolerance and spittlebug resistance, the feed value for the promising lines is assessed to provide the market with superior hybrids to ensure profitable animal production.

Materials and Methods

In February 2007 leaves of 168 Brachiaria hybrids BR06 were harvested after 6 weeks re-growth in pots in single replicates in the green house for evaluation by NIRS System 6500 for crude protein (CP) and in-vitro organic matter digestibility (IVOMD) after drying at 60 ºC and milling.

Of those, 168 hybrids 81 plants were planted in the field in Santander de Quilichao experimental station in March 2007 in duplicates together with CIAT 606 (16 replicates), CIAT 36062 (6 replicates) and CIAT 36087 (4 replicates). After standardization on 9 May 2007 the first harvest of leaves took place on 7 June and the second harvest on 4 July 2007.

After each cut plants were fertilized with 2g of 46% urea per plant in the field.

Results and Discussion

The range of crude protein content in *Brachiaria* leaves differed from the pots compared to the field. On average it was 2.5 times higher in the field and was with 22 % in DM on a very high level comparable to legumes. That might be explained by the fertilizing practice. The IVOMD had a wider range in the greenhouse and was lower than in the field. Data of the second harvest in the field are not presented here but were similar to the first harvest, with about 1.5 % lower in CP and IVOMD on average (Table 1).

Extremes in CP content and IVOMD in the pots were not the same accessions as in the field.

In the future, evaluation shall be more adapted to practice conditions and reduce confounding effects for higher repeatability. It is desirable to plant small plots of the same accessions to increase the inter-plant competition and to get a more representative sample amount. Whole plants (from 15 cm upwards) will be harvested and evaluated to converge to grazing and cutting practice. It is considered to reduce or abolish the N-fertilization to evaluate the competitiveness under suboptimal conditions. Modifications in the experimental design have still to be adjusted to the CIAT facilities at Santander de Quilichao experimental station.

Table 1. Crude protein content and in-vitro organic matter digestibility of BR06 leaves

	CP [% of DM]			IVOMD [%]		
Greenhouse	range	average	median	range	average	median
168 accessions	6.1-12.2	8.8	8.6	37.4-64.6	53.2	53.9
81 sel. accessions	6.1-12.2	8.8	8.7	37.4-63.8	53.2	53.7
Field / 1st harvest						
Control 606	19.1-25.1	21.8	21.6	55.8-65.6	60.7	60.9
Control 36062	20.2-25.9	23.1	23.6	53.0-60.0	56.8	56.2
Control 36087	21.8-22.6	22.3	22.5	53.7-59.3	55.6	54.6
81 sel. accessions	17.2-27.2	22.2	22.1	48.4-64.1	58.4	58.8

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

Highlight

- Reproductive mode was assessed by progeny test of 164 preselected hybrids originally evaluated in 2006.

1.2.1 Determine reproductive mode of new *Brachiaria* hybrids (Series BR06) preselected at Quilichao and Matazul

1.2.1.2 Determine reproductive mode (by progeny test) of 164 pre-selected BR06 hybrids in replicated field trial at Quilichao

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

Rationale

The hybrid (testcross) progenies produced and evaluated to assess the merit of 233 SX05 genotypes generated a cohort of promising "preselections", candidates for possible development to cultivar status. Since only apomictic hybrids are considered for commercial release, reproductive mode of the new preselected hybrids needed to be determined.

Materials and Methods

Of a total of 2230 testcross individuals (Series BR06) evaluated in 2006, 353 individual plants were preselected. Open-pollinated seed was harvested from these 353 plants by enclosing inflorescences in mesh bags. An estimate of seed fill was obtained by expressing clean seed as a proportion of the crude seed recovered. One hundred eighty-nine clones (53.5%) were culled on poor seed fill. Seed of the remaining 164 preselected plants was acid-scarified and sown in sand in the greenhouse. Seedlings were transplanted to 10.16-cm plastic pots. At approx. 8 wks of age, individual seedlings were transplanted as spaced plants in field plots. A total of 20 siblings per progeny were transplanted in four, single-row, 5-plant plots at 1.2 x 2.5 m. Four check genotypes were included in the trial for a total of 168 entries (672 plots). Entries were completely randomized among experimental units.

Results and Discussion

The 5-plant plots were rated several times for apparent morphological uniformity, and ratings across replications compared. Sixty-nine of the 164 hybrids were classified as apomicts (or highly apomictic facultative apomicts). Forty-seven hybrids were classified as "Sexual". Forty hybrids were classified as "Facultative Apomicts", but discrimination between a highly sexual facultative apomict and a truly sexual hybrid was often difficult. Reproductive mode of eight hybrids could not be assessed on the basis of the progeny test.

1.2.1.3 Harvest seed from selected apomictic hybrids by bagging inflorescences tied in "living sheaves"

Highlight

- Initial seed increase was harvested from 62 apomictic progenies.

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

Rationale

New hybrids, candidates for commercial release, require further evaluation and culling by our private sector partner (Semillas Papalotla). They conduct agronomic trials, for which seed is required, in several locations. The progeny trial (See sub-sub-activity 2.1.3.1), in addition to revealing the reproductive mode of promising new hybrids, provides an initial opportunity for significant seed increase.

Materials and Methods

After assessment of reproductive mode (See sub-sub-activity 2.1.3.1), reproductive tillers of the plants in plots of apomictic hybrids are tied in "living sheaves" and inflorescences enclosed in mesh bags. Crude seed collects in the mesh bags as it ripens and abscises. A rough assessment of seed fill is obtained by expressing weight of clean seed as a proportion of total crude seed recovered.

Results and Discussion

Seed was harvested from 62 hybrids. These have subsequently been culled by over 50% on reaction to spittlebugs and on seed set.

1.2.2 Genetic control and molecular markers for spittlebug and reproductive mode in *Brachiaria*

Highlight

- Good agreement between presence/absence of apolocus marker N-14 and reproductive mode as assessed by progeny trial was obtained in a set of preselected hybrids with *B. decumbens* cv. Basilisk: Over 90% of hybrids classified as apomicts have the marker.

1.2.2.1 Assess presence/absence of "apolocus" marker (SCAR N-14) in hybrids with cv. Basilisk (series BR06). Correlate presence of marker with reproductive mode as determined by progeny test

Contributors: J. Vargas (BRU); J. Tohme (BRU); J.W. Miles (CIAT)

Rationale

A reliable molecular marker of apomixis would be a valuable tool as it will allow determination of reproductive mode of plants still in the seedling stage.

Materials and Methods

Vegetative propagules of the original 164 preselected hybrids grown in the greenhouse were the source of leaf tissue. Samples of leaf tissue were taken and the SCAR marker N-14 assessed on each individual by standard PCR proceedures.

Presence/absence of marker N-14 was compared with assessment of reproductive mode based on progeny test (See sub-sub-activity 2.1.3.1).

Results and Discussion

The N-14 SCAR marker was detected in 91 of 164 hybrids (55.5%). This does not differ significantly from the expected 50%.

For the 116 hybrids whose reproductive mode could more or less reliably be determined (See sub-sub-activity 2.1.3.1), agreement with presence (in apomicts) or absence (in sexuals) of the N-14 marker of the "apomixis gene" was very good. Only three of the 69 hybrids classified as apomicts (4.3%) lacked the marker; five of the 47 hybrids classified as sexuals (10.6%) had the marker. Some of the latter inconsistencies are probably attributable to erroneous classification of highly sexual facultative apomicts as sexual.

In spite of previous inconsistencies between progeny test results and presence/absence of the N-14 marker, it now appears that this marker will be a useful tool in the *Brachiaria* breeding program, at least to make early identification of probable apomicts in hybrid (testcross) populations produced with the cv. Basilisk pollen parent. This is a significant breakthrough.

1.3 *Brachiaria* genotypes resistant to spittlebug and other biotic stresses.

Highlight

- Seed of selected apomictic hybrids was delivered to Semillas Papalotla for advanced agronomic evaluation and eventual development to cultivar status.

1.3.1 Seed of 20 apomictic BR05 hybrids, 8 BR04 hybrids, and 10 MX02 hybrids delivered to Papalotla for further multiplication and evaluation

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

Rationale

Following culling from several thousand "raw" hybrids to, perhaps, several dozen (based on general agronomic merit, spittlebug reaction, seed set, and other characters, the selected hybrids are delivered to our private sector partner (Semillas Papalotla) for further development to cultivar status. Effective delivery depends on availability of seed.

Materials and Methods

Until 2007, only small quantities of seed were recovered, by direct hand harvest, from progeny trials. Hence, plots of promising hybrids, specifically for further seed multiplication, had to be established subsequently at CIAT-Popayán. This required an additional year in the product development process.

Seed was hand-harvested from these plots, cleaned, and submitted to Colombian quarantine authorities in preparation for delivery.

Better organization of progeny tests beginning in 2007, as well as strict culling of hybrids with poor seed set, has allowed significant volumes of seed to be recovered at this progeny test stage of cultivar development, making the whole process more efficient.

Results and Discussion

Between about 200 and 900 gm of clean seed were multiplied for selected new hybrids. Seed of 38 new hybrids was delivered to Semillas Papalotla early in 2007.

1.3.2 Seed of approx. 20-30 apomictic BR06 hybrids, harvested and processed for delivery to Papalotla (early 2008) for further multiplication and evaluation

Highlight

- Significant volumes of clean seed (from 70 gm to over 1 kg) of apomictic BR06 hybrids were harvested from this year's progeny trial, which included progenies of a total of 164 new hybrids.

Contributors: A. Betancourt; F. Pizarro; J.W. Miles.

Rationale

Following culling from several thousand "raw" hybrids to, perhaps, several dozen (based on general agronomic merit, spittlebug reaction, seed set, and other characters), the selected hybrids are delivered to our private sector partner (Semillas Papalotla) for further development to cultivar status. Effective delivery depends on availability of seed.

Materials and Methods

Seed was harvested from 62 apomictic hybrid progenies, cleaned, and prepared for submission to Colombian authorities for quarantine inspection and issuance of a phytosanitary certificate.

Results and Discussion

After culling, mainly on seed set and spittlebug reaction, we are preparing to deliver seed of 28 BR06 hybrids to Semillas Papalotla early in 2008.

1.4 Screening *Brachiaria* genotypes for spittlebug resistance

Highlights

- Very high levels of antibiotic resistance to nymphs of *A. varia, A. reducta,* and *Z. carbonaria* were detected in elite apomictic hybrids (series BR06) previously selected for good agronomic performance.
- The new technique to screen for adult feeding damage was fully implemented in 2007.
- Resistance to adult feeding damage was characterized. No resistance to adult damage was found in 164 BR06 apomictic hybrids tested.
- Field screening of genotypes in Caquetá continued. Results confirmed resistance levels detected under greenhouse conditions.

1.4.1 Continuous mass rearing of spittlebug species in Palmira and Macagual

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

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.

1.4.2 Identify *Brachiaria* genotypes resistant to spittlebug

1.4.2.1 Greenhouse screening of *Brachiaria* accessions and hybrids for resistance to five spittlebug species

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

Rationale

Assessment of resistance to spittlebugs is an essential step in the process of breeding superior *Brachiaria* cultivars at CIAT. In 2007, intensive screening of selected hybrids was conducted under greenhouse and field conditions.

Materials and Methods

Screenings for resistance in the greenhouse were conducted with *Aeneolamia varia, A. reducta, Zulia carbonaria, Z. pubescens, Mahanarva trifissa* 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 (usually 5-10 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%). All those rated as resistant or intermediate were reconfirmed. All susceptible hybrids were discarded.

Results and Discussion

A set of 164 apomictic hybrids were screened for resistance to both nymphs and adults of *A. varia*, *A. reducta,* and *Z. carbonaria*. Results with adults are shown in section 2.4 (Identify host mechanisms for spittlebug resistance in *Brachiaria*).

As shown in Table 2, correlations between damage scores and percentage nymph survival were high and significant ($P < 0.01$).

Table 2. Correlation coefficients between damage scores and percentage nymph survival in 164 apomictic hybrids tested for resistance to nymphs of three spittlebug species

Correlations	*A. reducta*	*A. varia*	*Z. carbonaria*
Pearson	0.796**	0.756**	0.804**
Spearman	0.766**	0.757**	0.748**

** Significant at the 1% level.

Most of the 164 hybrids were resistant to nymphs on the basis of damage scores (Figure 1) and percentage nymph survival (Figure 2). Based on the combination damage scores – percentage nymph survival, most of the genotypes were classified as antibiotic (Figure 3) to all three spittlebug species indicating that careful selection for both parameters allows us to select superior genotypes with true antibiotic resistance.

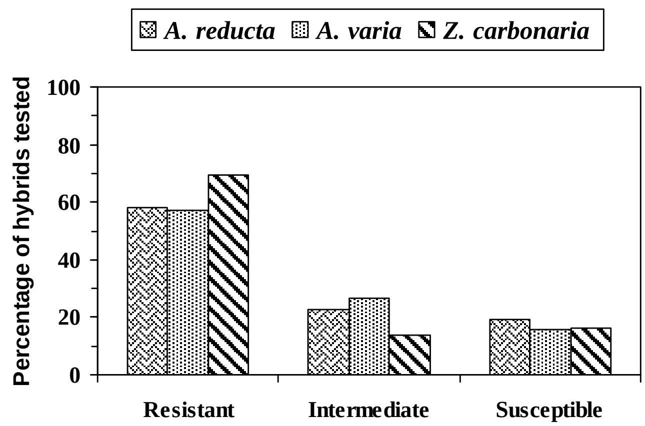


Figure 1. Classification of 164 hybrids based on damage scores (nymphs); 1 - 2, resistant; 2.1 - 3, intermediate; 3.1 - 5, susceptible.

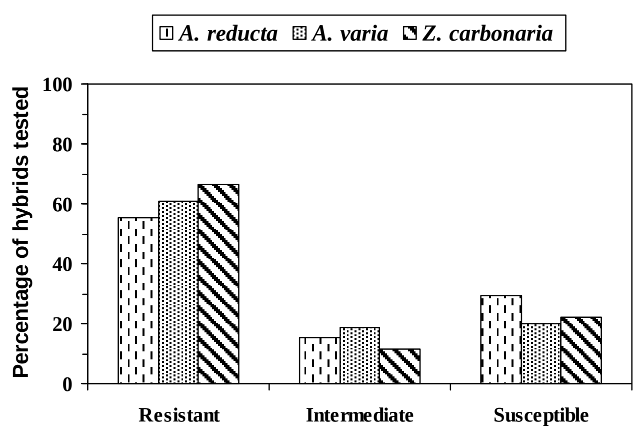


Figure 2. Classification of 164 hybrids based on nymph survival; < 30%, resistant; 30.1 – 50%, intermediate; > 50%, susceptible

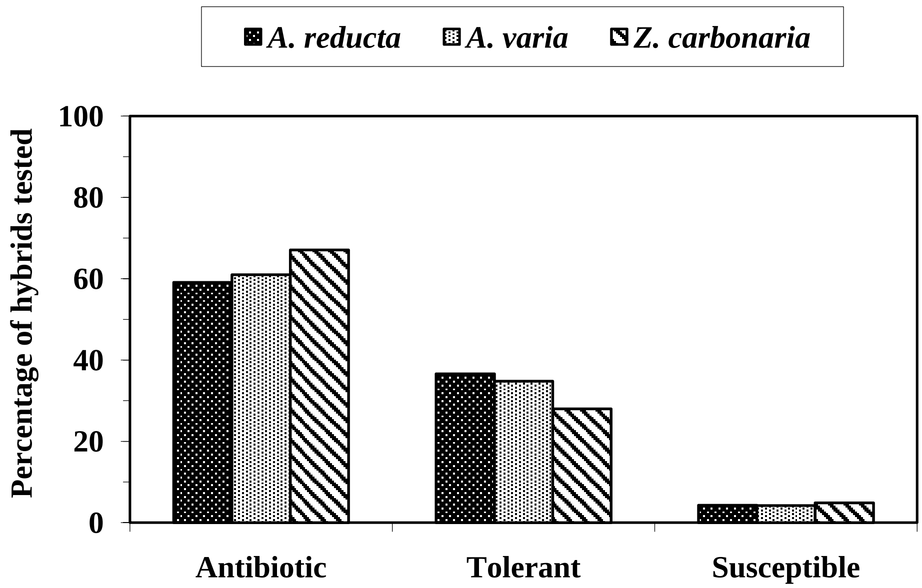


Figure 3. Frequency distribution of 164 hybrids showing antibiosis resistance, tolerance or susceptibility to nymphs three spittlebug species

Analysis of variance performed on data for both selection parameters indicated highly significant differences among genotypes. For all three species tested, those classified as resistant were as resistant as the resistant checks and highly superior to both commercial and susceptible checks (Table 3).

Table 3. Levels of resistance to nymphs of three spittlebug species detected in a set of 164 apomictic hybrids of the series BR06NO.

Type of genotype	***Aeneolamia reducta***	***Aeneolamia varia***	***Zulia carbonaria***
	Damage scores		
Resistant hybrids	1.4 ± 0.03e	1.5 ± 0.04e	1.3 ± 0.02e
Intermediate hybrids	2.5 ± 0.05c	2.6 ± 0.06c	2.7 ± 0.08c
Susceptible hybrids	3.6 ± 0.05b	3.5 ± 0.07b	3.5 ± 0.07b
	Susceptible checks		
BRX 44-02	4.8 ± 0.08	4.9 ± 0.05	4.4 ± 0.11
CIAT 0606	4.3 ± 0.10	4.5 ± 0.09	4.2 ± 0.12
Mean susceptible checks	4.6 ± 0.11a	4.7 ± 0.14a	4.3 ± 0.08a
	Commercial resistant checks		
CIAT 36087(Mulato 2)	2.0 ± 0.21	1.9 ± 0.14	1.2 ± 0.09
CIAT 6294(Marandu)	2.5 ± 0.17	2.4 ± 0.22	2.2 ± 0.15
Mean commercial checks	2.2 ± 0.11d	2.1 ± 0.14d	1.7 ± 0.13d
	Resistant checks		
SX01NO/0102	1.2 ± 0.11	1.2 ± 0.09	1.1 ± 0.05
CIAT 36062	1.3 ± 0.10	1.3 ± 0.09	1.5 ± 0.09
Mean resistant checks	1.3 ± 0.11e	1.2 ± 0.13e	1.3 ± 0.06e

Continues…

Table 3. Levels of resistance to nymphs of three spittlebug species detected in a set of 164 apomictic hybrids of the series BR06NO.

Type of genotype	*Aeneolamia reducta*	*Aeneolamia varia*	*Zulia carbonaria*
	Percentage nymph survival		
Resistant hybrids	6.5 ± 0.91d	6.4 ± 0.73e	6.8 ± 0.75f
Intermediate hybrids	42.5 ± 1.73c	46.2 ± 1.23c	38.6 ± 1.78c
Susceptible hybrids	64.6 ± 1.26b	66.1 ± 1.36b	63.2 ± 1.22b
	Susceptible checks		
BRX 44-02	93.3 ± 2.18	88.9 ± 3.51	80.9 ± 4.22
CIAT 0606	91.7 ± 2.89	94.0 ± 2.21	74.4 ± 6.27
Mean susceptible checks	92.5 ± 3.27a	91.4 ± 2.74a	77.6 ± 2.88a
	Commercial checks		
CIAT 36087 (Mulato 2)	35.6 ± 10.14	35.6 ± 6.05	8.9 ± 4.26
CIAT 6294 (Marandu)	52.1 ± 7.50	26.9 ± 4.82	53.3 ± 6.54
Mean commercial checks	43.4 ± 3.33c	31.5 ± 2.79d	31.1 ± 2.83d
	Resistant checks		
SX01NO/0102	6.7 ± 5.58	0.0	6.7 ± 3.17
CIAT 36062	4.4 ± 1.97	3.6 ± 2.57	19.9 ± 5.90
Mean resistant checks	5.6 ± 3.22d	1.8 ± 2.74f	13.3 ± 2.83e

Means of 10 reps per genotype per 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.

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

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

Rationale

Assessment of spittlebug resistance under natural levels of infestation in the field is very 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 Annual Report, the genotypes (usually 10 replicates) are initially infested in the greenhouse with an average of 10 eggs per stem. 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 stems per clump 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, 9 screening trials (three with *A. varia*, two with *Zulia carbonaria*, two with *Z. pubescens*, and two with *Mahanarva* *trifissa*) were conducted in Caquetá in 2007. The main purpose of these trials was to reconfirm resistance in 42 BR 05-RZ 05 apomictic hybrids previously evaluated in Palmira for insect and disease resistance 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 of the BR05 and RZ05 hybrids tested were resistant to spittlebug. Those combining resistances to two or more species are listed in Table 4.

Table 4. 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*
Selected hybrids				
BR05NO/0671	0.93	1.06	0.74	1.19
BR05NO/0731	0.96	1.24	0.91	1.03
BR05NO/1447	0.79	1.49	0.87	1.07
BR05NO/1857	0.89	1.16	1.04	0.98
RZ05NO/3355	0.96	1.13	1.10	0.99
RZ05NO/3362	0.82	1.20	0.99	1.04
RZ05NO/3377	0.85	1.65	1.04	1.10
RZ05NO/3397	0.83	1.19	1.09	1.02
RZ05NO/3483	0.80	1.39	1.00	1.10
RZ05NO/3579	0.78	1.15	1.07	0.98
Mean selected hybrids	0.86a	1.27a	0.98a	1.05a
Resistant checks				
CIAT 6294	0.99	1.03	0.95	1.05
CIAT 36062	1.02	1.01	0.96	1.01
Mean resistant checks	1.00a	1.02b	0.95a	1.03a
Commercial checks				
CIAT 36087	0.96a	1.04b	0.99a	1.01a
Susceptible checks				
CIAT 0606	0.32	0.43	0.41	0.58
BRX44-02	0.28	0.37	0.36	0.47
Mean susceptible checks	0.30b	0.45c	0.38b	0.52b

Means of 10 reps per genotype per species per trial; 2 trials in the case of *A. varia*, and *Z. pubescens,* 3 trials with *Z. carbonaria* and one with *M. trifissa*. 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.

1.4.3 Identify host mechanisms for spittlebug resistance in *Brachiaria*

Highlights

- The mass screening technique to screen for resistance to adult feeding damage was successfully utilized to screen the 164 BR06 hybrids for resistance to adults of three species

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

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

Rationale

Our studies have clearly identified nymphal antibiosis as the main mechanism of resistance to several different species of spittlebug in many different *Brachiaria* genotypes. In fact, we have also been able to document rapid progress 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 as damaging as the 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* was studied in detail in 2006. For the first time, in 2007 the new technique was utilized to study the levels of resistance to adults in the same set of 164 BR06 hybrids that were evaluated for resistance to nymphs. This allowed us to compare between resistance to nymphs and resistance to adults in the materials that are being handled within the recurrent selection scheme that is being followed to breed for superior *Brachiaria* genotypes.

Materials and Methods

Three spittlebug species were utilized: *A. varia, A. reducta*, and *Z. carbonaria*. Based on results obtained in 2005 and 2006, twenty-day old plants were infested with four neonate adults per plant and the infestation was allowed to proceed until all adults died (usually, 8-10 days after infestation). Percentage adult survival was recorded on a daily basis. Damage scores in a 1-5 visual damage score scale were taken 10 days after infestation. To measure chlorophyll loss as a result of adult feeding, we used a SPAD-502 chlorophyll meter 10 days after infestation. Four representative readings per plant were taken and their averages were recorded. SPAD index values were then calculated with respect to the uninfested checks. At the end of the trial, when all insects had died, plants were cut at soil level 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. These methodologies were used to test for resistance 164 BR06 hybrids *Brachiaria* genotypes of well-known reaction to nymphal attack.

Results and Discussion

At the level of infestation used in these experiments, adult survival was not affected by the genotypes. This confirms previous results indicating that antibiosis does not seem to play a role in resistance to adult feeding damage. As shown in Table 5, correlations between damage scores and percentage chlorophyll loss were high and significant ($P < 0.01$).

Table 5. Correlation coefficients between damage scores and percentage nymph survival in 164 apomictic hybrids tested for resistance to adults of three spittlebug species

Correlations	*A. reducta*	*A. varia*	*Z. carbonaria*
Pearson	0.773**	0.669**	0.803**
Spearman	0.750**	0.586**	0.748**

** Significant at the 1% level.

On the basis of damage scores, most of the 164 BR06 hybrids tested were susceptible to the three spittlebug species tested. However, some levels of intermediate resistance to all three species were detected. None of the hybrids was classified as resistant (Figure 4).

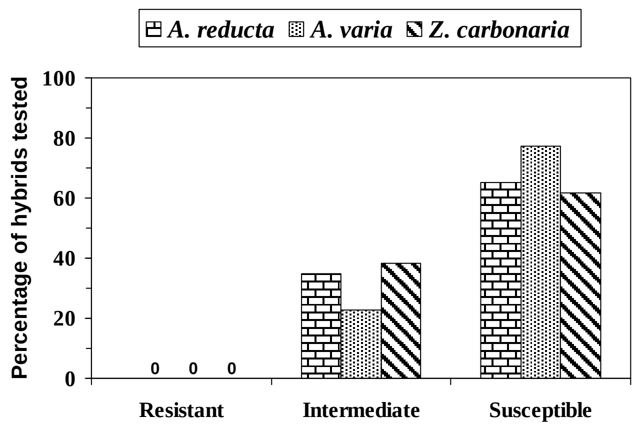


Figure 4. Classification of 164 hybrids based on damage scores (adults). 1 - 2, resistant; 2.1 - 3, intermediate; 3.1 - 5.0, susceptible.

Based on percentage chlorophyll loss (Figure 5), most of the hybrids were classified as susceptible and a few as intermediate. No resistance to *A. varia* and *Z. carbonaria* was detected. A few of the hybrids showed resistance (less chlorophyll loss) due to *A. reducta* attack. However, calculation of functional plant loss indexes (a combination of damage scores and biomass losses) revealed that average losses due to adult feeding were high in all but a few of the hybrids tested (Figure 6). This means that, in general, the levels of tolerance to adult feeding in most of these genotypes are not high enough to prevent significant losses due to insect attack. Graphic representation of results obtained with nymphs and adults (Figure 7) and statistical analysis of the data (Table 6) clearly revealed that while high levels of antibiotic resistance to nymphs have been incorporated, no significant levels of tolerance to adults have been achieved. This suggests that there is a need to select for this characteristic in forthcoming cycles of recurrent selection

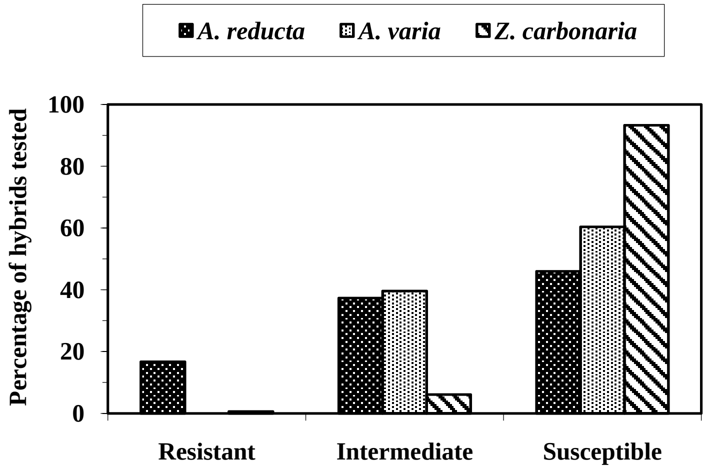


Figure 5. Classification of 164 hybrids based on percentage chlorophyll loss due to adult damage < 20%, resistant; 20.1 – 40, intermediate; > 40%, susceptible.

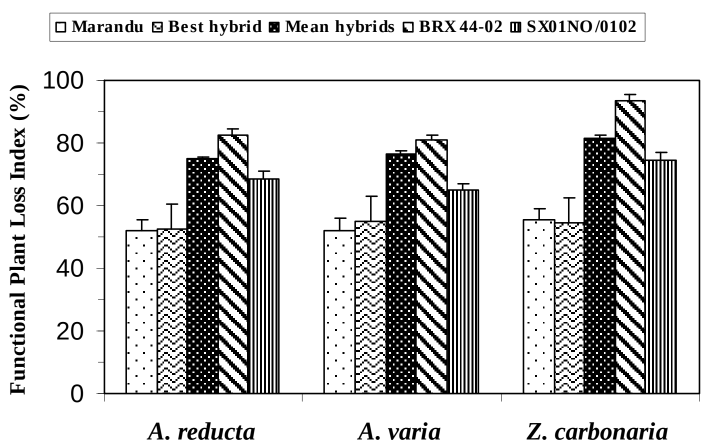


Figure 6. Functional plant loss indexes calculated for 164 BR06 hybrids tested for resistance to adults of three spittlebug species.

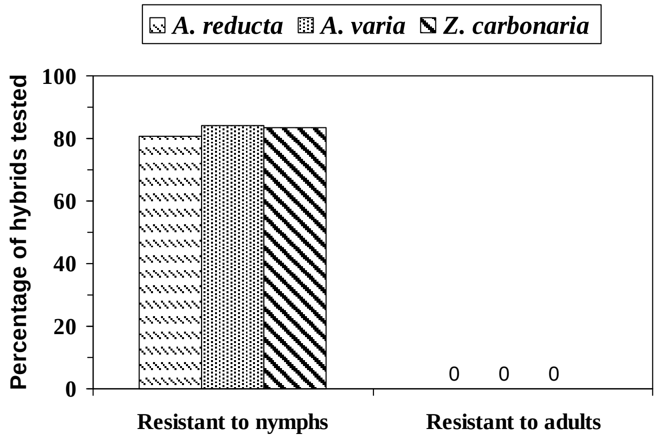


Figure 7. Classification of 164 hybrids based on damage scores due to nymphs and adults of three spittlebug species.

Table 6. Levels of resistance to adults of three spittlebug species detected in a set of 164 apomictic hybrids of the series BR06NO.

Type of genotype	*Aeneolamia reducta*	*Aeneolamia varia*	*Zulia carbonaria*
	Damage scores		
Resistant hybrids	1.8 ± 0.052e	1.8 ± 0.07d	1.9 ± 0.08e
Intermediate hybrids	2.8 ± 0.02c	2.7 ± 0.03c	2.8 ± 0.04c
Susceptible hybrids	3.9 ± 0.02a	4.1 ± 0.02a	4.2 ± 0.02a
	Susceptible checks		
BRX 44-02	3.7 ± 0.14	3.7 ± 0.15	4.6 ± 0.11
CIAT 0606	3.6 ± 0.16	3.6 ± 0.19	3.5 ± 0.23
Mean susceptible checks	3.6 ± 0.06b	3.7 ± 0.07b	4.0 ± 0.08b
	Commercial resistant checks		
CIAT 36087(Mulato 2)	1.9 ± 0.08	2.2 ± 0.10	2.2 ± 0.13
CIAT 6294(Marandu)	1.6 ± 0.06	1.7 ± 0.07	1.9 ± 0.14
Mean commercial checks	1.8 ± 0.06e	2.0 ± 0.07d	2.1 ± 0.08d
	Resistant checks		
SX01NO/0102	2.5 ± 0.12	2.6 ± 0.16	3.0 ± 0.14
CIAT 36062	2.4 ± 0.08	2.8 ± 0.17	2.6 ± 0.14
Mean resistant checks	2.5 ± 0.06d	2.7 ± 0.07c	2.8 ± 0.08c
	Percentage chlorophyll loss		
Resistant hybrids	13.8 ± 1.10e	13.9 ± 1.39e	20.9 ± 1.54e
Intermediate hybrids	31.0 ± 0.66c	30.8 ± 0.62c	41.8 ± 1.01b
Susceptible hybrids	56.4 ± 0.58a	57.3 ± 0.58a	70.9 ± 0.60a
	Susceptible checks		
BRX 44-02	53.2 ± 3.95	53.0 ± 3.15	82.5 ± 2.12
CIAT 0606	50.2 ± 2.98	45.7 ± 2.64	59.0 ± 4.60
Mean susceptible checks	51.6 ± 1.58b	49.3 ± 1.48b	70.7 ± 1.80a
	Commercial checks		
CIAT 36087 (Mulato 2)	16.3 ± 1.70	21.9 ± 2.11	29.4 ± 3.23
CIAT 6294 (Marandu)	18.5 ± 2.07	20.4 ± 2.62	24.1 ± 3.56
Mean commercial checks	17.4 ± 1.51e	21.2 ± 1.51d	26.9 ± 1.84d
	Resistant checks		
SX01NO/0102	29.1 ± 2.95	33.9 ± 2.88	42.5 ± 3.96
CIAT 36062	22.9 ± 2.38	31.1 ± 2.87	31.5 ± 4.09
Mean resistant checks	26.1 ± 1.49d	32.5 ± 1.49c	37.0 ± 1.80c

Means of 10 reps per genotype per species per trial. 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.

1.5 Define interactions between host and pathogen in *Brachiaria*.

Highlight

- Major advances were achieved in developing a reliable, high throughput screening methodology for assessing resistance to Rhizoctonia foliar blight.

1.5.1 Evaluation of *Brachiaria* hybrids for resistance to *Rhizoctonia solani*.

1.5.1.1 Develop and refine a robust, high throughput screening methodology for reaction to *Rhizoctonia solani*, based on greenhouse-grown plants and artificial inoculation

Contributors: G. Sotelo; G. Segura; X. Bonilla; J.W. Miles (CIAT)

Rationale

Rhizoctonia foliar blight is an important disease affecting susceptible brachiariagrass genotypes, particularly under humid conditions. Host plant resistance is perceived as an important component in management of the disease and minimizing its impact on animal productivity and pasture persistence. Breeding progress will be achieved only when a reliable, high throughput methodology is available to assess host plant resistance.

Materials and Methods

Vegetative propagules of test plants are grown in a PVC "unit" identical to that used in spittlebug evaluations. The aerial part of each plant is enclosed in a clear plastic bottle (recycled, 600 cc drinking water bottles). The plastic bottle serves two purposes: i) it creates a relative humidity approaching 100% surrounding the foliage of each plant, and ii) it provides a physical barrier around each plant that isolates it from it's neighbors, thus preventing unwanted cross-inoculation between plants.

Several preliminary, methodological trials were conducted in the second half of 2007, including tests of inoculation method and evaluation method.

Results and Discussion

The plastic bottle provides an effective barrier to cross-inoculation between adjacent plants. Uninoculated check plants remain healthy throughout the course of the trials, showing no symptom of Rhizoctonia.

Inoculation methods based on spraying foliage with mycilial suspension were not effective.

Methods based on physical contact between the fungus and the base of the plant stem at the soil surface were much more effective. These methods used sclerotia or Rhizoctonia-infected agar as inocula. We have tentatively settled on using two pre-germinated (to ensure viability) sclerotia, placed in direct contact with the base of the plant stem. Disease development can be assessed visually approximately two weeks following inoculation.

1.6 Genotypes of *Brachiaria* with adaptation to abiotic constraints

1.6.1 Edaphic adaptation of *Brachiaria*

Highlights

- A major outcome from collaborative research between ETH-Zurich (Swiss Federal Institute of Technology-Zurich), Switzerland and CIAT, Colombia is defining the major plant mechanisms that elucidate differences in edaphic adaptation between two *Brachiaria* grasses (signalgrass and ruzigrass) on high-Al and low-P acid soils.
- Evaluated 192 clones for phenotypic differences in root vigor and Al resistance and observed significant genetic variability in the population for Al resistance and also found transgressive segregation for Al resistance. Several clones were found to be superior in their level of Al resistance than the Al resistant parent, *B. decumbens*.
- Showed that among the 15 *Brachiaria* hybrids tested under acid soil conditions in the Llanos of Colombia, BR02NO/0465 and BR02NO/1728 were more productive than the other BR02NO hybrids in terms of green forage (leaf + stem) yield in the rainy season at 36 months after establishment with low initial fertilizer and no maintenance fertilizer application. But neither of these hybrids was superior to cv. Mulato 2. The superior adaptation of the two hybrids seems to be associated with lower amount of stem P content.

1.6.1.1 Adaptation of *Brachiaria* grasses to low P soils

Contributors: A. Louw-Gaume, N. Schweizer, A. Gaume, E. Frossard (ETH-Zürich, Switzerland) and S. M. Kerguelén and I.M. Rao (CIAT, Colombia)

Forages are a particularly versatile resource to achieve intensification in smallholder farming systems in an environmentally sustainable manner. In Latin America, the introduction of *Brachiaria* grasses have had a significant impact on livestock productivity as improved forage alternatives to native grasses. However, intensive grazing and a lack of maintenance fertilizer application results in severely degraded *Brachiaria* pastures. The development of *Brachiaria* hybrids combining different desirable traits (resistant to spittlebug, tolerant to low phosphorus (P) soil, resistant to high Al, resistant to drought and tolerant to waterlogging, high forage quality for animal nutrition, high seed production potential) is the ultimate objective of the *Brachiaria* improvement program at CIAT. The main aim of the collaborative research by scientists from CIAT in Colombia and the ETH-Zurich (Swiss Federal Institute of Technology-Zurich) in Switzerland funded by ZIL-SDC (Swiss Centre for International Agriculture-Swiss Agency for Development and Cooperation) is to define the mechanisms facilitating the survival and productivity of *Brachiaria* grasses on high-Al and low-P acid soils.

(i) Morphological and physiological mechanisms of adaptation to low-P availability

A study of low-P tolerance mechanisms in plants requires that reliable growth techniques and systems are available. In this regard, the development of both a sand-based growth system and a nutrient solution-based (hydroponic) growth system for the evaluation of morphological and physiological responses could be considered as an important result. Both these growth systems hold the potential to be used in screening procedures for the evaluation of large numbers of genetic recombinants. The applicability of the sand-based system stems from consistent differences between species that were found in a gradient of P availability, an approach that involved evaluation of plant growth parameters in the presence of both soluble and insoluble P sources. The utility of the hydroponic system derives from the use of an apatite source as a slow-releasing P source, and where the release of phosphate ions (Pi) is pH-dependent. This system could be considered as an innovative attempt at mimicking low tropical soil P concentrations. In addition, the system proved to be useful for an investigation of growth parameters between species, and also, in particular, for studying physiological mechanisms for P uptake. Results obtained in both growth systems relied on the use of seedlings (starting from seeds) and growth responses were followed until plant maturity. Indeed, our findings suggest that the understanding of low-P tolerance mechanisms requires a distinction between plant responses on the short and long term and thorough analysis of *Brachiaria* growth and development under low P supply.

Findings from experiments in sand culture have not only provided understanding of the functionality of root traits and root plasticity responses for P acquisition, but more insight has been gathered on whole plant behavior in low-P environments. Through the implementation of ecological approaches, it was possible to develop a conceptual model of understanding plant growth parameters for low-P tolerance in the two species. The model is very useful for the functional evaluation of the plant's investment pattern by considering not only biomass allocation but also morphology and tissue structure as variation in these traits might help to overcome the constraints imposed by biomass allocation. Specific leaf area and root fineness appear to be the respective shoot and root trait to differ between species.

Studies on the role of vesicular arbuscular mycorrhizae on P uptake in the two species indicated strain-specific effects as mycorrhizal root colonization by certain mycorrhizal strains significantly altered root morphology and reduced root plasticity, suggesting that these fungi may adopt the foraging function of these grass roots. Evaluation of hydroponic-grown plants indicated that a strong link exists between the development of critical internal P concentrations for growth and the induction of physiological mechanisms for higher P uptake. A high P demand for growth in ruzigrass resulted in the earlier onset of both oxalic acid exudation and acid phosphatase secretion while in signalgrass, strong temporal coordination of these responses were found. The finding of oxalic acid as an exuded organic acid is novel as strong associations between plant P deficiency and oxalic acid in other plants were only recently reported. Indeed, together with the role of acid phosphatases in hydrolyzing organically bound-P, the exudation of oxalic acid is a finding with particular relevance for P forms present in high P-fixing tropical soils.

Overall, both morphological and physiological markers have been identified by studying two of the parental species in the *Brachiaria* breeding program and it is anticipated that these findings could be extrapolated and serve as selection criteria for the development of P efficient *Brachiaria* germplasm. In addition, early indications point towards the importance of nutrient interactions, i.e. the role of carbon and nitrogen in understanding plant P relations in brachiariagrasses.

In summary, investigations into low-P tolerance mechanisms indicated towards the importance of root morphology and root physiology in understanding P efficiency in these grasses. Root traits were investigated in relation to shoot plant traits using eco-physiological approaches which incorporated the monitoring of whole plant behavioral responses. Root morphology was found to be affected by mycorrhizal root colonization. Root physiological mechanisms with relevance for enhanced P uptake in acidic tropical soils have been identified. Specifically, the processes of exudation of oxalic acid and secretion of acid phosphatases are activated when *Brachiaria* species become P deficient. Fine-tuning in the induction process of these physiological mechanisms differed between species. Furthermore, a few *Brachiaria* hybrids with superior rooting ability under low P conditions compared with the well adapted parent, *B. decumbens*, were identified. These genotypes are of particular interest as they might hold the solution to the identification of key genes responsible for combined adaptation to high-Al and low-P soils.

(ii) Phenotypic evaluation of hybrids for identification of candidate genes responsible for low-P adaptation

One of the constraints in the phenotypic evaluation of genotypes adapted to low available P with high Al saturation conditions in the soil, is to rely on methodologies at greenhouse level that allow to identify well adapted genotypes, that also have good correlation when these are tested under real field conditions. With the intention of creating a close enough approach to these conditions, root evaluation techniques from soil grown plants that prevented loss of root integrity were designed. During the course of the project a methodology at greenhouse level was developed, using low-P and high Al saturation soil (oxisol), that established the contrasting levels of soil available P (low and high) which allow to characterize differences in adaptation to these stress conditions, both in parents and hybrids. This method can be used by the *Brachiaria* improvement program at initial stages of evaluation, where a large number of hybrids are generated, which makes field evaluations very expensive and time consuming.

In the evaluation of parental genotypes to low available P in the soil in presence of toxic levels of aluminum (Oxisol), at 6 weeks after sowing, no differences were found among the two parents (*B. decumbens*, well adapted and *B. ruziziensis*, less adapted) in most of the morphological and physiological root and shoot traits evaluated. *B. ruziziensis* showed greater amounts of root and leaf P than *B. decumbens*, which allows it to have good adaptation during short evaluation periods. Among the hybrids tested, the well adapted hybrids presented greater root length, shoot biomass and P uptake than the less adapted hybrids. Under low P supply, the leaf area was the variable that explained the most of the variability in shoot biomass production among the hybrids. The variables that correlated positively with shoot biomass (forage yield) were leaf area, root dry weight, root length, root volume and leaf, stem and root P content and total P uptake indicating that improved root vigor in low P adapted hybrids contributed to improved forage yield. In the process of validating the evaluation techniques for hybrids in low P conditions, it was found that the use of hydroponic solutions does not allow long enough periods of evaluation for the well adapted parent, *B. decumbens*, to present morphological and physiological superiority in relation to the less adapted parent, *B. ruziziensis*. Thus, a soil based system was developed for phenotypic characterization and identification of candidate genes responsible for low P adaptation.

Conclusions

Acid soil adaptation in *Brachiaria* grasses has been associated with the root traits of these grasses, specifically increasing root growth at the expense of shoot growth. In addition, previous research indicated that *B. decumbens*, one of the two grasses investigated in the present study, was able to take up large amounts of scarcely mobile soil P from an oxisol, a possibility that led to the hypothesis that novel mechanisms for P acquisition might exist in brachiariagrasses. Hence, root exudates, specifically organic acids and acid phosphatase enzymes, were proposed to have functional significance in understanding the differences in adaptation between *B. decumbens* (signalgrass) and *B. ruziziensis* (ruzigrass) to low-P soils.

A major outcome from collaborative research between ETHZ-Switzerland and CIAT, Colombia is defining the major plant mechanisms that elucidate differences in edaphic adaptation between two *Brachiaria* grasses on high-Al and low-P acid soils. The possibility now exists to use morphological and physiological markers to screen genetic recombinants for low-P tolerance in novel growth systems that were developed to mimic low P concentrations in tropical soil solutions.

1.6.1.2 Cloning and characterization of aluminum-regulated genes in *Brachiaria*

Contributors: M. E. Rodríguez-Moskera, A. F. Salcedo, M. Recio, M. Ishitani (SB-2 Project), J. Ricaurte and I. M. Rao (IP-5 Project)

Rationale

Previous research showed that there are significant physiological differences in aluminum resistance between *B. decumbens* (Al resistant) and *B. ruzisiensis* (Al sensitive). Currently, we are attempting to isolate and characterize the genes involved in such a marked difference in Al resistance to elucidate likely mechanism(s) related to Al-resistance in *Brachiaria*. In addition, we identified homologous genes of STOP1 and aluminum-activated citrate transporter in *Brachiaria* which are shown to be involved in aluminum resistance in other plants.

Materials and methods

Plant Material and RNA isolation: The methodology to obtain the plant material and total RNA was published in the 2006 forages annual report on cDNA synthesis and the details reported on data analysis were also according to the information published in that annual report.

RACE (Rapid Amplification of cDNA Ends): This technique uses the strategy of PCR for the amplification and quick isolation of specific cDNAs or genomic DNA. This technique avoids the construction and screening of genomic DNA libraries, which sometimes is very complicated and consumes a lot of time and resources. The protocol to obtain the cDNA fragments was the one provided with the BD SMART TM RACE cDNA Amplification kit (Catalog #634914, BD Biosciences Clontech) and the 5' RACE 2.0 kit (Invitrogen).

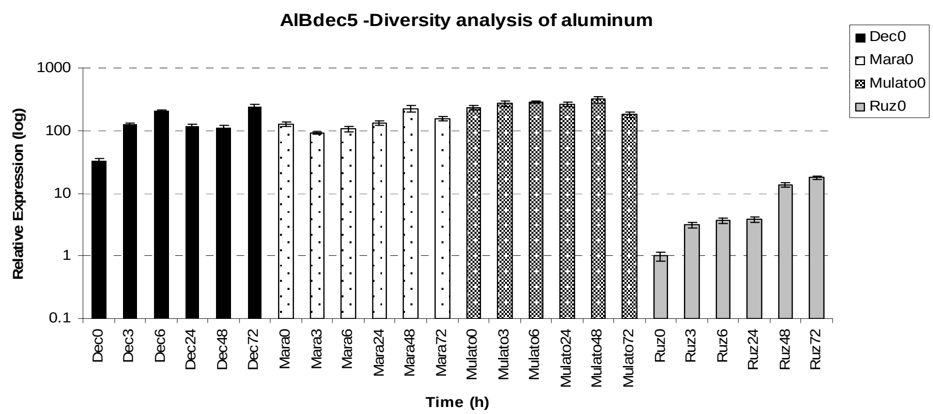
Plasmid preparation and transformation into E. coli: The fragments from the purified cDNA-RACE were sub-cloned into the pGEM-T Easy vector (Promega) taking advantage of the adenine residual Taq polimerase leaves at the 3' ends. The ligation reaction was done according to specific instructions given by the kit’s manufacturer. The electroporation method was used for transformation of plasmid DNA into E. coli cells. Selection of positive clones (plasmids that contain the specific insert) was done through the induction of the β-Galactosidase gene in plates containing LB/Amp/IPTG/X-Gal.

Gene expression analysis: Comparative expression analysis of seven differentially expressed genes in root and leaves were carried out using the root and leaf tissues from *B. decumbens*, *B. brizantha* cv Marandu, *Brachiaria* hybrid Mulato 2 and *B. ruziziensis* at 0, 3, 6, 24, 48 and 72 hours of Al-exposure. cDNA from root tips was evaluated by real time PCR using gene-specific primer. We also assessed the performance of these genes in leaves of seedlings under Al-stress conditions at 0, 6, 24 and 48 hours of exposure to with (200 μM Al) and without Al.

Results and discussion

The 7 differentially expressed genes found in *B. decumbens* -AlBdec3, AlBdec5, AlBdec8, AlBdec10, AlBdec14, AlBdec15, and AlBdec16- (refer to the IP-5 annual report of 2006 for detalis) were evaluated in four *Brachiaria* materials at different times of Al exposure (0, 3, 6, 24, 48 and 72 hours). In general terms, similar results were observed in the expression of these genes in the three Al-resistant genotypes (*B. decumbens, B. brizantha* cv Marandu, and *Brachiaria* hybrid Mulato 2) (Figure 8).

We obtained several contigs by RACE, which allowed us to deduce the complete sequence of the AlBdec10 gene (Figure 9). The BLAST algorithm enabled us to confirm that this sequence corresponds to the Metal-dependent protein hydrolase family. A probable function for the HD domain of this family corresponds to signal transduction. This family of proteins contains a large number of metal binding residues. Within this family are the phosphohydrolases, which usually are metalloenzymes that contain distinctive combinations of metal-chelating residues, typically histidines and aspartates.



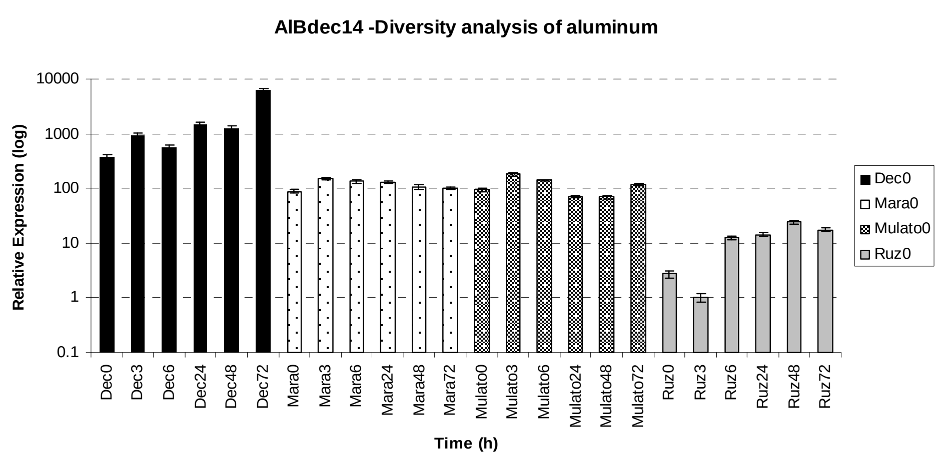


Figure 8. Gene relative differential expression obtained by Real-Time PCR from *Brachiaria* root tips. Black bars, *B. decumbes*; white bars, *B. Brizantha* cv Marandu; gray bars with white points, *Brachiaria* Hybrid Mulato II, and gray bars, *B. ruziziensis*. Logarithmic scales are presented (0, 3, 6, 24, 48 and 72 hours after Al exposure, respectively).

Sequence homologue for STOP1: Recently, a C2H2-type zinc finger transcription factor (*STOP1*) was identified as an upstream regulatory factor for AtALMT1. Iuchi *et al.,* 2007, evaluated the expression level of *STOP1* at various pH and Al treatments in *Arabidoposis* (Col-0 (WT)) by quantitative RT-PCR. Although their results indicated that *STOP1* plays a critical role in *Arabidopsis* conferring tolerance to major stress factors in acid soils, they could not conclude that STOP1 was involved in the mechanism of the phenotypic variations of Al tolerance in *Arabidopsis.*

Assembly of 3 sequences into 1 group(s)

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TGTCACAGCGAGCCGTCACGTCTCCTCTCCTTGGCATCGGCGGGCGATCCCAAATCCGGAA
CCCTTTCCCCACCATGGCGTCTCTCTCGCCGGCAGCCGCCTCCTCGCCCAAGAGGCTGCGG
GTCTACTCGTCCGCCCCCACCCCCACCGACGGCGACGGGAGCGGCAAGCGCGTGGGGACC
CACAASGGCAGCTTCCACTGCGACGAGGCGCTCGGCTGCTTYCTYATCCGCCTCACCTCCC
ARTTCRCCGGCGCYGACGTCRTCCGCACCCGCGACTCSCAGATCCTTGATACACTGGATGC
CGTGCTTGATGTTGGTGGTGTCTATGATCCCAGCCGGCACCGCTATGATCATCATCAGAAT
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ACAAGCATTTTGGTAAGGAGATAATTGCTAAGGAGCTTGGGGTTAATGAGGACCATGAAG
ATGTTCACCGCTTGTACCTTGCAATATATAAAAGCTTTGTTGAGGCACTTGACGCGATTGA
TAATGGAATCAATCAATACGACACAGACCAACCGCCAAAGTATGTGAACAATACACACTT
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GAGAATGCAGCATTTCAACAGGCAATGATGCTTGCTGGAAGTGAATTTATGGAGAGTGTTC
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GGAAAGGTTGACCCAAGTGAAGAAATCATGGTTTTGGATAGATTCTGCCCGTGGAAGCTTC
ATCTATTTGAGCTTGAAGAGGAGCTGAAGATTGATCCTCTGACCAAGTATGTGCTTTATCA
GGATGAGAGGAGCMAGAGCTGGCGAGTGCAAGCYGTTGSTGTTGCTCCYGACAGGTTCGA
GAGCCGAAAGGCTCTGCCAGAGAAGTGGAGGGGCATGAGAGACGATGAACTGTCTGCAG
AAACTGGCATTCCCGGCTGTGTGTTTGTCCATATGAGCGGTTTCATTGGGGGCAACAAGAC
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TTCCAGTAACAGTCTTTCCCCATGTTACCATTGGTTTAGTAAACACATCAGAGTTTCAGCAA
ACNCAGTCTGAAATTGGGCCTTCNCCCATGTTATCTTTGACCCATCTTCGTAGCTAACATTG
AGAATACTCATTCTGTTATCTTCGTCTTACAGAAGAGGTCTTAATTAAAATTTTCCGCCTTT
GTATTATCTGGTAATGAGCTAGAAGGTGACAATTTATTTTAAAAAAAGTGTTGGAACATAT
TAAAAAAAAAAAAAAAAAAAAAAAAAAA
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Figure 9. Alignment of three contigs of the AlBdec10 gene showing punctual variations in some nucleotides. Character in yellow shows putative polymorphism. The start codon is highlighted in blue, while the stop codon in fuchsia.

We found a partial sequence homologue of the STOP1 gene from cDNA of *B. decumbens*. We designed a set of specific PCR primers obtained from consensus sequences of this gene reported for different species in the gene bank (www.ncbi.nlm.nih.gov). By doing a Blastx and Tblastx analysis with the sequenced PCR products discovered as a query, we identified similarity with the *STOP1* gene from rice and *A. thaliana* (Figure 10).

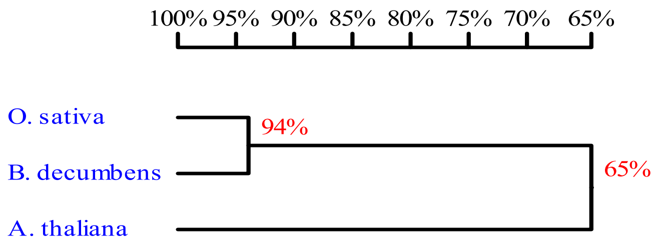


Figure 10. Similarity dendogram between translated PCR products sequences from *B. decumbens* and STOP1 protein sequences from *O. sativa* and *A. thaliana*.

Sequence homologues for aluminum-activated citrate transporter: We identified in *B. decumbens* a PCR product homologue to the HvAACT1 gene (Figure 11), which is responsible for the Al-activated citrate secretion in barley (*Hordeum vulgare)*. This gene belongs to the multi-drug and toxic compound extrusion (MATE) family and was constitutively expressed mainly in the roots of an Al-resistant barley cultivar and in apices of rice bean roots. This is consistent with the hypothesis that *Brachiaria* species might employ citrate and other organic acids to bind and detoxify Al within root apices (i.e., through internal detoxification mechanism).

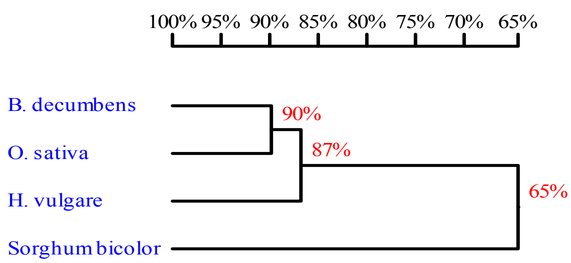
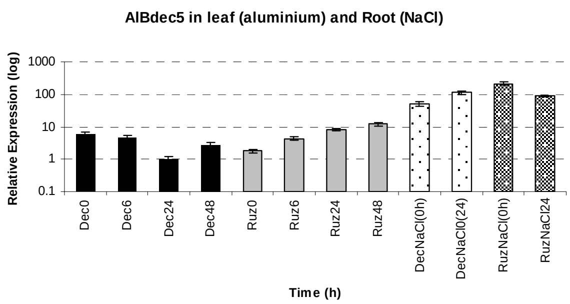


Figure 11. Similarity dendrogram between translated PCR products sequences from *B. decumbens* and MATE protein sequences from *O. sativa, H. vulgare* and *A. thaliana*.

Figure 12. Comparison of the deduced amino acid sequences of candidate genes found at the GenBank.

Partial sequence homologues of the ALMT gene: The release of organic anions from root tips has been implicated as a mechanism to protect plants from aluminum (Al) toxicity. We are examining whether homologues of TaALMT1 wheat gene are present in *B. decumbens* and whether they have differential expression between *B. decumbens* (resistant) and *B. ruzisiensis* (sensitive). We already isolated two partial TaALMT1 homologues (Figure 12).

Gene expression in Brachiaria leaves: The results showed that the expression of genes in leaves is not consistent with the expression in the root tips. In some cases, there was no differential expression between *B. decumbens* with respect to *B. ruzisiensis* (Figure 13). This was also observed in the expression of these genes in root tips of seedlings under stress by NaCl (Figure 13).



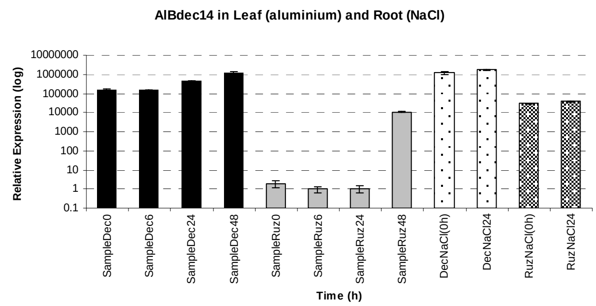


Figure 13. Gene relative differential expression obtained by Real-Time PCR from leaves (seedlings in Al solution, Black bars= *B. decumbens* and gray bars= *B. ruziziensis*) and root tips (seedlings in NaCl solution, white bars= *B. decumbens* and gray bars with white points = *B. ruziziensis*).

Root elongation of Brachiaria in hydroponicculture: We also evaluated the impact of different doses of Al on root growth and development of *Brachiaria* in hydroponic culture (data not shown). Likewise, we evaluated the effects of other types of stress on root development. Stress caused by 200 mM NaCl inhibited completely the growth of the roots in both species (Bd, Br), while 100 mM NaCl resulted in a 50% inhibition of *B. decumbens* and only 35% in *B. ruziziensis*. This trial also showed that the pH did not have a significant effect on root development of *B. decumbens* and *B. ruziziensis*. At least, under our experimental conditions we did not obtain differences in growth when seedlings were exposed to pH 4.2 or pH 6.0 (data not shown).

1.6.1.3 Phenotypic differences in aluminum resistance of genetic recombinants of the cross between *B. ruziziensis* and *B. decumbens*

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

Rationale

For the last six years, 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. This year, we evaluated 192 clones of the cross between *B. ruziziensis* x *B. decumbens* for phenotypic differences in Al resistance so that these data can be used to identify QTLs for Al resistance in *Brachiaria*. An earlier population of the same cross was affected by bacterial infection and therefore this new population was developed by the breeding team and we used this population for phenotyping for Al resistance.

Materials and methods

192 clones of the cross between *B. ruziziensis* x *B. decumbens* together with 2 parents (*B. decumbens* CIAT 606, *B. ruziziensis* 44-02) were included for evaluation of Al resistance. The clones that did not root in nutrient solution were excluded from further evaluation. Six incomplete sets (separate experiments) of the clones were evaluated with and without Al in solution. The sets were incomplete because some of the hybrids did not root well in each experiment. Mean values from all the experiments are reported. Stem cuttings of hybrids and checks 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 stained and scanned on a flatbed scanner. Image analysis software (WinRHIZO) 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, mean root diameter and root volume under both without and with Al treatment (Table 7). The results showed significant transgressive segregation for all the three root traits measured. Similar results were observed before with the previous population of the same cross.

As expected, total root length of the clones was markedly decreased with Al (Figure 14, Table 7). The mean root length was 5.7 m $plant^{-1}$ under without Al treatment and this value decreased to 2.7 m $plant^{-1}$ under with Al treatment showing a reduction of 54%. The mean root diameter increased from 0.3 mm to 0.39 mm with exposure to Al (Figure 15). The decrease in root length and increase in root diameter with Al exposure is due to Al toxicity effect on root elongation process.

Table 7. Root length and mean root diameter of 192 clones and 2 parents of the cross Br x Bd evaluated with (200 μM Al) and without Al (0 μM Al) in solution in comparison with 12 checks.

Clones	Root length ($cm\ plant^{-1}$)		Mean root diameter (mm)		Clones	Root length ($cm\ plant^{-1}$)		Mean root diameter (mm)	
	0 Al	200 μM Al	0 Al	200 μM Al		0 Al	200 μM Al	0 Al	200 μM Al
6	791	629	0.293	0.314	55	764	257	0.292	0.397
103	1032	612	0.269	0.323	187	541	257	0.263	0.361
180	931	518	0.269	0.330	114	583	255	0.291	0.416
163	928	493	0.261	0.279	99	731	255	0.268	0.290
94	661	480	0.261	0.306	78	489	253	0.334	0.402
3	1003	473	0.273	0.347	188	749	252	0.306	0.416
86	907	465	0.266	0.341	182	657	247	0.325	0.415
189	775	446	0.274	0.335	100	524	247	0.340	0.448
33	620	440	0.262	0.291	157	579	247	0.280	0.352
177	835	434	0.294	0.336	196	467	246	0.302	0.387
186	896	425	0.278	0.350	115	736	245	0.279	0.374
106	723	422	0.272	0.316	19	613	245	0.316	0.396
65	1038	420	0.283	0.340	191	595	244	0.315	0.431
90	689	419	0.313	0.366	181	492	239	0.310	0.397
174	874	412	0.299	0.379	141	582	236	0.285	0.359
2	959	411	0.275	0.290	199	578	236	0.340	0.412
59	796	409	0.314	0.393	179	390	235	0.336	0.386
79	932	406	0.272	0.335	108	589	234	0.242	0.298
80	601	405	0.335	0.390	24	681	234	0.282	0.415
154	750	396	0.290	0.368	75	503	232	0.328	0.405
23	870	394	0.277	0.330	42	449	231	0.322	0.374
121	799	389	0.248	0.337	30	487	230	0.301	0.413
56	901	389	0.278	0.366	129	372	228	0.270	0.347
197	734	379	0.304	0.357	122	599	227	0.297	0.395
109	682	378	0.244	0.323	156	304	226	0.340	0.386
36	704	378	0.270	0.348	178	454	226	0.280	0.350
66	761	374	0.263	0.330	146	615	226	0.309	0.406
41	689	373	0.275	0.353	195	529	224	0.301	0.412
53	581	369	0.295	0.317	142	533	224	0.313	0.400
134	599	368	0.322	0.390	117	644	223	0.311	0.432
14	850	364	0.314	0.412	91	578	223	0.319	0.405
93	652	359	0.303	0.369	112	339	222	0.284	0.443
92	561	357	0.293	0.363	148	663	221	0.314	0.439
31	689	353	0.302	0.424	128	531	220	0.334	0.426
21	715	350	0.280	0.329	98	531	216	0.295	0.385
192	863	350	0.268	0.345	76	585	206	0.298	0.418
68	612	348	0.295	0.335	62	514	204	0.214	0.384
111	868	347	0.297	0.403	60	377	202	0.294	0.361
13	799	347	0.277	0.370	137	484	202	0.321	0.378
113	484	345	0.332	0.375	101	514	201	0.292	0.362
172	818	345	0.318	0.412	130	630	199	0.260	0.356
155	712	338	0.254	0.328	118	214	197	0.297	0.379
171	698	333	0.333	0.412	147	419	189	0.331	0.413
89	734	332	0.260	0.326	126	554	189	0.343	0.447
8	937	323	0.296	0.297	150	480	188	0.292	0.298
25	678	323	0.259	0.373	47	337	186	0.359	0.401

Continues…

Table 7. Root length and mean root diameter of 192 clones and 2 parents of the cross Br x Bd evaluated with (200 µM Al) and without Al (0 µM Al) in solution in comparison with 12 checks.

Clones	Root length (cm plant^{-1})		Mean root diameter (mm)		Clones	Root length (cm plant^{-1})		Mean root diameter (mm)	
	0 Al	200 µM Al	0 Al	200 µM Al		0 Al	200 µM Al	0 Al	200 µM Al
85	587	321	0.288	0.347	123	296	185	0.308	0.383
81	738	321	0.323	0.418	72	275	182	0.324	0.452
176	723	318	0.284	0.346	162	597	181	0.329	0.493
159	519	315	0.282	0.341	125	300	178	0.373	0.461
167	560	314	0.276	0.339	175	536	177	0.307	0.444
173	542	313	0.269	0.323	40	398	176	0.325	0.394
190	535	312	0.322	0.389	185	328	176	0.338	0.375
151	571	311	0.288	0.366	143	417	176	0.330	0.434
194	736	311	0.287	0.348	49	366	172	0.306	0.385
16	447	309	0.236	0.337	105	343	168	0.362	0.420
69	574	309	0.339	0.392	120	395	167	0.301	0.381
198	566	306	0.267	0.341	12	408	163	0.269	0.428
7	632	303	0.331	0.380	77	476	162	0.351	0.440
87	644	302	0.300	0.393	158	317	159	0.302	0.380
18	767	302	0.277	0.355	67	501	155	0.287	0.381
165	442	302	0.330	0.415	183	465	153	0.315	0.431
34	730	300	0.285	0.368	35	276	142	0.328	0.408
184	693	296	0.310	0.397	82	355	141	0.388	0.441
15	598	296	0.293	0.353	83	480	141	0.331	0.481
84	772	294	0.268	0.307	133	258	139	0.321	0.425
127	586	293	0.341	0.429	136	239	135	0.362	0.455
139	606	290	0.286	0.352	32	273	131	0.342	0.495
149	664	289	0.327	0.409	9	229	129	0.345	0.393
64	652	288	0.265	0.406	73	386	128	0.306	0.424
135	602	287	0.292	0.384	153	441	126	0.331	0.444
58	671	285	0.311	0.375	28	366	120	0.353	0.451
110	536	285	0.276	0.357	124	223	119	0.323	0.430
26	816	285	0.267	0.335	88	321	90	0.350	0.498
96	447	282	0.303	0.397	102	281	86	0.295	0.392
70	435	281	0.300	0.374	CIAT 606	483	314	0.268	0.307
51	515	279	0.340	0.401	Bruz 44-02	190	89	0.377	0.468
160	598	278	0.314	0.368	BR02/1245	434	211	0.271	0.397
166	620	273	0.286	0.348	BR02/1372	867	360	0.259	0.332
152	557	272	0.277	0.351	BR02/1485	645	251	0.311	0.444
74	467	271	0.306	0.379	BR02/1752	510	263	0.354	0.423
61	802	270	0.287	0.386	CIAT 679	598	234	0.216	0.280
39	530	270	0.301	0.336	CIAT 6133	311	211	0.257	0.278
119	832	269	0.275	0.373	CIAT 6294	476	163	0.296	0.433
169	699	269	0.288	0.381	CIAT 26110	149	59	0.404	0.702
161	456	268	0.290	0.336	CIAT 36061	542	259	0.435	0.565
27	711	266	0.275	0.329	CIAT 36087	297	130	0.484	0.656
193	385	259	0.347	0.367					
132	578	258	0.319	0.432	**Mean**	**580**	**272**	**0.306**	**0.390**
20	401	258	0.273	0.362	**$LSD_{0.05}$**	**275**	**147**	**0.049**	**0.067**

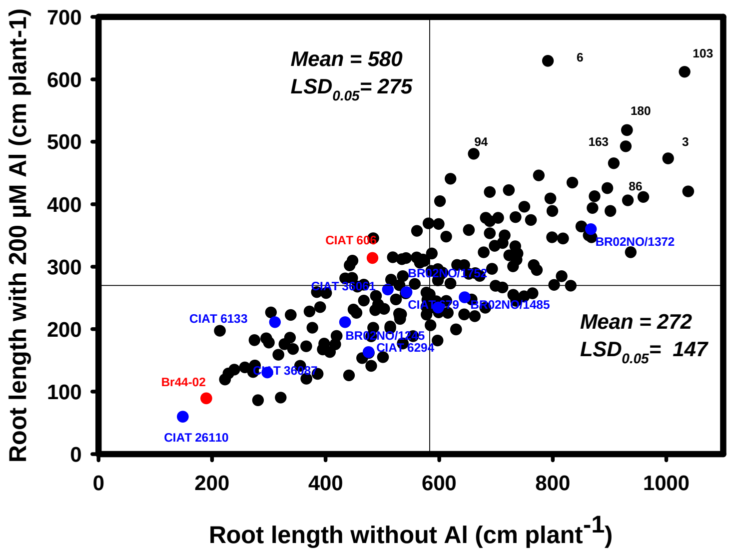


Figure 14. Relationship between total root length with Al and total root length without Al in solution of 192 clones and 2 parents of the cross Br x Bd grown for 3 weeks. *Brachiaria* gentoypes that developed greater root length under both conditions were identified in the upper, right hand quadrant.

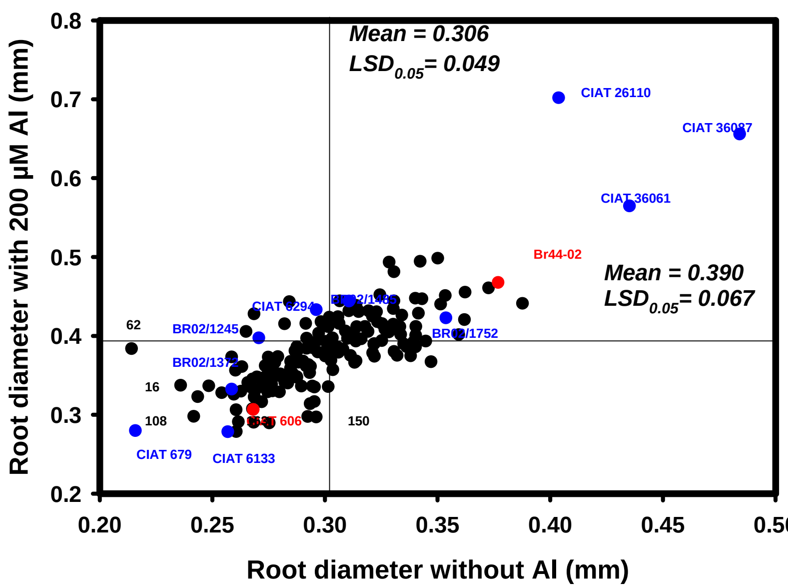


Figure 15. Relationship between mean root diameter with Al and mean root diameter without Al in solution of 192 clones and 2 parents of the cross Br x Bd grown for 3 weeks. *Brachiaria* gentoypes that developed finer roots under both conditions were identified in the lower, left hand quadrant.

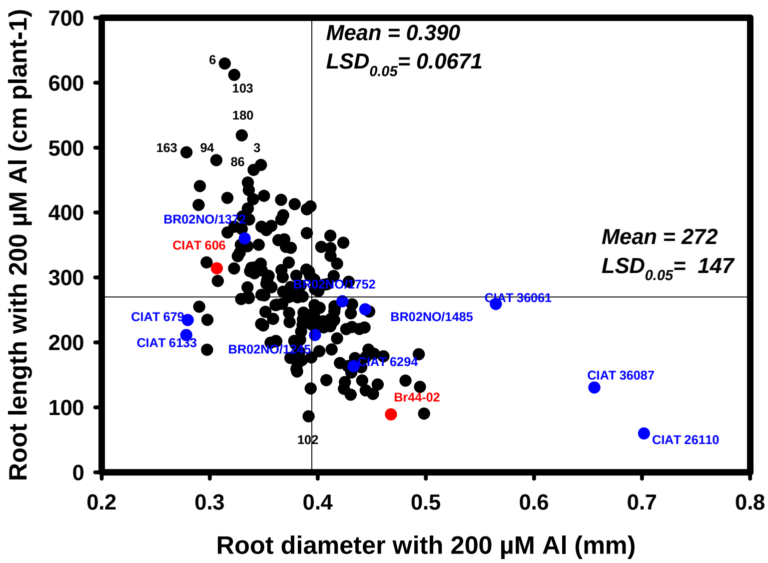


Figure 16. Relationship between total root length with Al and mean root diameter with Al in solution of 192 clones and 2 parents of the cross Br x Bd grown for 3 weeks. *Brachiaria* gentoypes that developed greater root length with finer root system were identified in the upper, left hand quadrant.

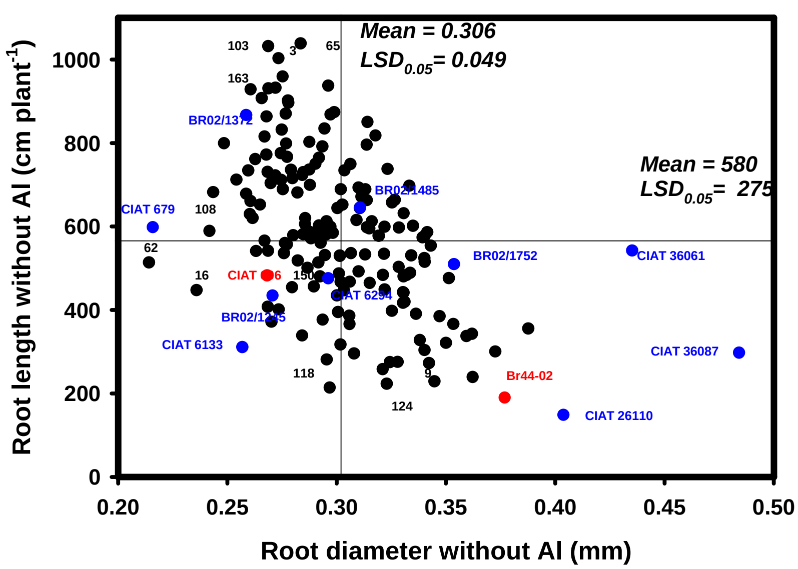


Figure 17. Relationship between total root length with Al and mean root diameter with Al in solution of 192 clones and 2 parents of the cross Br x Bd grown for 3 weeks. *Brachiaria* gentoypes that developed greater root length with finer root system were identified in the upper, left hand quadrant.

The relationship between total root length and mean root diameter under with or without Al in nutrient solution indicated that four clones (hybrids) 103, 180, 3 and 163 were outstanding in their Al resistance due to their ability to produce greater root length with lower values of mean root diameter, i.e., fine root system (Figures 15 to 17). There was significant negative relationship between total root length and mean root diameter under both with and without Al in nutrient solution (Table 8). These results are consistent with previous observations made using another population of the same cross. Clones such as 6 had higher level of Al resistance but do not have high root vigor (greater root length) in the absence of Al in nutrient solution (Table 7, Figure 17). Clones such as 2 and 65 showed very high root vigor in the absence of Al in solution but were not very resistant to Al (Figure 17, Table 7). These type of clones may be better suited to moderately fertile acid soil conditions.

Table 8. Correlation coeeficients between root length, mean root diameter and root volume of 192 clones of the cross between *B. ruziziensis* x *B. decumbens* that were evaluated under without and with Al in solution.

Root characteristics	Root length (m plant^{-1})	
	0 µM Al	200 µM Al
Root diameter	-0.44**	-0.48**
Root volume	0.71**	0.72**

*, ** significant at the probability level of 0.05 and 0.01, respectively.

Results on the relationship between total root volume and total root length under with or without Al in nutrient solution are shown in Figure 16. Total root length showed highly positive correlation with root volume (Table 8). Clones such as 103 and 163 combined high root vigor with higher level of Al resistance than the Al resistant parent, Bd (Figures 15 and 16). These 2 clones could serve as source of genes in the breeding program for high root vigor and Al resistance.

It is desirable to identify *Brachiaria* hybrids that are not only resistant to toxic level of Al in soil but also responsive to moderately fertile soil conditions through high root vigor. Clones such as 2, 103, 163, 65, 180, 3 and 86 showed this combination of root traits (Table 7, Figure 17).

Figure 18 shows the phenotypic differences in root system development among the 2 parents (Al resistant Bd, Al sensitive Br) and 2 selected clones (Al resistant clone 163 and Al-sensitive clone 133) when grown under with or without Al in solution. Clone H-163 showed greater root vigor and Al resistance than the Al resistant parent Bd while clone 33 was inferior to Al sensitive parent, Br under both with and without Al in solution. The extent of phenotypic variation observed in this population for root vigor and Al resistance indicates that it is possible to develop *Brachiaria* hybrids with great root vigor and Al resistance together with other desirable traits. There was a marked effect of transgressive segregation for root traits in *Brachiaria*. These results are consistent with our previous observations.

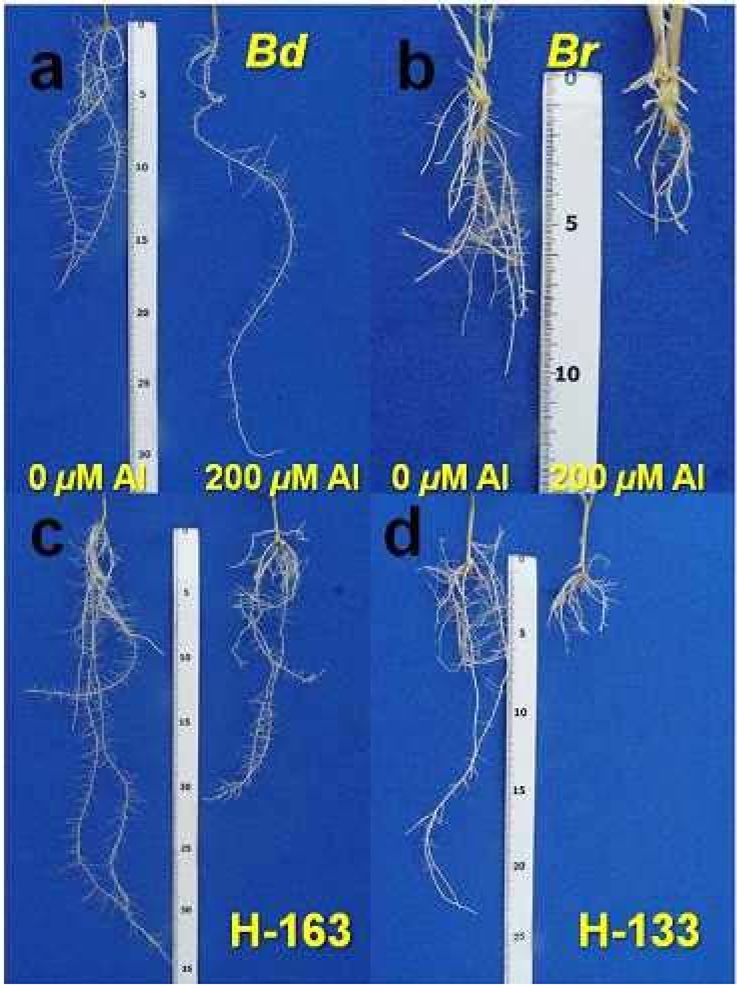


Figure 18. Phenotypic differences in root development of *Bd*, *Br* and 2 selected clones grown in nutrient solution in the absence or presence of Al for 3 weeks: a) root system of Al resistant parent, Bd; b) root system of Al sensitive parent, *Br;* c) root system of Al resistant clone, 163; and d) root system of Al sensitive clone, 133.

Conclusions

We evaluated 192 clones for phenotypic differences in root vigor and Al resistance and observed significant genetic variability in the population for 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 will be used to identify QTLS related to Al resistance in *Brachiaria*.

1.6.1.4 Field evaluation of promising hybrids of *Brachiaria* in the Llanos of Colombia

Contributors: J. Ricaurte, C. Plazas, J. Miles and I. M. Rao (CIAT)

Rationale

Field evaluation of a number *Brachiaria* hybrids under infertile acid soil conditions with low or high amounts of initial application of fertilizer and application of maintenance fertilizer with half of the amounts of initial applications at 2 year intervals improved the persistence of several hybrids and not allowed to distinguish differences between moderately adapted cultivars (cv. Marandu) and the promising hybrids. Therefore a field experiment was established in 2004 with 15 hybrids along with the 3 parents and 4 checks with low amounts of initial fertilizer and no maintenance fertilizer application to select hybrids that persist and produce green forage under acid infertile soil conditions. In 2005, we showed that among the 15 *Brachiaria* hybrids tested, BR02NO/1794 and BR02NO/0465 were more productive than other hybrids in terms of green forage (leaf + stem) yield in the rainy season at 13 months after establishment with low initial fertilizer application and this adaptation seems to be closely associated with lower amounts of stem N content. In 2006, we showed that BR02NO/0465 and BR02NO/1728 were more productive than the other BR02NO hybrids in terms of green forage (leaf + stem) yield in the rainy season at 26 months after establishment with low initial fertilizer and no maintenance fertilizer application. But neither of these hybrids was superior to cv. Mulato 2. The superior adaptation of the two hybrids seems to be associated with lower amounts of stem N and P content. In 2007, we tested the performance of these hybrids in the rainy season at 36 months after establishment with no maintenance fertilizer application.

Materials and methods

A field trial was established at Matazul farm on 29 June of 2004. The trial included 15 *Brachiaria* hybrids (BR02NO/0465; BR02NO/0768; BR02NO/ 0771; BR02NO/0799; BR02NO/1245; BR02NO/1372; BR02NO/1452; BR02NO/1485; BR02NO/1718; BR02NO/1720; BR02NO/1728; BR02NO/1747; BR02NO/1752; BR02NO/1794 and BR02NO/1811), three parents (*B. decumbens* CIAT 606 and *B. brizantha* CIAT 6294 and *B.ruziziensis* 44-02) and four CIAT checks (*B.brizantha* CIAT 26110, *B.brizantha* CIAT 26646, *Brachiaria* hybrids CIAT 36061-Mulato and CIAT 36087- Mulato 2).

The trial was planted as a randomized block with 4 replications. One low level of initial fertilizer application was applied (kg/ha of 20 P, 20 K, 33 Ca, 14 Mg, 10 S) at the time of establishment. Maintenance fertilizer was not scheduled for application in order to identify genotypes that are better adapted to infertile acid soil conditions. The plot size was 5 m x 2.5 m. A number of plant attributes including forage yield, dry matter distribution, shoot P uptake and shoot (leaf and stem) total nonstructural carbohydrate (TNC) content were measured in the rainy season at 36 months after establishment (August, 2007).

Results and discussion

At 9 months after establishment CIAT 606, CIAT 36061, CIAT 36087, BR02NO/1452, BR02NO/1485, BR02NO/1720, BR02NO/1747, BR02NO/1752 and BR02NO/1794 were affected by bacterial infection and this affected their performance.

At 36 months after establishment, the dead shoot biomass was greater with 3 hybrids (BR02NO/0465, BR02NO/1811 and BR02NO/1728) than with the other hybrids tested (Figure 19, Table 9). Production of green leaf biomass was greater with CIAT 26110, CIAT 36087 and CIAT 6294. The two hybrids BR02NO/1811 and BR02NO/0465 were outstanding in the production of stem biomass and therefore also in total biomass production. As expected BRUZ 44-02 (sexual parent) did not persist under no maintenance fertilizer. Among the hybrids tested, BR02NO/0465 and BR02NO/1728 were more productive than the other BR02NO hybrids in terms of green forage (leaf + stem) yield (Table 9). These 2 hybrids were also outstanding in their performance at 26 months after establishment. But these 2 hybrids were less productive than CIAT 36087 (cv. Mulato 2). The hybrid Mulato 2 outperformed the checks and the hybrids. Results on shoot phosphorus uptake also indicated that the hybrid BR02NO/0465 was superior to the other BR02NO hybrids (Figure 20, Table 9). These results were similar to those found at 26 months after establishment. The amount of TNC in leaves and stems were lower for the hybrid BR02NO/0465 compared with the other BR02NO hybrids. The lower values of TNC may indicate greater utilization of photosynthates for leaf expansion.

Table 9. Genotypic variation in shoot biomass production, shoot P uptake and shoot TNC (total nonstructural carbohydrate) content of three parents (CIAT 606, 6294 and *B.ruziziensis* 44-02), four CIAT accessions (26110, 26646, 36061 and 36087) and 15 genetic recombinants (BR02NO/0465; 0768; 0771; 0799; 1245; 1372; 1452; 1485; 1718; 1720; 1728; 1747; 1752; 1794 and 1811) of *Brachiaria* grown in a sandy loam oxisol at Matazul, Colombia. Plant attributes were measured at 36 months after establishment (August 2007). LSD values are at the 0.05 probability level. NS = not significant.

Genotypes	Shoot biomass (kg ha^{-1})					Shoot P uptake	Shoot TNC (mg g^{-1})	
	Leaves	Stems	Living (L+S)	Dead	Total biomass	(kg ha^{-1})	Leaves	Stems
BR02NO/0465	**1371**	**1042**	**2413**	**391**	**2804**	**3.863**	**99**	**99**
BR02NO/0768	409	49	458	103	561	0.821	175	120
BR02NO/0771	331	63	394	95	489	0.778	162	118
BR02NO/0799	169	68	237	183	420	0.458	148	114
BR02NO/1245	723	375	1098	226	1324	2.877	139	107
BR02NO/1372	491	258	749	308	1057	1.497	178	110
BR02NO/1452	207	74	281	125	406	0.554	142	103
BR02NO/1485	566	209	775	307	1082	1.778	162	124
BR02NO/1718	240	96	336	142	478	0.741	159	132
BR02NO/1720	421	278	699	200	899	1.249	137	103
BR02NO/1728	**707**	**732**	**1439**	**485**	**1924**	**2.257**	**139**	**86**
BR02N0/1747	320	273	593	219	812	1.168	166	128
BR02NO/1752	410	239	649	351	1000	1.273	167	141
BR02NO/1794	584	404	988	296	1284	1.767	159	125
BR02NO/1811	577	1145	1722	294	2016	2.761	137	108
Bruz44-02	.	.	.	.	.	.	.	.
CIAT 606	344	267	611	414	1025	1.016	169	111
CIAT 6294	994	543	1537	898	2435	2.800	140	132
CIAT 26110	1894	800	2694	381	3075	3.813	145	132
CIAT 26646	775	466	1241	329	1570	2.277	158	144
CIAT 36061	425	178	603	82	685	1.225	133	147
CIAT 36087	1532	368	1900	203	2103	3.908	110	135
Mean	**642**	**377**	**1020**	**287**	**1307**	**1.851**	**149**	**120**
LSD (p<0.05)	**389**	**371**		**317**		**1.460**		

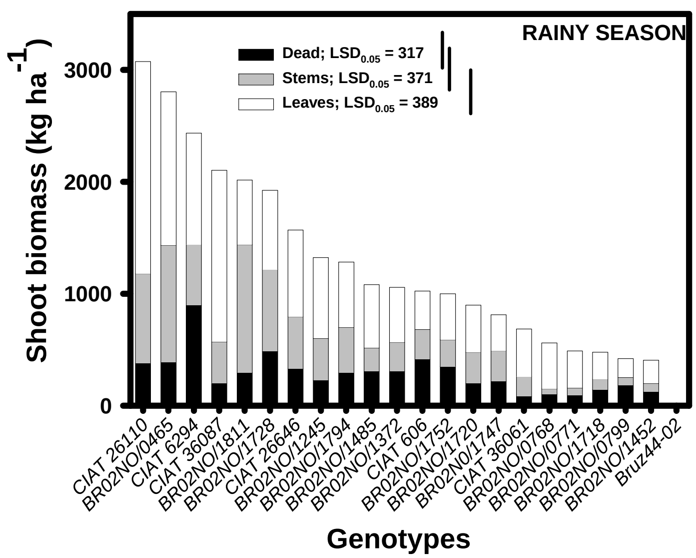


Figure 19. Genotypic variation in shoot biomass production (forage yield) of three parents (CIAT 606, 6294 and *B.ruziziensis* 44-02), four CIAT accessions (26110, 26646, 36061 and 36087) and 15 genetic recombinants (BR02NO/0465; 0768; 0771; 0799; 1245; 1372; 1452; 1485; 1718; 1720; 1728; 1747; 1752; 1794 and 1811) of *Brachiaria* grown in a sandy loam oxisol at Matazul, Colombia. Plant attributes were measured at 36 months after establishment (August 2007). LSD values are at the 0.05 probability level. NS = not significant.

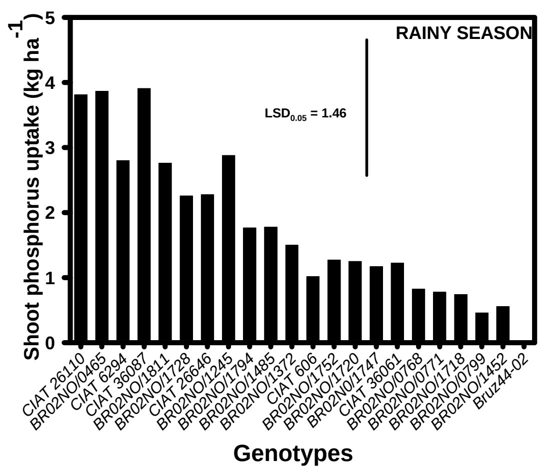


Figure 20. Genotypic variation in living shoot phosphorus of three parents (CIAT 606, 6294 and *B.ruziziensis* 44-02), four CIAT accessions (26110, 26646, 36061 and 36087) and 15 genetic recombinants (BR02NO/0465; 0768; 0771; 0799; 1245; 1372; 1452; 1485; 1718; 1720; 1728; 1747; 1752; 1794 and 1811) of *Brachiaria* grown in a sandy loam oxisol at Matazul, Colombia. Plant attributes were measured at 36 months after establishment (August 2007). LSD values are at the 0.05 probability level. NS = not significant.

Correlation coefficients between green forage yield and other plant attributes indicated that greater phosphorus acquisition contributed to superior performance (Table 10). Significant negative correlation was observed between leaf total nonstructural carbohydrate (TNC) content and live forage yield. Adaptation to infertile acid soil conditions seem to be closely associated with lower amounts of stem P content. This indicates the importance of greater P use efficiency to produce forage yield.

Table 10. Correlation coefficients (r) between green forage yield (t/ha) and other shoot traits of *Brachiaria* genotypes grown with low initial fertilizer application in a sandy loam oxisol in Matazul, Colombia.

Shoot traits	Low fertilizer
Total (live + dead) shoot biomass (t/ha)	0.96***
Dead shoot biomass (t/ha)	0.32**
Leaf biomass (t/ha)	0.93***
Stem biomass (t/ha)	0.88***
Leaf TNC content (mg g^{-1})	-0.36 ***
Leaf P content (%)	-0.16
Stem TNC content (mg g^{-1})	-0.07
Stem P content (%)	-0.38***
Shoot P uptake (kg/ha)	0.89***

Conclusions

Results from this field study indicated that among the 15 *Brachiaria* hybrids tested, BR02NO/0465 and BR02NO/1728 were more productive than the other BR02NO hybrids in terms of green forage (leaf + stem) yield in rainy season at 36 months after establishment with low initial fertilizer application and no maintenance fertilizer application. But neither of these hybrids was superior to cv. Mulato 2. The superior adaptation of the two hybrids seems to be associated with lower amount of stem P content.

1.6.2 Genotypes of *Brachiaria* with dry season tolerance

Highlights

- Greenhouse study using soil tubes showed 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.
- Showed that among the 15 *Brachiaria* hybrids tested under acid soil conditions in the Llanos of Colombia, four hybrids BR02NO/1794, BR02NO/1372, BR02NO/1245 and BR02NO/0465 were more productive than the other BR02NO hybrids in terms of green forage (leaf + stem) yield in the dry season at 32 months after establishment with low initial fertilizer and no maintenance fertilizer application. The superior adaptation of these three hybrids seems to be associated with greater uptake of phosphorus.

1.6.2.1 Phenotypic differences in adaptation to drought stress in *Brachiaria* grasses

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

Rationale

Water stress results in a decrease in cell volume, an increase in the concentration of cellular sap and the progressive dehydration of the protoplasm. There is no living process that is unaffected by a decrease in water potential. The first response to water deficits is a restriction in leaf expansion that results in reduced leaf growth under water stress. Total biomass as well as the partitioning of biomass between the shoot and the roots is influenced by the plant water status. In most cases, when water is limiting, an increase in root production relative to the shoot has been observed. There is very limited knowledge on the physiological and biochemical bases of adaptation of *Brachiaria* grasses to drought. Seasonal drought affects both quantity and quality of forage in tropical subhumid environments. *Brachiaria* grasses differ in drought resistance. *B. brizantha* CIAT 6780, *B. decumbens* CIAT 606, Mulato and Mulato 2 are known to be relatively more adapted to drought stress. Our objective was to determine 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.

Materials and methods

A greenhouse experiment was conducted to determine differences in shoot and root attributes of 12 *Brachiaria* genotypes (3 parents of the breeding program: *Brachiaria decumbens* CIAT 606, *Brachiaria ruziziensis* 44-02, and *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 and SX03/2367) that were subjected to drought conditions for 21 days.

The experimental system to evaluate the response to drought stress is shown in Figure 21. Plants were sown in 80 cm plastic tubes using one stolon per soil tube containing 5.5 kg of Matazul soil mixed with sand in a 2:1 ratio with a final bulk density of 1.33 g cm-3. 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). These plastic soil tubes were inserted into PVC tubes to decrease higher temperature effects in the greenhouse. The average maximum and minimum temperature values were 35ºC and 21ºC, respectively with a maximum photon flux density of 1000 µmol m-2 s-1. Three watering levels were maintained: 100% field capacity (FC) as control or well watered, 50% FC to simulate intermittent drought and terminal drought by withholding water after establishment. The treatments of 100% FC and 50% FC were kept at their respective levels by weighing the soil tubes at every 2 days and applying water to the surface of the soil. Terminal drought treatment was imposed at three weeks after planting. The experiment comprised a completely randomized block design with 3 replicates (watering levels as main plots and genotypes as subplots).

At harvest, shoot traits such as leaf biomass, stem biomass, leaf area, and total nonstructural carbohydrates, ash, nitrogen and phosphorous contents in leaves and stems were determined. Other shoot traits such as leaf chlorophyll content, rate of transpiration and stomatal conductance were also determined at weekly intervals during the stress treatment.

For the root traits, at the time of harvest, the soil tubes were cut into 0-5, 5-10, 10-20, 20-40, 40-60, 60-75 cm soil depths in order to determine root length, mean root diameter and root volume across soil depth and total nonstructural carbohydrates at the 0-20 and 20-40 cm soil depth. These samples were washed free of soil using a hydropneumatic elutriation system (Gillison's Variety Fabrication, Benzonia, Michigan, USA). 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 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.

The results were analyzed using the GLM procedure and LSD test of SAS v.9 for Windows. Pearson correlation coefficients served as a tool to screen variables for higher association with shoot biomass.

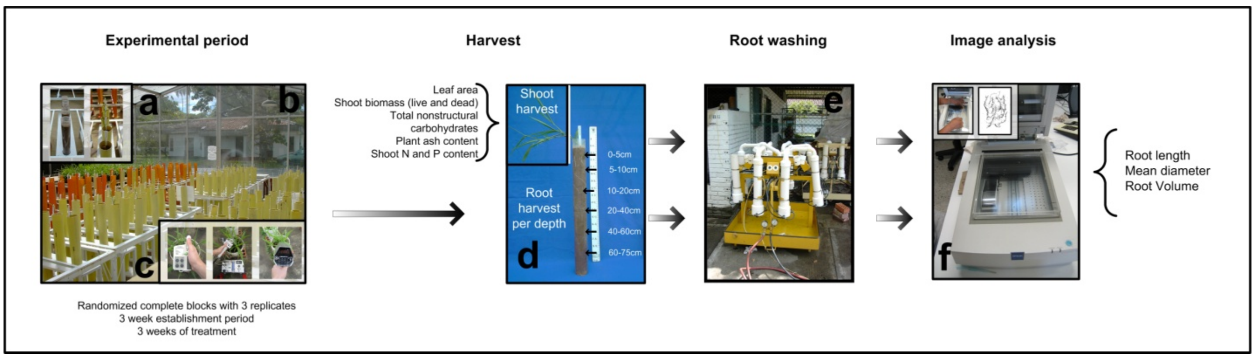


Figure 21. Methodology for screening Brachiaria genotypes, a) plastic tubes were covered with PVC pipes to protect from higher temperature, b) final arrangement of the experiment, c) chlorophyll, rate of transpiration, stomatal conductance and leaf temperature were measured at weekly intervals for 21 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.

Results and discussion

Highly significant differences were found among genotypes and treatments ($p<0.01$) on live shoot biomass production (Figure 22). However, there was no effect on genotype x watering level interaction in shoot biomass production. Genotypic differences in shoot biomass were nonsignificant for well watered or control treatment but were significant for terminal and intermittent drought treatments. It is important to note that adequate amount of nutrients were supplied in the system. It is known that under lower nutrient supply *B. decumbens* CIAT 606 performs better than *B. brizantha* CIAT 6294 and *B. ruziziensis* 44-02. As expected, drought reduced the genotypic mean values of shoot biomass by 39% and 70% for intermittent and terminal drought, respectively. Among the 12 genotypes tested, *Brachiaria decumbens* CIAT 606 performed better under water stress conditions while the sexual hybrid SX03/0881 was the poor performer in terms of shoot biomass production. Among the hybrids, Mulato CIAT 36061 performed better under both intermittent and terminal drought stress. The sexual parent *Brachiaria ruziziensis* 44-02 was outstanding in producing shoot biomass under control treatment but its shoot growth was markedly affected by drought stress, particularly with terminal drought stress (Figure 22). This genotype requires adequate nutrient supply to perform better under well watered conditions.

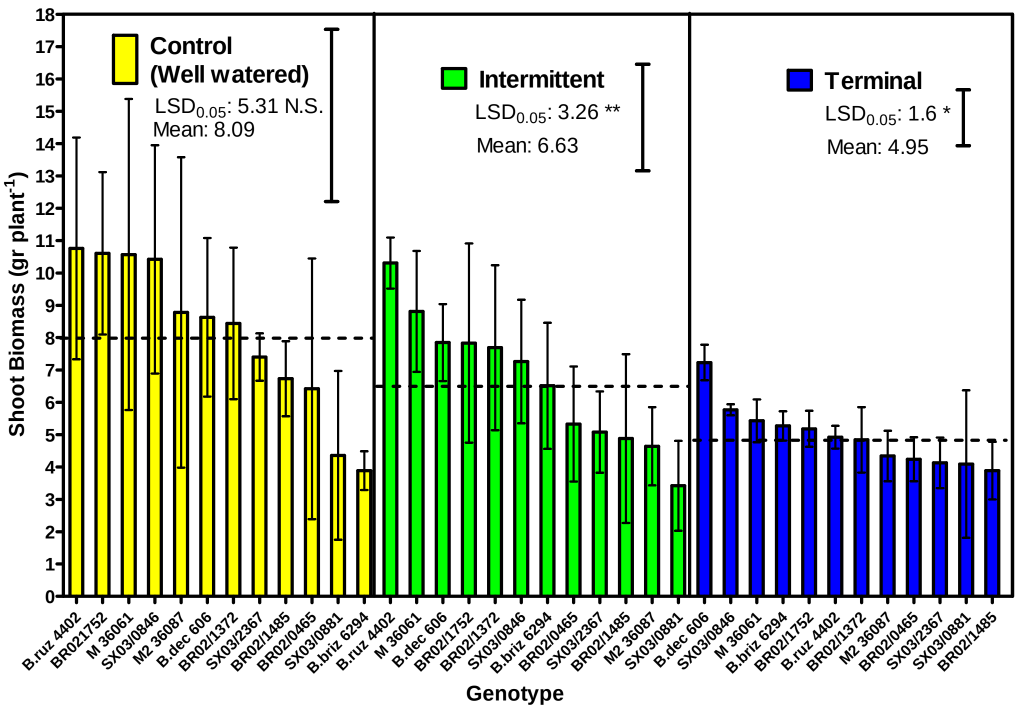


Figure 22. Live shoot biomass production of 12 Brachiaria genotypes grown under control (well watered), intermittent and terminal drought stress conditions. M = Mulato, M2 = Mulato 2. **, *: Significant at the 0.01 and 0.05 probability level, respectively. N.S.= not significant. The bars indicate LSD values at the 0.05 probability level. Dotted horizontal lines indicate the mean values.

The relationship between live shoot biomass production and other plant attributes is shown in Table 11. While the shoot biomass production was significantly related to leaf area production across all three treatments, the relationship was stronger with well watered conditions than the drought treatments. The dead leaf biomass was in terminal drought stress was positively associated with shoot biomass production indicating the importance of internal mobilization of photosynthates and nutrients to the growth of green leaves. Leaf chlorophyll content was positively associated with shoot biomass production under intermittent drought stress and this could be due to new leaf growth. Under terminal drought stress, leaf chlorophyll content was negatively associated with shoot biomass indicating the importance of remobilization of photosynthates and N. The rate of transpiration at 18 days after terminal drought stress showed negative relationship with green leaf area production indicating the importance of stomatal regulation for improving water use efficiency (Figure 23). Genotypes that combined higher values of green leaf area with lower values of the rate of transpiration are shown in lower right quadrant. These included *Brachiaria decumbens* CIAT 606, BR02/1752, BR02/0465 Mulato CIAT 36061 and *Brachiaria brizantha* CIAT 6294 cv. Marandú that could be more efficient in using water for producing green leaf area under terminal drought stress. Among the hybrids tested, the sexual hybrid SX03/0881 showed lower value of green leaf area and moderately high value of the rate of transpiration. The highest rate of transpiration was observed with Mulato 2 CIAT 36087. Rate of transpiration and stomatal conductance were negatively related to shoot biomass production at 18 days across treatments but the relationship was not significant (Table 11). With intermittent drought stress, the level of leaf and stem total nonstructural carbohydrates (TNC) showed significant positive association with live shoot biomass indicating greater availability of photosynthates for new shoot growth.

As in shoot biomass, the genotypic mean values of total root length were reduced by both intermittent and terminal drought stress compared with control treatment (Figure 24). Among the hybrids, Mulato CIAT 36061 performed better in terms of total root length under drought stress, particularly under terminal stress. One of the sexual hybrids, SX03/881 showed the lowest value of total root length across the three treatments. One of the apomictic hybrids, BR02/1372 that was known to have higher level of Al resistance showed moderate values of total root length under both intermittent and terminal drought stress.

Differences in root length, mean root diameter, root biomass and specific root length across soil depth under different treatments for 5 contrasting Brachiaria genotypes are shown in Figure 25. Results on root length distribution across soil depth showed significant genotypic differences under terminal drought stress. Mulato CIAT 36061, *B. decumbens* CIAT 606 and *B. brizantha* CIAT 6294 cv. Marandu showed greater values of root length and root biomass across soil depth in all three treatments. The sexual hybrid SX030881 showed lower values of both root length and root biomass distribution across soil depth. The sexual parent, *B. ruziziensis* 44-02 had greater values of root length and root biomass under well watered conditions but drought stress decreased the values, particularly under terminal drought stress.

Relationships between shoot biomass production and root attributes are shown in Table 11. Root length (10-75 cm soil depth) and root volume were positively associated with shoot biomass production under well watered and intermittent drought stress conditions. Under well watered conditions, root diameter also showed positive association with shoot biomass indicating that the thicker the root system the greater the vigor of the shoot when neither water nor nutrients were limiting in the system. Negative association was observed between root diameter and shoot biomass under terminal drought stress indicating the importance of development of finer roots in deeper soil layers.

Table 11. Correlations (r) between live shoot biomass production and other plant attributes of 12 *Brachiaria* genotypes subjected to drought stress

Variable	**Shoot biomass**		
	Control	**Intermittent drought**	**Terminal drought**
Leaf area (cm^2)	0.808**	0.510**	0.342*
Dead leaf biomass(g)	0.074	-0.136	0.346*
Chlorophyll content (SPAD)	0.215	0.460**	-0.402*
Rate of transpiration (mmol H_2O m^{-2} s^{-1}) at 18 days after treatment	-0.036	-0.221	-0.311
Mean stomatal conductance (mmol H_2O m^{-2} s^{-1}) at 18 days after treatment	-0.031	-0.231	-0.280
Total nonstructural carbohydrates in leaves (mg/g)	0.274	0.600**	0.145
Total nonstructural carbohydrates in stems (mg/g)	0.430**	0.456**	0.126
Root length (10-75 cm)	0.514**	0.485**	0.209
Root diameter (0-20 cm)	0.257*	0.189	-0.116
Root volume (0-75 cm)	0.454**	0.268*	0.059

*, ** significant at the 0.05and 0.01 level, respectively.

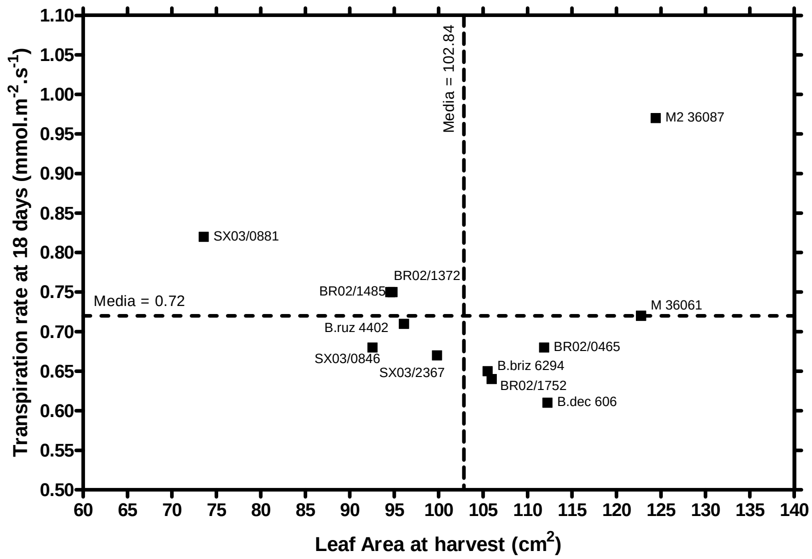


Figure 23. Relationship between leaf area at harvest and the rate of transpiration measured at 18 days of terminal drought stress for 12 *Brachiaria* genotypes. M = Mulato, M2 = Mulato 2. Vertical and horizontal dotted lines represent the genotypic mean values.

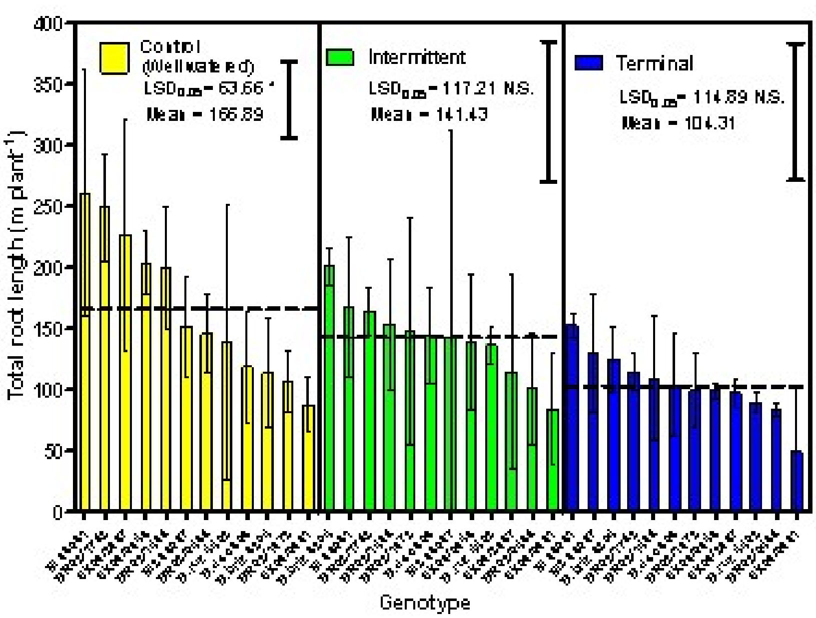


Figure 24. Total root length of 12 *Brachiaria* genotypes grown under control (well watered), intermittent and terminal drought stress conditions. M = Mulato, M2 = Mulato 2. **, *: Significant at the 0.01 and 0.05 probability level, respectively. N.S.= not significant. The bars indicate LSD values at the 0.05 probability level. Dotted horizontal lines indicate the mean values.

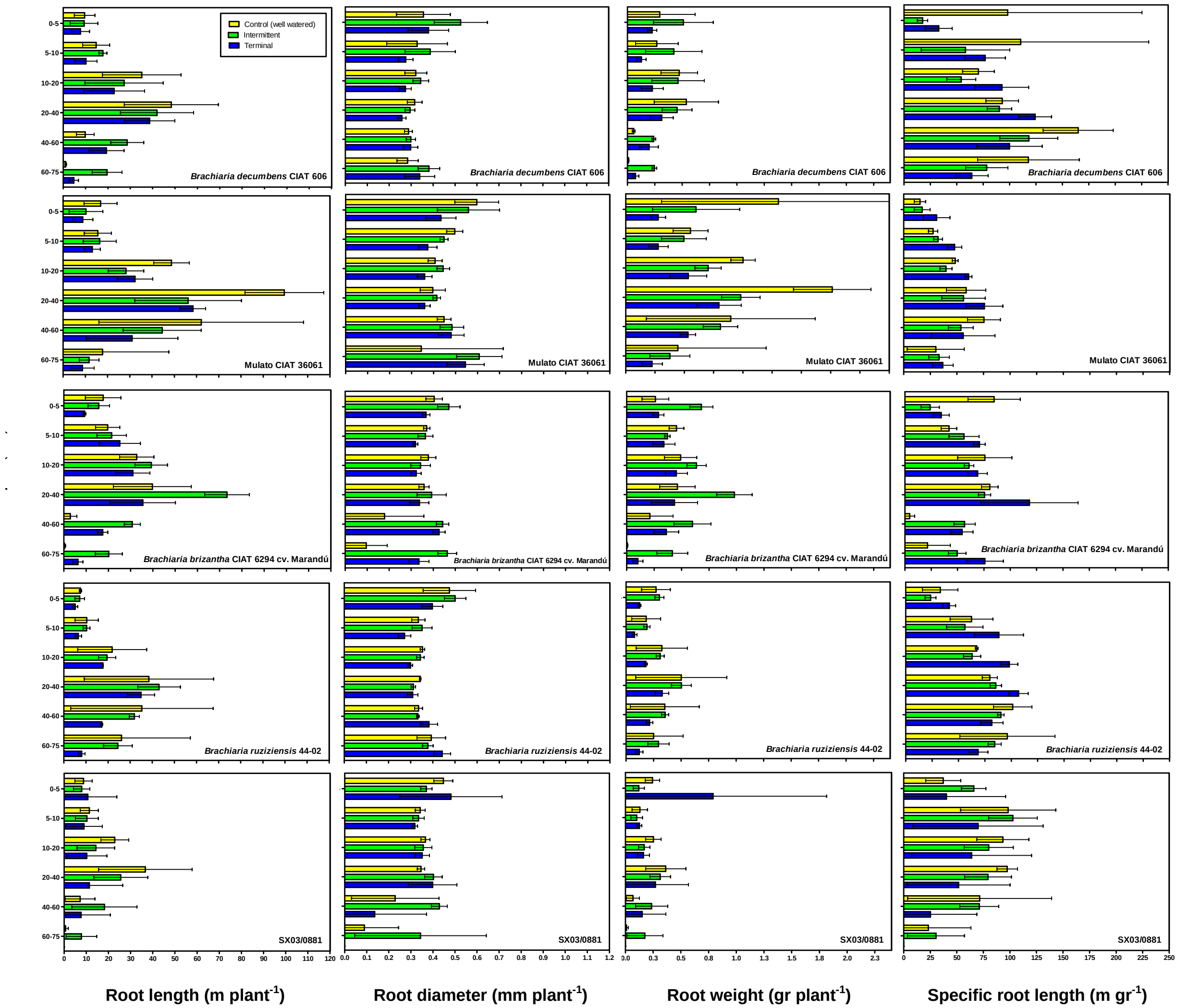
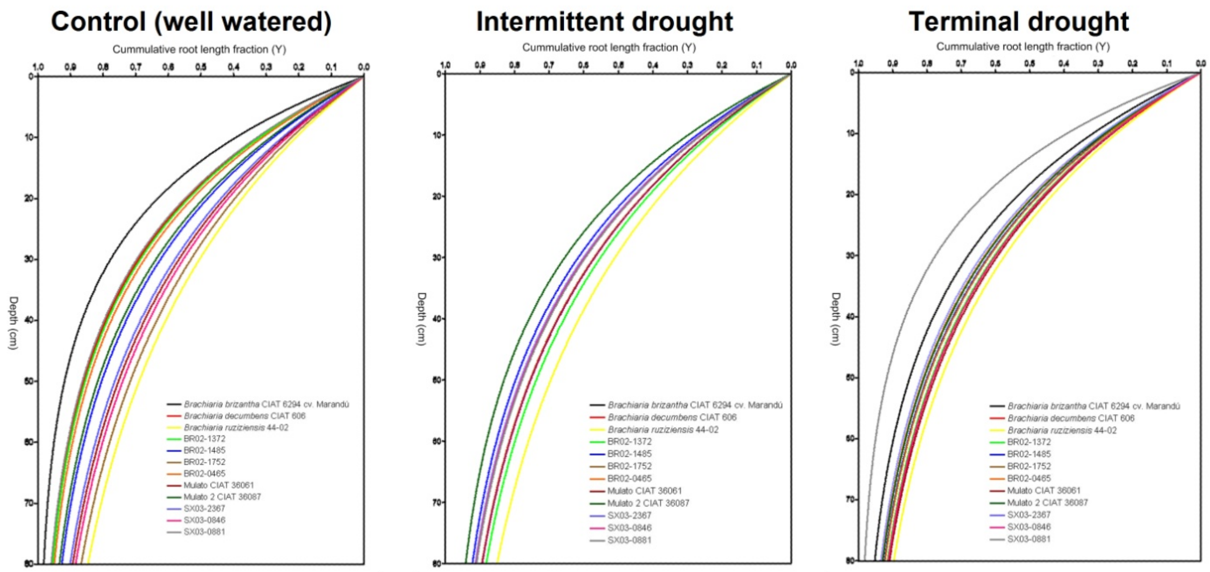


Figure 25. Differences in root length, root diameter, root biomass and specific root length across the soil profile at harvest for 5 contrasting *Brachiaria* genotypes (*Brachiaria decumbens* CIAT 606, Mulato CIAT 36061, *Brachiaria brizantha* CIAT 6294 *cv*. Marandú, *Brachiaria ruziziensis* 44-02 and SX03/0881) that were subjected to drought conditions for 21 days.

Figure 26 shows differences in vertical root length distribution (cumulative proportion) among the *Brachiaria* genotypes together with the values of β and R^2 for each of the treatments. The higher values of β indicate greater proportion of root length at deeper soil layers while the lower values indicate greater proportion of root length in surface soil layers. Among the genotypes tested, Mulato CIAT 36061 maintained its deep rooting ability across stress treatments. The sexual parent *B. ruziziensis* showed deeper rooting ability under well watered and intermittent stress conditions. Among the 12 genotypes tested, the sexual hybrid SX03/0881 showed lower value of β under terminal drought stress indicating greater proportion of root length in the top soil layers.



Genotype	β	R^2
B.ruz 44-02	0.98	0.95
BR02/1752	0.98	0.94
SX03/0846	0.97	0.95
Mulato 36061	0.97	0.95
SX03/2367	0.97	0.97
BR02-1485	0.97	0.96
Mulato 2 36087	0.97	0.95
BR02/0465	0.96	0.96
BR02/1372	0.96	0.98
B.dec 606	0.96	0.96
SX03/0881	0.96	0.96
B.briz 6294	0.95	0.98

Genotype	β	R^2
B.ruz 4402	0.98	0.95
BR02/1372	0.97	0.96
Mulato 36061	0.97	0.95
B.dec 606	0.97	0.97
BR02/1752	0.97	0.96
SX03/0881	0.97	0.98
SX03/0846	0.97	0.97
B.briz 6294	0.97	0.97
BR02/0465	0.97	0.99
SX03/2367	0.97	0.99
BR02/1485	0.97	0.97
Mulato 2 36087	0.97	0.98

Genotype	β	R^2
B.ruz 4402	0.97	0.95
Mulato 36061	0.97	0.95
SX03/0846	0.97	0.95
BR02/1372	0.97	0.96
BR02/1752	0.97	0.95
B.dec 606	0.97	0.96
BR02/1485	0.97	0.97
Mulato 2 36087	0.97	0.97
BR02/0465	0.97	0.97
SX03/2367	0.97	0.97
B.briz 6294	0.96	0.98
SX03/0881	0.95	1.00

Figure 26. Vertical root length distribution (cumulative proportion) for 12 *Brachiaria* genotypes under different drought stress treatments at the time of harvest as a function of β. Higher values of β indicate deeper root system.

Conclusions

Results from this study indicate 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.

1.6.2.2 Dry season tolerance of promising hybrids of *Brachiaria* under field conditions

Contributors: J. Ricaurte, C. Plazas, J. Miles and I. M. Rao (CIAT)

Rationale

Field evaluation of a number *Brachiaria* hybrids under infertile acid soil conditions with low or high amounts of initial application of fertilizer and application of maintenance fertilizer with half of the amounts of initial applications at 2 year intervals improved the persistence of several hybrids and not allowed to distinguish differences between moderately adapted cultivars (cv. Marandu) and the promising hybrids in dry season tolerance. Therefore a field experiment was established in 2004 with 15 hybrids along with the parents and checks with low amounts of initial application of fertilizer and no maintenance fertilizer application to select hybrids that persist and produce green forage under drought and acid infertile soil conditions. In 2005 evaluation at 9 months after establishment, we showed that among the 15 *Brachiaria* hybrids tested, BR02NO/1811 was more productive than the other hybrids in terms of green forage (leaf + stem) yield in the dry season and this adaptation seems to be closely associated with lower amounts of stem P content. In 2006 evaluation at 19 months after establishment, we showed that among the 15 *Brachiaria* hybrids tested BR02NO/1794 and BR02NO/1718 were more productive than the other BR02NO hybrids in terms of green forage (leaf + stem) yield in dry season and this superior adaptation seems to be associated with greater uptake of nitrogen and phosphorus. In 2007, we tested the performance of these hybrids in the dry season at 32 months after establishment under no maintenance fertilizer application.

Materials and methods

A field trial was established at Matazul farm on 29 June of 2004. The trial included 15 *Brachiaria* hybrids (BR02NO/0465; BR02NO/0768; BR02NO/ 0771; BR02NO/0799; BR02NO/1245; BR02NO/1372; BR02NO/1452; BR02NO/1485; BR02NO/1718; BR02NO/1720; BR02NO/1728; BR02NO/1747; BR02NO/1752; BR02NO/1794 and BR02NO/1811), three parents (*B. decumbens* CIAT 606; *B. brizantha* CIAT 6294 and *B.ruziziensis* 44-02) and four CIAT checks (*B.brizantha* CIAT 26110; *B.brizantha* CIAT 26646; *Brachiaria* hybrids CIAT 36061 (Mulato) and CIAT 36087 (Mulato 2).

The trial was planted as a randomized block with 4 replications. One low level of initial fertilizer application was applied (kg/ha of 20P, 20K, 33Ca, 14 Mg, 10S) at the time of establishment. Maintenance fertilizer was not scheduled for application in order to identify genotypes that are better adapted to infertile acid soil conditions. The plot size was 5 m x 2.5 m. A number of plant attributes including forage yield, dry matter distribution, P uptake and leaf and stem total nonstructural carbohydrate (TNC) contents were measured at the end of the 4 month dry season at 32 months after establishment (April, 2007).

Results and discussion

At 9 months after establishment CIAT 606, CIAT 36061, CIAT 36087, BRO2NO/1452, BRO2NO/1485, BRO2NO/1720, BRO2NO/1747, BRO2NO/1752 and BRO2NO/1794 were affected by bacterial infection. Among the hybrids, BR02NO/1752 was relatively more affected. The dead shoot biomass was greater with 2 hybrids (BR02NO/0465 and BR02NO/1794) and a check (CIAT 6294) (Figure 27, Table 12). Four hybrids (BR02NO/1794, BR02NO/1372, BR02NO/1245 and BR02NO/0465) were outstanding among the BR02NO hybrids in producing the green forage (leaf + stem biomass) than the other hybrids. Mulato 2 (CIAT 36087) was outstanding in green leaf forage production as was observed for the last two years. Among the BRO2NO hybrids tested BR02NO/1794, BR02NO/1372 and BR02NO/0465 were outstanding in green leaf biomass production. As expected BRUZ 44-02 (sexual parent) did not persist under no maintenance fertilizer application. Results on shoot phosphorus uptake also indicated that the hybrid BR02NO/1794 was superior to most of the BR02NO hybrids (Figure 28, Table 12). Lower values of leaf and stem TNC content were observed with the hybrid BR02NO/0465. The lower values of TNC may indicate greater utilization of photosynthates for leaf expansion under dry conditions.

Table 12. Genotypic variation in shoot biomass production (leaf, stem, living leaf + stem, dead, and total biomass), living biomass P uptake and shoot total non structural carbohydrate content of three parents (CIAT 606; 6294 and *B.ruziziensis* 44-02), four CIAT accessions (26110; 26646; 36061 and 36087) and 15 genetic recombinants (BR02NO/0465; 0768; 0771; 0799; 1245; 1372; 1452; 1485; 1718; 1720; 1728; 1747; 1752; 1794 and 1811) of *Brachiaria* grown in a sandy loam oxisol at Matazul, Colombia. Plant attributes were measured at 32 months after establishment (April 2007). LSD values are at the 0.05 probability level. NS = not significant.

Genotypes			Shoot biomass (kg ha^{-1})			Shoot	Shoot TNC (mg g^{-1})	
	Leaves	Stems	Living (L+S)	Dead	Living + Dead	P uptake (kg ha^{-1})	Leaves	Stems
BR02NO/0465	**125**	**56**	**181**	**1740**	**1921**	**0.454**	**148**	**127**
BR02NO/0768	50	13	63	90	153	0.147	185	144
BR02NO/0771	32	20	52	200	252	0.105	167	145
BR02NO/0799	61	23	84	380	464	0.196	180	152
BR02NO/1245	**116**	**65**	**181**	**340**	**521**	**0.475**	**183**	**152**
BR02NO/1372	**132**	**57**	**189**	**440**	**629**	**0.501**	**198**	**122**
BR02NO/1452	53	26	79	330	409	0.216	126	153
BR02NO/1485	91	38	129	550	679	0.323	183	133
BR02NO/1718	100	26	126	220	346	0.264	236	175
BR02NO/1720	101	31	132	310	442	0.314	207	145
BR02NO/1728	105	66	171	940	1111	0.378	164	134
BR02N0/1747	81	40	121	430	551	0.236	195	138
BR02NO/1752	86	41	127	400	527	0.392	214	161
BR02NO/1794	**146**	**67**	**213**	**620**	**833**	**0.552**	**194**	**172**
BR02NO/1811	104	42	146	440	586	0.293	171	146
Bruz44-02	.	.	.	.	.	.	.	.
CIAT 606	78	55	133	750	883	0.262	189	155
CIAT 6294	165	67	232	1270	1502	0.622	132	166
CIAT 26110	166	86	252	810	1062	0.476	158	160
CIAT 26646	62	24	86	660	746	0.234	182	120
CIAT 36061	81	23	104	160	264	0.216	215	129
CIAT 36087	155	30	185	630	815	0.479	174	165
Mean	**100**	**43**	**142**	**558**	**700**	**0.340**	**183**	**147**
LSD (p<0.05)	**55**	**41**		**91**		**0.234**		

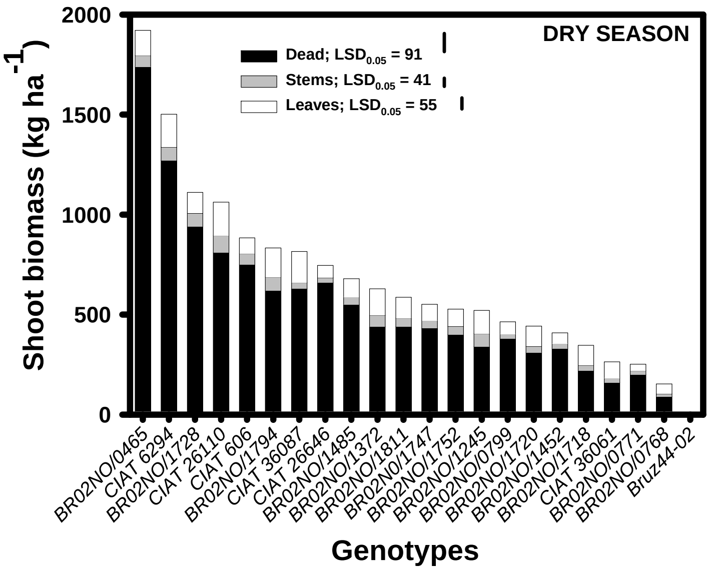


Figure 27. Genotypic variation in shoot biomass production (leaf, stem, dead biomass) of three parents (CIAT 606; 6294 and *B.ruziziensis* 44-02), four CIATs accessions (26110; 26646; 36061 and 36087) and 15 genetic recombinants (BR02NO/0465; 0768; 0771; 0799; 1245; 1372; 1452; 1485; 1718; 1720; 1728; 1747; 1752; 1794 and 1811) of *Brachiaria* grown in a sandy loam oxisol at Matazul, Colombia. Plant attributes were measured at 32 months after establishment (April, 2007). LSD values are at the 0.05 probability level. NS = not significant.

Correlation coefficients between green forage yield and other plant attributes indicated that greater phosphorus acquisition contributed to superior performance (Table 13). Significant negative correlation was observed between leaf total nonstructural carbohydrate (TNC) content and live forage yield. Adaptation to dry season under infertile acid soil conditions seems to be closely associated with greater acquisition of P and high use efficiency of P for green forage production.

Table 13. Correlation coefficients (r) between green forage yield (t/ha) and other shoot traits of *Brachiaria* genotypes grown with low initial fertilizer application in a sandy loam oxisol in Matazul, Colombia.

Shoot traits	Low fertilizer
Total (live + dead) shoot biomass (t/ha)	0.63***
Dead shoot biomass (t/ha)	0.52***
Leaf biomass (t/ha)	0.97***
Stem biomass (t/ha)	0.91***
Leaf TNC content (mg g^{-1})	-0.26*
Leaf P content (%)	0.06
Stem TNC content (mg g^{-1})	-0.05
Stem P content (%)	0.03
Shoot P uptake (kg/ha)	0.93***

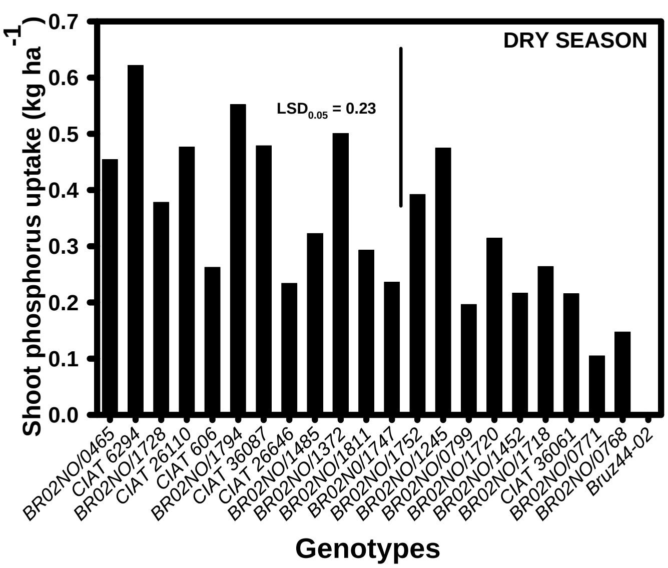


Figure 28. Genotypic variation in shoot phosphorus uptake of three parents (CIAT 606; 6294 and *B.ruziziensis* 44-02), four CIAT accessions (26110; 26646; 36061 and 36087) and 15 genetic recombinants (BR02NO/0465; 0768; 0771; 0799; 1245; 1372; 1452; 1485; 1718; 1720; 1728; 1747; 1752; 1794 and 1811) of *Brachiaria* grown in a sandy loam oxisol at Matazul, Colombia. Plant attributes were measured at 32 months after establishment (April, 2007). LSD values are at the 0.05 probability level. NS = not significant.

Conclusions

Results from this field study indicated that among the 15 *Brachiaria* hybrids tested, four hybrids (BR02NO/1794, BR02NO/1372, BR02NO/1245 and BR02NO/0465) were more productive than the other BR02NO hybrids in terms of green forage (leaf + stem) yield in dry season at 32 months after establishment with low initial fertilizer application and no maintenance fertilizer application. The superior adaptation of the three hybrids seems to be associated with greater uptake of phosphorous.

1.6.3 Grasses with adaptation to poorly drained soils

Highlights

- Implemented the screening method to evaluate for tolerance to waterlogging and screened 37 hybrids of SX05NO series that were preselected for spittlebug resistance and identified three sexual hybrids (SX05/1918, SX05/2043, SX05/2411) that were superior to other sexual hybrids in their tolerance to waterlogging. The superior performance of these hybrids was related to their ability to produce green leaf biomass, green leaf area and green leaf biomass proportion to total leaf biomass.

1.6.3.1 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

In late 2006, 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. Screening of the same population of SX05 sexual hybrids for other desirable traits such as spittlebug resistance resulted in assembling a group of 37 hybrids for further crossing and improvement of this population. These hybrids were tested in a replicated trial to quantify the extent of genetic variability for waterlogging tolerance among sexual hybrids of *Brachiaria*.

Material and methods

A pot experiment was conducted outside in the Forages patio area of CIAT Palmira between 8 August to 29 August 2007 to determine differences in tolerance to waterlogging among 40 *Brachiaria* genotypes (37 hybrids – SX05NO series; and 3 checks – *B. brizantha* CIAT 26110; *Brachiaria* hybrid cv. Mulato CIAT 36061; *B. brizantha* CIAT 6294). The trial was planted as completely randomized block with 5 replications. Each experimental unit consisted of one pot filled with 3.5 kg of top soil (0-20 cm) from Santander de Quilichao's Oxisol and sown with two vegetative propagules (stem cuttings). 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 50 days under field capacity conditions before applying waterlogging treatment. Waterlogging treatment was imposed by an excessive water supply (5 cm over soil surface) for 21 days. After inducing waterlogging treatment, leaf chlorophyll content (SPAD) was measured at weekly intervals on a full-expanded young leaf that was marked at the initiation of waterlogging treatment. At the end of the 21 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

The maximum temperature during the experimental period ranged from 27 to 31.4 °C while the minimum temperature ranged from 13.1 to 23.2 °C. The solar radiation was 11.2 to 21.8 MJ m^{-2} d^{-1}. Results on shoot attributes measured after 21 days of waterlogging treatment showed that three hybrids (SX05/1918, SX05/2043, SX05/2411) were superior in their ability to produce green leaf biomass, green leaf area and green leaf biomass proportion to total leaf biomass under stress (Table 12). The sexual hybrid SX05/1918 also performed well in an unreplicated trial that included 231 sexual clones of SX05 population (Figure 29). Five other sexual hybrids (SX05/2004, SX05/2010, SX05/2107, SX05/2329, SX05/2200) showed moderate level of tolerance to waterlogging based on green leaf biomass proportion to total leaf biomass. Based on green leaf biomass, the tolerant check *B. brizantha* CIAT 26110 cv. Toledo was outstanding in its level of tolerance to waterlogging (Table 14). The other two checks *B. brizantha* CIAT 6294 and the hybrid cv. Mulato (CIAT 36061) showed lower level of waterlogging tolerance.

Table 14. Green leaf biomass, green leaf area, leaf chlorophyll content, dead leaf biomass and green leaf biomass proportion to total leaf biomass of 40 *Brachiaria* genotypes after 21 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)	Dead leaf biomass (cm^2 plant^{-1})	Green leaf biomass proportion (%)
Checks					
CAT 26110	12.39	700	36.38	3.67	77
CIAT 36061	1.17	101	25.86	12.28	9
CIAT 6294	1.18	114	26.25	10.36	7
Hybrids					
SX05NO/1905	0.01	1.06	27.16	8.67	0
SX05NO/1918	**4.85**	**474**	**24.08**	**8.06**	**38**
SX05NO/1921	1.61	169	21.06	8.47	16
SX05NO/1928	1.16	117	21.70	9.31	11
SX05NO/1929	1.42	144	20.10	9.98	12
SX05NO/1939	0.81	58.7	20.04	7.75	9
SX05NO/1948	1.85	169	19.80	8.03	19
SX05NO/1955	0.38	35.3	22.05	8.72	4
SX05NO/1962	0.40	42.6	19.69	6.12	6
SX05NO/1981	0.51	51.6	25.87	4.83	10
SX05NO/1988	1.14	111	26.44	7.38	13
SX05NO/1990	0.86	86.0	25.49	9.11	9
SX05NO/2004	2.34	250	25.95	6.13	28
SX05NO/2010	2.07	183	29.02	7.12	23
SX05NO/2032	0.74	71.2	22.50	8.13	8
SX05NO/2043	**3.80**	**377**	**29.22**	**6.15**	**38**
SX05NO/2066	0.14	15.4	18.80	11.06	1
SX05NO/2093	0.42	31.3	26.37	6.48	6
SX05NO/2103	2.19	240	23.83	9.25	19
SX05NO/2105	0.08	5.76	23.26	9.44	1
SX05NO/2107	2.40	193	25.43	8.01	23
SX05NO/2108	1.40	152	21.50	6.97	17
SX05NO/2165	2.03	215	27.17	8.59	19
SX05NO/2180	0.60	46.7	22.12	7.15	8
SX05NO/2184	0.88	98.6	26.91	7.28	11
SX05NO/2200	1.94	234	29.79	6.96	22
SX05NO/2206	0.16	19.3	20.62	8.85	2
SX05NO/2264	0.79	73.4	17.69	9.08	8
SX05NO/2280	2.03	217	27.41	9.14	18
SX05NO/2329	2.36	197	28.39	6.75	26
SX05NO/2389	1.99	189	23.88	8.07	20
SX05NO/2411	**2.51**	**202**	**29.20**	**5.31**	**32**
SX05NO/2440	0.67	77.7	24.18	8.73	7
SX05NO/2446	1.69	176	18.08	8.86	16
SX05NO/2519	0.79	57.9	30.07	7.00	10
SX05NO/2534	1.34	137	28.64	7.73	15
SX05NO/2560	0.73	82.7	23.86	5.37	12
Mean	**1.65**	**148**	**24.65**	**7.91**	**16**
LSD $_{0.05}$	**1.29**	**134**	**4.55**	**2.13**	

Green leaf biomass production under waterlogging stress was found to be positively associated with the ability to produce green leaf area and negatively associated with dead leaf biomass (Table 15). Leaf chlorophyll content and stem biomass production were also positively associated with green leaf biomass.

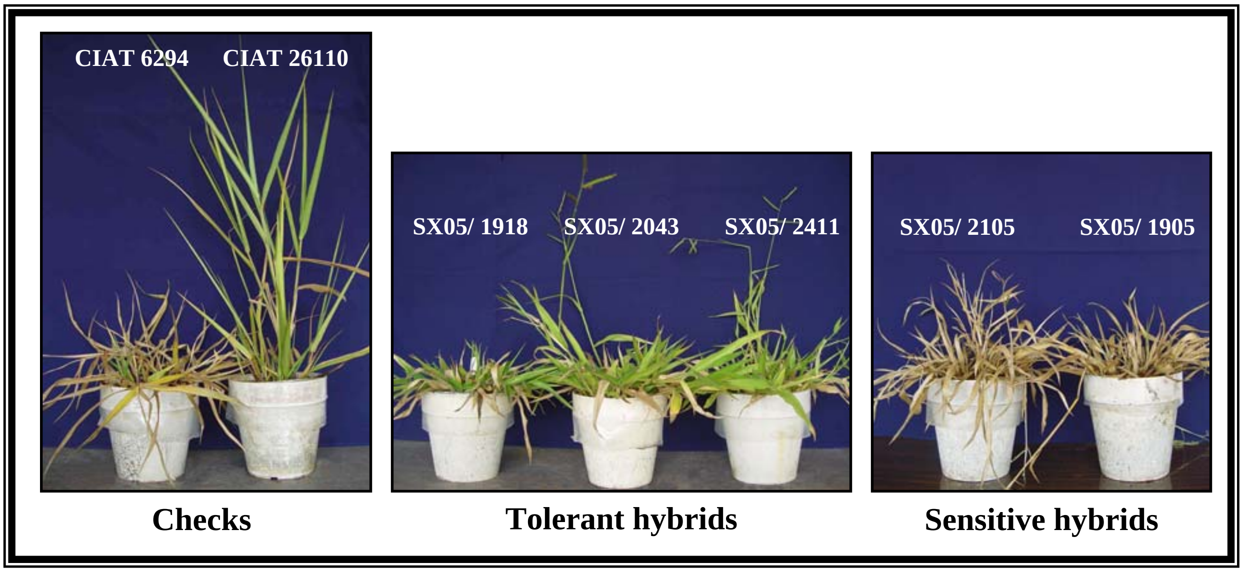


Figure 29. Influence of waterlogging on shoot growth at harvest time (21 days of waterlogging treatment). *B. brizantha* CIAT 6294 (sensitive check); *B. brizantha* CIAT 26110 (tolerant check); SX05NO/1918, SX05NO/2043, SX05NO/2411 (tolerant hybrids); SX05NO/2105, SX05NO/1905 (sensitive hybrids).

Table 15. Correlation coefficients (r) between green leaf biomass (g plant^{-1}) and other shoot traits of 40 *Brachiaria* genotypes under waterlogging in an Oxisol from Santander de Quilichao, Colombia.

Plant traits	Waterlogging
Total chlorophyll content (SPAD)	0.49***
Green leaf area (cm^2 plant^{-1})	0.92***
Dead leaf biomass (g plant^{-1})	-0.33***
Stem biomass (g plant^{-1})	0.49***

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

Conclusions

We screened 37 hybrids of SX05NO series for tolerance to waterlogging (that were preselected for spittlebug resistance) and identified three sexual hybrids (SX05/1918, SX05/2043, SX05/2411) that were superior to other sexual hybrids in their tolerance to waterlogging. The superior performance of these hybrids was related to their ability to produce green leaf biomass, green leaf area and green leaf biomass proportion to total leaf biomass. These results indicate that it is possible to genetically improve the level of waterlogging tolerance in *Brachiaria* hybrids through breeding and evaluation.

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

Highlight

- Two *B. humidicola* crossing blocks were established and open-pollinated seed was harvested.

1.7.1 Assess reproductive mode of *B. humidicola* hybrids. Establish recombination (crossing) blocks including 14 available *B. humidicola* hybrids (CIAT 26146 x CIAT 26149)

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

Rationale

A small number of tetraploid *B. humidicola* hybrids were successfully obtained in 2006, demonstrating the existence of sexual reproduction in *B. humidicola* and hence, the promise of achieving effective genetic recombination in this important species. This development opens the way to develop a broad-based, sexual tetraploid breeding population.

Materials and Methods

Fourteen hybrids from a single, bi-parental cross, and 19 *B. humidicola* accessions reported to be tetraploid were propagated vegetatively. A space-planted crossing block was established in the field at CIAT-Popayán, and a second crossing block was established with pot-grown plants at CIAT-Palmira. Clones were randomized. Individual plants were spaced approx. 1 m apart, both in the field and in pots. Following flowering, seed was hand harvested from individual plants between May and October 2007 at Popayán and between June and July 2007 at CIAT-Palmira.

Results and Discussion

All clones flowered at one or the other of the two locations. Flowering was earlier and more prolific at CIAT-Popayán, presumably owing to lower temperature at this higher elevation site.

Early attempts late in 2007, to germinate harvested open-pollinated seed have not been very successful owing presumably to the strong seed dormancy typical of *B. humidicola*. Efforts will continue in 2008, to germinate seed from these two crossing blocks in order to generate sufficient progeny seedlings to establish a large progeny trial during 2008. This will allow determination of reproductive mode of hybrids and accessions as well as allow further recombination among the tetraploid *B. humidicola* germplasm.

1.7.2 Screen 19 tetraploid *B. humidicola* germplasm accessions for reproductive mode.

Highlight

- Open pollinated seed of 19 tetraploid *B. humidicola* accessions was harvested from crossing blocks established at CIAT-Popayán and at CIAT-Palmira.

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

Rationale

In addition to *B. humidicola* accession CIAT 26146, whose sexual reproduction we have confirmed, several additional tetraploid *B. humidicola* accessions are reported to be sexually reproducing. We seek to confirm sexual reproduction in these and possibly other tetraploid *B. humidicola* accessions as well as begin to recombine the entire CIAT collection of 19 tetraploid *B. humidicola* accessions.

Materials and Methods

Greenhouse-grown plants, derived vegetatively from germplasm plots maintained by CIAT's Genetic Resources Unit at CIAT-Popayán were propagated vegetatively to produce sufficient transplants to establish two crossing blocks (see Sub-Activity 2.2.1). Open pollinated seed has been harvested from the CIAT *B. humidicola* accessions at both locations.

Results and Discussion

Seed set was notably and consistently higher on plants of the CIAT accessions than on plants of hybrid clones. It is not clear why the hybrids should have low seed set, since they derive from an intraspecific cross. A progeny trial will be established in 2008 to assess reproductive mode of the CIAT tetraploid *B. humidicola* accessions (and hybrids).

1.8 Biological nitrification inhibition (BNI) in tropical grasses

Highlights

- Screened 21 accessions of *Brachiaria humidicola* for biological nitrification inhibitory (BNI) activity and quantified genetic diversity in BNI and identified contrasting accessions with very high (CIAT 26181, 26416, 16182) and low BNI activity (CIAT 26411). The rhizosphere soil incubation method to measure the rate of nitrification seems to be reliable to quantify differences in BNI ability among *Brachiaria* genotypes.
- Field measurements of BNI activity over 3 years indicated that nitrification rates were lower with the two accessions of *Brachiaria humidicola* (CIAT 16888, CIAT 679) than the accession of *Panicum maximum* (CIAT 16028*)*. The rhizosphere soil incubation method used to determine nitrification rates is highly sensitive to detect even small differences in nitrification rates among the grasses. This method can thus be used as an evaluation tool to determine the BNI ability in forage grasses.

1.8.1 Screening for genetic variability in the ability to inhibit nitrification in accessions of *B. humidicola*

Contributors: M. P. Hurtado, M.Rondón[1], I.M.Rao, A.L.Chávez, M. Ishitani, J. Miles and C.E.Lascano[2] (CIAT), G.V.Subbarao, T.Ishikawa, T. Watanabe and O.Ito (JIRCAS, Japan)
Present address: [1]IDRC, Canada; [2]CORPOICA, Colombia

Rationale

Ongoing collaborative research with JIRCAS (Japan International Research Center for Agricultural Sciences), Japan, has shown that *B. humidicola* CIAT 679 and *B. humidicola* CIAT

16888 inhibit nitrification of ammonium and reduces the emission of nitrous oxide into the atmosphere. On the other hand, *P. maximum* CIAT 16028 does not have this property to inhibit nitrification. Given these findings with *B. humidícola* accessions, and the fact that a range of inhibition of nitrification was observed among different tropical grasses, there is a need to determine the extent of genetic variation among the 69 accessions of *B. humidicola* that are part of CIAT germplasm bank. This information will be useful to develop screening methods to select genetic recombinants of *Brachiaria* grasses that not only are resistant to major biotic and abiotic stress factors but also can protect the environment. Given the vast areas under *B. humidicola* in the tropics, reductions in net emissions of N_2O could also have important environmental implications.

As a continuation of this work, we assembled a set of 21 accessions of *B. humidicola* to conduct a study to test the genetic diversity in biological nitrification inhibition (BNI) in a single experiment under similar growing conditions. The main objective was to quantify differences among these accessions of *B. humidicola* using two independent methods: (i) using the bioassay developed at JIRCAS and adapted at CIAT; and (ii) using the rhizosphere soil to determine nitrification rate.

Materials and methods

A sandy loam Oxisol from the Llanos (Matazul) of Colombia was used to grow the plants (1 kg of soil/pot) under greenhouse conditions. A basal level of nutrients were applied before planting (kg/ha): 40 N, 50 P, 66 Ca, 100 K, 20 S and micronutrients at 2 Zn, 2 Cu, 0.1 B and 0.1 Mo. A total of 23 accessions were used (accessions *P. maximum* CIAT 16028, Hybrid Mulato and *B. humidicola* CIAT 679, 6133, 16182, 16517, 16870, 16871, 16885, 16888, 16894, 26145, 26146, 26149, 26155, 26159, 26181, 26371, 26375, 26411, 26416, 26427, and 26430). A control treatment without plants was also included. The experiment was arranged as a completely randomized block design with three replications. Each pot contained 6 plants to increase root biomass per unit soil volume. After sowing, plants were allowed to grow for 15 weeks and were cut to 10 cm height to simulate grazing effects under field conditions.

NH_4- N (nitrogen source was ammonium sulfate) was added in four applications: 40 kg N/ha added to the soil when filling the pots, and 40 kg N at each time of 30, 60 and 90 days after planting. Four weeks after the final application of N (i.e., at 16 weeks after sowing) plants were harvested. At the time of harvest, plants were carefully removed from soil minimizing mechanical damage to the roots. Soil adhered to the fine roots was removed and the roots were rinsed with deionized water.

BNI determination using the bioassay: Once clean, the roots were fully submersed in 1 mM NH_4Cl for 1 hour to trigger further BNI active compound exudation. Then the roots were immersed in 500 ml of deionized water during 24 hours. The root exudate was subsampled and about 100 ml of the subsample was sent to Biotechnology Unit of CIAT for testing the BNI activity level. Another 100 mL subsample was stored in the cold room as a backup for analyses at JIRCAS. The final concentrate was tested for its nitrification inhibitory activity using a specific bioassay developed by JIRCAS and adapted at CIAT.

BNI determination using nitrification rates: At harvest time, rhizosphere soil samples (3 g) were incubated with 0.6 mL of 1000 mg N L^{-1} $(NH_4)_2SO_4$ – 20 mM $NaClO_3$ solution (1:1). The proportion (water/dry soil) was adjusted to 0.60 by adding distilled water. The soil incubation was maintained at 30 ^{0}C and the samples were extracted with 0.012 M $CaSO_4$ (1:10) and analyzed for nitrate and nitrite levels at 1, 3 and 6 days after incubation, using UV- VIS spectrophotometer.

Harvested plants were separated into leaves, stem and roots. Dry matter content and N status of leaves, stem and root biomass was determined.

Results and discussion

Results on dry matter partitioning among shoot and root biomass from the comparative evaluation of the 23 accessions are presented in Table 16. Significant differences were found in root biomass, stem biomass, leaf biomass and total biomass. The *B. humidicola* accessions CIAT 679, 26155, 26181, 26371 and hybrid Mulato produced the highest values of total biomass while Bh accessions CIAT 16182, 16517 and 26149 were lower than the rest of the Bh accessions. The Bh accession CIAT 26181 and *P. maximum* 16028 produced the highest root biomass among the tested accessions. Values of root biomass of those accessions were more than four fold greater than the values for the lowest in the group, the Bh accessions CIAT 26149 and CIAT 16517.

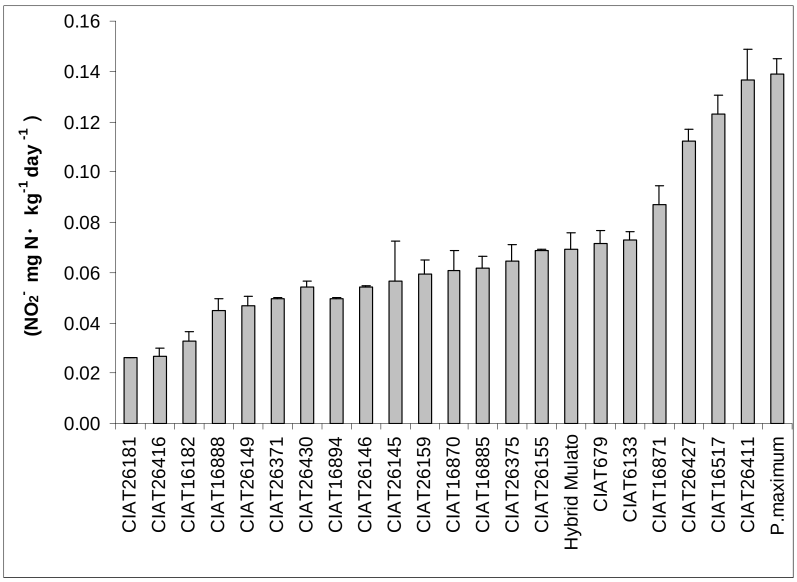


Figure 30. Genotypic differences in nitrification rates measured from soil incubation for 6 days at 30^0C.

Results from the rhizosphere soil incubation test indicated substantial level of genotypic differences in BNI activity of the accessions tested (Figure 30). *P. maximum* 16028 and CIAT 26411, showed highest nitrification rates (low BNI activity) while CIAT 26181, 26416 and 16182 exhibited lowest values of nitrification rates (high BNI activity). These three accesions showed greater values of BNI than that of CIAT 16888. The nitrification rates were in the range from 0.026 to 0.139 NO_2^- mg N kg $^{-1}$ day $^{-1}$.

The commercial cultivar, CIAT 679, which had been used in most of the previous work, presented similar values (0.071 NO_2^- mg N kg $^{-1}$ day $^{-1}$) to the accessions of CIAT 6133, CIAT 26155 and hybrid *cv*. Mulato.

Results on BNI activity indicate that wide genetic variability exists among accessions of *B. humidicola* in relation to the effectiveness of root exudates to inhibit nitrification in soils. This genetic variability for BNI activity could be exploited in a breeding program to select for genotypes with different levels of BNI activity. Accessions with superior BNI activity could be used as parents to regulate BNI activity in the genetic recombinants together with other desirable agronomic traits.

The specific activity values of BNI determined at CIAT were compared with results obtained at JIRCAS from previous experiments conducted at CIAT (Table 17). The nitrification rates with specific BNI activity obtained at CIAT and JIRCAS, exhibited correlation coefficients of 0.63 and 0.91, respectively (Table 17). Rhizosphere soil incubation experiment for *in situ* quantification of BNI also showed strong positive association with the specific BNI activity.

Table 16. Dry matter partitioning differences among 23 accessions of B.*humidicola* grown in pots under greenhouse conditions. Plants were harvested at four months after planting.

CIAT Accession Number	Dry matter (g/pot)			
	Root biomass	Shoot biomass	Root / Shoot	Total biomass
679	8.07 (0.64)	13.3 (1.15)	0.61 (0.01)	21.3 (1.79)
6133	7.58 (1.11)	9.83 (0.67)	0.77 (0.11)	17.4 (1.46)
16182	5.65 (0.41)	7.91 (0.36)	0.72 (0.08)	13.6 (0.05)
16517	2.81 (0.70)	8.71 (0.88)	0.32 (0.06)	11.5 (1.46)
16870	7.62 (0.65)	9.89 (0.70)	0.78 (0.12)	17.5 (0.38)
16871	6.30 (0.42)	10.2 (1.37)	0.63 (0.10)	16.5 (1.38)
16885	5.35 (0.39)	11.9 (1.02)	0.45 (0.04)	17.2 (1.23)
16888	6.95 (0.80)	12.8 (0.61)	0.55 (0.06)	19.7 (1.09)
16894	5.10 (0.91)	15.3 (1.16)	0.34 (0.07)	20.4 (1.11)
26145	8.00 (0.80)	11.1 (0.13)	0.72 (0.07)	19.1 (0.80)
26146	4.00 (0.79)	10.8 (0.74)	0.37 (0.09)	14.8 (0.80)
26149	2.68 (0.28)	9.89 (0.86)	0.27 (0.05)	12.6 (0.59)
26155	8.79 (0.65)	12.8 (1.09)	0.69 (0.11)	21.5 (0.70)
26159	7.75 (0.57)	10.6 (0.60)	0.73 (0.03)	18.4 (1.11)
26181	10.9 (3.05)	11.1 (1.04)	0.97 (0.21)	22.0 (3.93)
26371	7.20 (0.71)	14.4 (0.16)	0.50 (0.05)	21.67 (0.69)
26375	4.59 (0.72)	12.7 (1.30)	0.36 (0.08)	17.3 (1.19)
26411	5.25 (0.30)	11.5 (0.63)	0.46 (0.05)	16.7 (0.33)
26416	8.34 (0.01)	9.96 (0.78)	0.84 (0.06)	18.3 (0.77)
26427	4.30 (1.20)	11.8 (0.34)	0.36 (0.09)	16.1 (1.52)
26430	9.79 (1.63)	8.99 (0.70)	1.09 (0.20)	18.9 (1.79)
Hybrid *cv.* Mulato	7.67 (0.15)	14.8 (1.01)	0.52 (0.03)	22.5 (1.08)
Panicum maximum	10.6 (1.86)	9.10 (1.00)	1.15 (0.11)	19.7 (2.82)
LSD (P<0.05)	**1.70**	**1.42**	**0.16**	**2.41**

Numbers in parenthesis indicate standard deviation.

Table 17. Specific activity (AT units g root dwt^{-1}) measured at CIAT from root exudates compared with nitrification rates (NO_2^- mg N • kg^{-1} day^{-1}) measured from soil incubation. Specific activity values measured at JIRCAS from previous experiments is included for comparison between the two bioassay measurements. Plants were grown for four months before the collection of root exudates.

CIAT Accession Number	Specific BNI activity CIAT (in AT units g root dwt^{-1})	Rate of nitrification CIAT (NO_2^- mg N • kg^{-1} day^{-1})	Specific BNI activity JIRCAS (in AT units g root dwt^{-1})
CIAT16888	5.81 (0.3)	0.045 (0.003)	24.2 (6.17)
CIAT26145	10.7 (1.7)	0.057 (0.016)	17.5 (5.78)
CIAT26155	10.7 (0.6)	0.069 (0.001)	12.3 (0.82)
CIAT26181	10.2 (1.4)	0.026 (0.003)	20.6 (8.16)
P.maximum	0.00 (0.0)	0.139 (0.006)	0.07 (0.06)

Numbers in parenthesis indicate standard deviation.

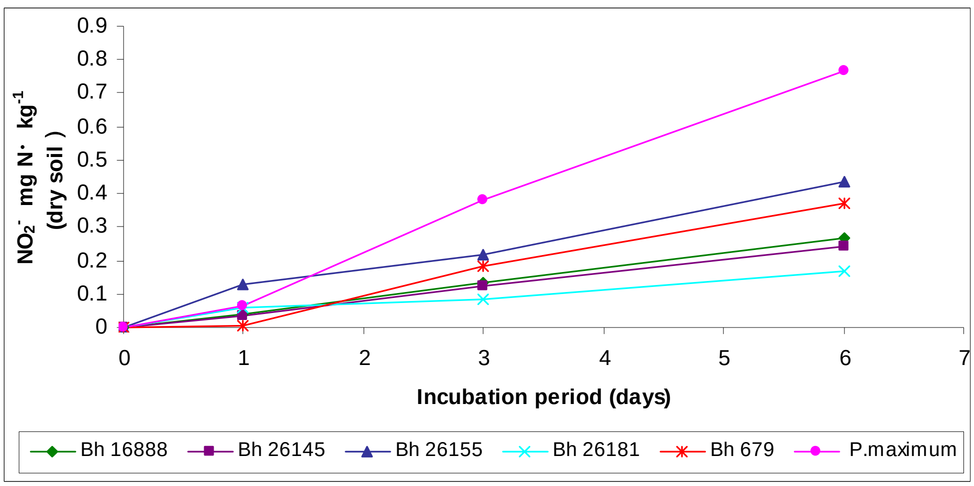


Figure 31. Differences in the rate of nitrification in rhizosphere soil during the incubation.

The presence of markedly lower rate of nitrification in the rhizosphere soil incubation experiment of CIAT 26181 compared with CIAT 16888, draws attention to the need to study this accession in more detail to understand the BNI phenomenon (Figure 31). The specific BNI activity of CIAT 26181 was higher than that of CIAT 16888 from the bioassay measurement made at CIAT. But comparison of BNI values from different experiments in the past showed significant variability in specific activity for the same accession although the tendencies in BNI were maintained.

The *Brachiaria humidicola* breeding program at CIAT has generated a hybrid population and this population will be useful to analyze the tradeoffs of BNI in terms of the relationships among forage productivity, forage quality and BNI activity. The rhizosphere soil incubation method to measure the rate of nitrification seems to be very reliable to quantify BNI ability of *Brachiaria* genotypes.

Conclusions

Screening of 21 accessions of *Brachiaria humidicola* for biological nitrification inhibitory (BNI) activity resulted in quantifying genetic diversity in BNI and in identifying contrasting accessions with very high (CIAT 26181, 26416, 16182) and low BNI activity (CIAT 26411). The rhizosphere soil incubation method to measure the rate of nitrification seems to be a reliable alternative method to quantify BNI ability of *Brachiaria* genotypes.

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

Contributors: M. P. Hurtado, M.Rondón[1], I.M.Rao, M. Ishitani, D. Moreta, J. Miles and C.E.Lascano[2] (CIAT), G.V.Subbarao, T.Ishikawa, T. Watanabe and O.Ito (JIRCAS, Japan)
Present address: [1]IDRC, Canda; [2]CORPOICA, Colombia

Rationale

A range of Biological Nitrification Inhibition (BNI) activity 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 the BNI activity 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. Various tropical forage grasses showing 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 included as controls.

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 ^{0}C. Two accesions of *B. humidicola* were used: the commercial reference material 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) is also used as a negative control due to its known effect on promoting nitrification. A plot without plants is 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 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 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 was cut at 20 cm height while the *B. humidicola* accessions were cut at 10 cm height. Similar procedure used for cv. Mulato was also used for *P.maximum*. 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. Gas samples for measuring N_2O fluxes were collected monthly and analyzed by Gas Cromatography with Electron Capture Detector (ECD).

Soil incubation test: Fresh rhizosphere soils at harvest (November 2007) from the field experiment 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.

Greenhouse experiment to determine soil nitrification rates: A sandy loam Oxisol from the Llanos (Matazul) of Colombia was used to grow the plants under greenhouse conditions. A basal level of nutrients were applied before planting (kg/ha): 40 N, 50 P, 66 Ca, 100 K, 20 S and micronutrients at 2 Zn, 2 Cu, 0.1 B and 0.1 Mo. A total of 3 accessions were used (accessions *P. maximum* CIAT 16028, *B. humidicola* CIAT 679, 16888). A control without plants was also included. The experiment was arranged as a completely randomized block design with three replications. Seedlings are grown for three weeks in vermiculite prior to transplanting to soil and three week old seedlings (1 plant/pot) were grown for three months with 200 g (dry soil weight) of soil in a vinyl pot (7.5 cm diameter with 6.5 cm height). NH_4- N (ammonium sulfate as N source) was added at 30 days after planting. At the end of the experiment, plants were removed from soil minimizing mechanical damage to the roots. Soil adhered to the fine roots (rhizosphere soil) was removed and the roots were rinsed with deionized water.

Harvested plants were separated into leaves, shoot and roots. Dry matter content and N status of leaves, shoot and root biomass was determined. At harvest time, soil samples were incubated with solution (1:1) of 1000 mg N $L^{-1}$$(NH_4)_2SO_4$ and 20 Mm $NaClO_3$ at 30 ^{0}C and at 0, 6 and 12 days after incubation, these samples were extracted with 0.012 M $CaSO_4$ (1:10) and analyzed for nitrate and nitrite levels by UV- VIS spectrophotometer.

Results and discussion

So far five soybean crops have been harvested (March and August, 2005; February and July, 2006; March 2007). In this report we present the data collected during the fifth cropping season on nitrification rate, the net fluxes of N_2O and a study on soil incubation to determinate accumulation of nitrate and nitrite in different treatments. The Figure 32 shows the differences in total shoot biomass harvested during the fifth crop cycle. The results between treatments presented significant differences (LSD, $p<0.001$). Total shoot biomass yields of *P. maximum* and the *B. humidicola* accessions were similar but lower than the biomass of hybrid cv. Mulato. Soybean had a total shoot biomass markedly lower than the forage grasses. The growth of the *B. humidicola* accessions had been stimulated with the ammonium sulfate application as nitrogen source.

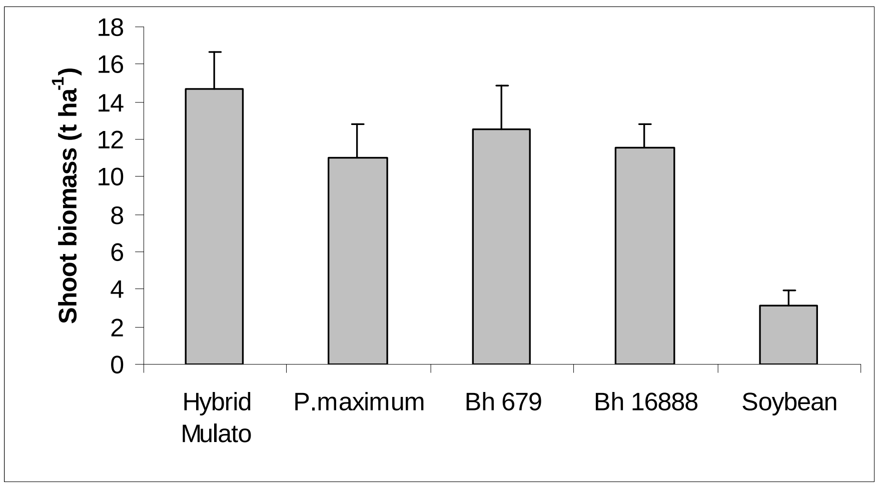


Figure 32. Differences among forage and crop components in shoot biomass production during the fifth cropping cycle (November 2006 - March 2007).

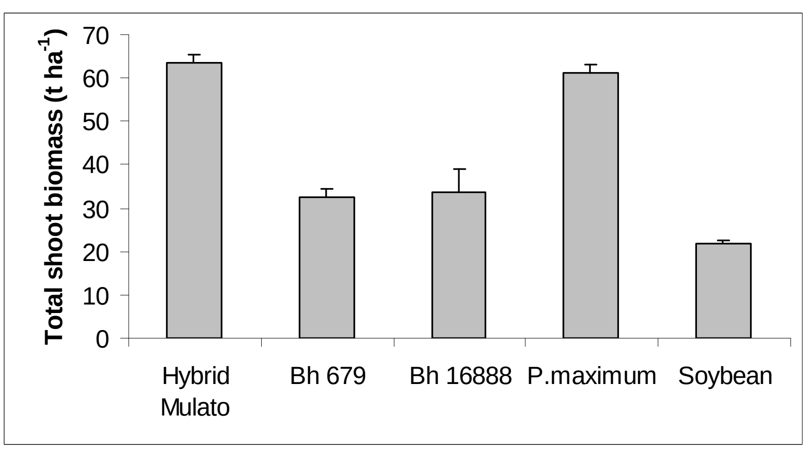


Figure 33. Differences among forage and crop components in total shoot biomass production over the period from September 2004 to March 2007.

Figure 33 shows total shoot biomass accumulated from the experimental plots over 5 cropping cycles. Total shoot yield of P.*maximum* and the hybrid cv. Mulato was significantly higher than that of soybean and the 2 accessions of *B. humidicola* (LSD, $p<0.001$).

Total nitrogen uptake by different species showed significant differences (LSD, $p<0.001$) (Figure 34). Hybrid Mulato accumulated considerably more nitrogen than Soybean and P.*maximum*. The 2 accesions of B.*humidicola* plots removed less N than what is being added as fertilizer. The grain yield of soybean was similar to the first, second and fourth cropping seasons (about 1.0 Mg ha $^{-1}$) which was slightly lower than that of the commercial average in the region.

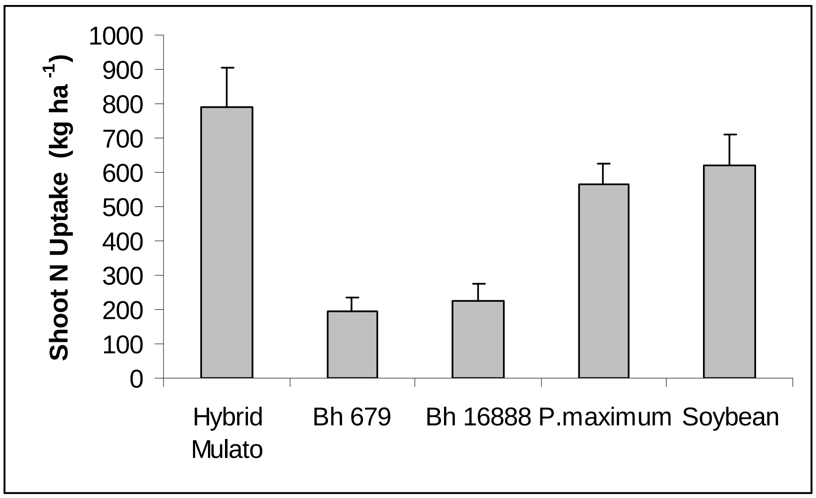


Figure 34. Differences among forage and crop components in total shoot nitrogen uptake for the period from September 2004 to March 2007.

Nitrous oxide emissions: Results on the behavior of the net fluxes of N_2O for the period from September 2004 to April 2007 showed significant differences (LSD, $p<0.001$) (Figure 35). The bare soil plot (with 1026 mg N_2O m^{-2} y^{-1}) and soybean plot (with 969 mg N_2O m^{-2} y^{-1}) showed highest emissions of nitrous oxide due to higher nitrification rates than those of *P. maximum* and hybrid cv. Mulato. In contrast, the plots from the two accessions of *B. humidicola* exhibited lower net fluxes of N_2O, which were of 380 mg N_2O m^{-2} y^{-1} and 100 mg N_2O m^{-2} y^{-1} for the *B. humidicola* 679 and *B. humidicola* 16888, respectively.

Figure 36 shows the net fluxes of N_2O for different forage grasses compared with the bare soil for the period September 2004 and November 2007. The soybean was not included in the figure, because this treatment was eliminated from the field experiment after fifth crop cycle. The *B. humidicola* accession 16888 showed lowest emission of nitrous oxide (128 mg N_2O m^{-2} y^{-1}). These data on N_2O emission also indicate greater inhibition of nitrification by this *B. humidicola* accession.

Soil nitrification rates (field experiment): Results presented in Figure 37 from the rhizosphere soil incubation test showed significant differences (LSD, $p<0.001$). 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 lower rates of nitrification than the values from *P. maximum* and hybrid cv. Mulato.

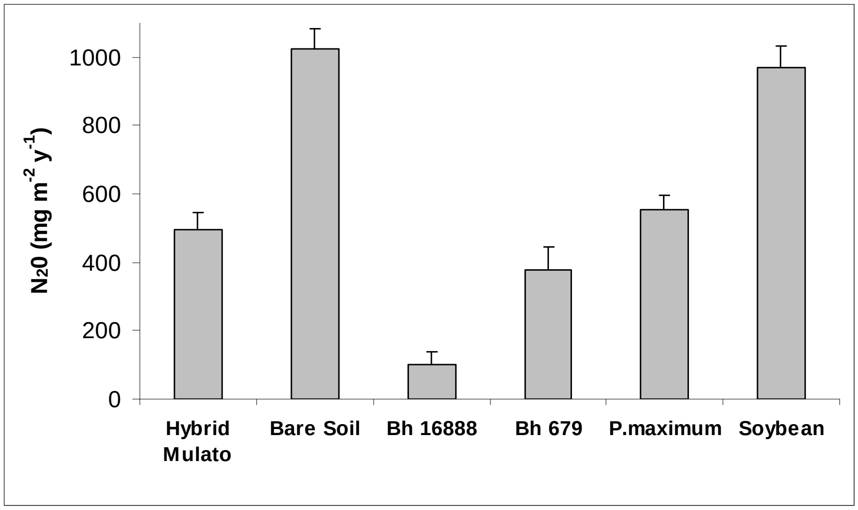


Figure 35. Differences in total emission of N_2O for the period September 2004 and April 2007.

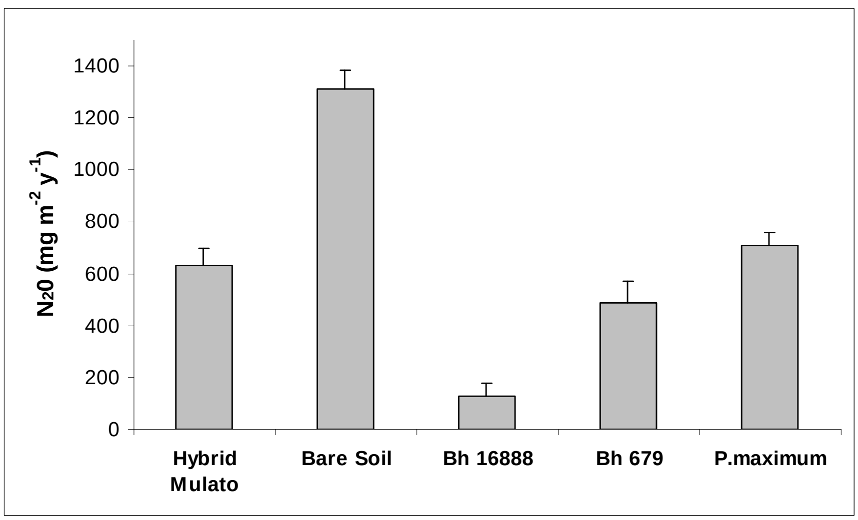


Figure 36. Differences among forage grasses in emission of N_2O for the period September 2004 and November 2007.

The rate nitrification of bare soil was more than eight fold greater than the value obtained for the two *B. humidicola* accessions (Figure 38). As expected the net fluxes of nitrous oxide showed a strong positive association (r^2= 0.85) with nitrification rates.

Greenhouse experiment to determine soil nitrification rates: Results on dry matter partitioning among shoot and root biomass from the comparative evaluation of the 3 accessions are presented in Figure 39. Significant differences were found in root biomass, stem + leaf biomass and total biomass. The accession CIAT 679 produced the highest values of total biomass and root biomass among the tested accessions.

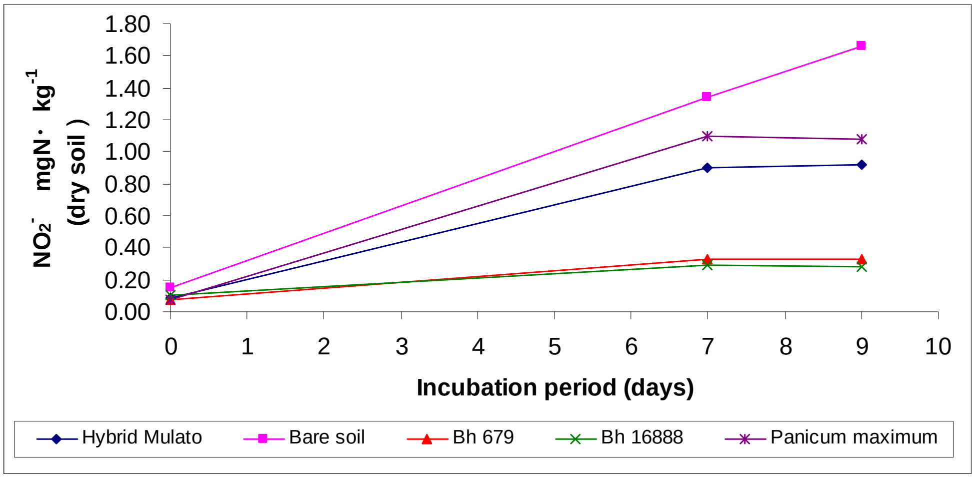


Figure 37. Differences among forage grasses in nitrite formation in rhizosphere soil during the incubation.

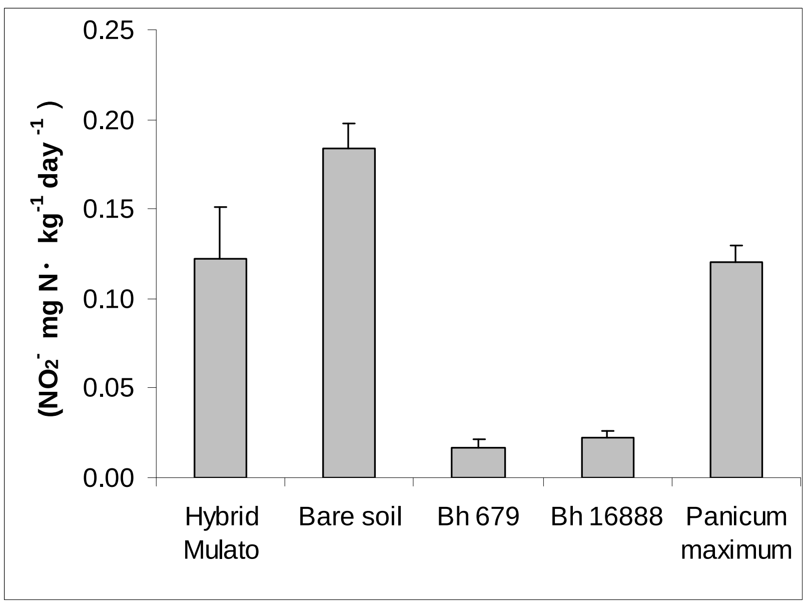


Figure 38. Differences in nitrification rates from incubated soils during 9 days.

Results presented in Figure 40 from the rhizosphere soil incubation test showed significant differences (LSD, $p<0.001$). Bare soil showed highest level of accumulation of nitrite + nitrate during the incubation while *B. humidicola* 679 (high BNI activity) and *B. humidicola* 16888 (highest BNI activity) exhibited lower nitrification rates than that of *P. maximum*. Correlation coefficient between nitrification rates obtained of rhizosphere soil incubation (from field experiment) and rhizosphere soil incubation (from greenhouse experiment) showed a strong positive association ($r^2= 0.90$).

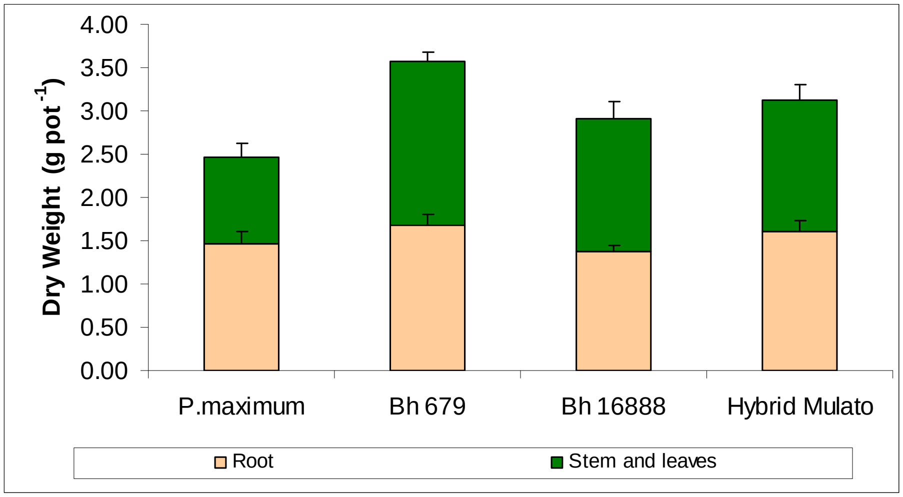


Figure 39. Differences in biomass production at the time of harvest.

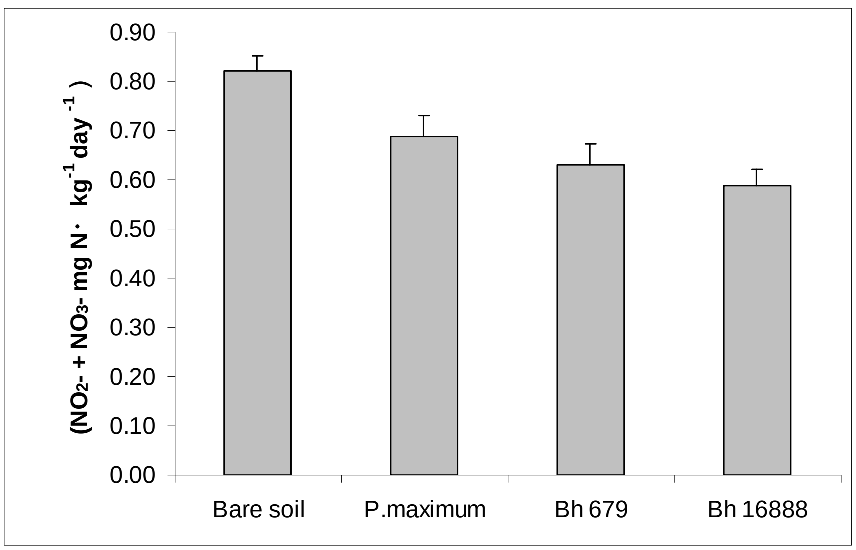


Figure 40. Differences in nitrification rates from incubated soils during 12 days.

Conclusions

This field study after three years of analyses for BNI activity indicated that nitrification rates were lower with the two accessions of *Brachiaria humidicola* (CIAT 16888, CIAT 679) than the accession of *Panicum maximum* (CIAT 16028). The soil incubation method used for this study to estimate nitrification rates seems to be highly sensitive to detect even small differences in nitrification rates among the grasses. Therefore it is a reliable analytical technique to quantify genotypic differences in BNI and that this method could be used as a screening tool to quantify BNI in forage grasses.

Outcome 2: Forages as and for 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

Contributors: Soukanh Keonouchanh (NAFRI), John Kopinski (Queensland Department of Primary Industries & Fisheries, Australia), Phonepaseuth Phengsavanh (CIAT/NAFRI) and Werner Stür (CIAT)

Rationale

An unexpected outcome of the introduction of planted forages in Southeast Asia was the use of the forage legume *Stylosanthes guianensis* CIAT 184 (Stylo 184) as a supplementary feed for village pigs. Farmers found that pigs liked Stylo 184 and reported (i) significant labor savings as Stylo 184 could be used instead of naturally occurring green feeds which take a long time to collect, and (ii) improved growth rates and productivity of pigs.

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, however, declining from overuse. Labor 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 project was designed to investigate the potential of using forage legumes as a supplement for village pigs. ACIAR agreed to fund this research from January 2006 to December 2008. The objectives of the project are:

1. To collate and analyze baseline information of the existing pig production systems in upland Lao villages.
2. To determine the nutritional factors of legumes that are responsible for improved pig productivity, and evaluate best-bet legumes for their feeding value for pigs.
3. To scale-out the integration of Stylo 184 in smallholder pig feeding systems, using Stylo 184 as a model for investigating on-farm factors that influence adoption of forage legumes.
4. To develop guidelines for scaling out of improved pig feeding systems using forage legumes.

The project is managed by CIAT and the National Agriculture and Forestry Research Institute (NAFRI). The QDPI&F is providing support in the area of pig nutrition.

Introduction

The project commenced in May 2006 and completed two studies describing village pig production and feeding systems, and the impact of the introduction of *Stylosanthes guianensis* CIAT 184 (Stylo 184) based on farmers' feedback in 2006; these have previously been reported. In 2007, two *in-vivo* experiments were carried out. The first experiment determined the performance of local 'Moolat' pigs fed a nutrient-dense diet. This experiment was designed to help us better understand the potential growth performance of local pigs as this information is not available but needed to enabled us to compare the effect of legume supplementation with growth potential as well as on-farm growth rates. The second experiment measured *in-vivo* digestibility of Stylo 184 using exotic pigs at QDPI&F in Brisbane, Australia. The Lao project leader, Mr. Soukanh Keonouchanh went to Australia to assist Dr John Kopinski to conduct this experiment. Data analysis of this experiment is not yet completed and will be reported in 2008. In addition, a small range of forage legumes was evaluated by farmer groups in Pek district, Xiengkhuang province and Pakou district, Luangphabang province for their suitability as alternatives to Stylo 184. Feedback from farmer groups is currently being conducted and will also be presented in 2008.

2.1.1.1 Performance of native Lao "Moolat" pigs fed a nutrient dense diet at various levels of intake restrictions

1. The performance of local Lao pig Moolat when fed high quality commercial pig diet in which energy and protein are excess to requirements.
2. The performance response of Moo lat growing pigs to various level of diet restriction based on body weight as a possible preliminary indicator of nutritional requirements.

Methods

The experiment was carried out at the Livestock Research Centre of the National Agriculture and Forestry Research Institute (NAFRI), from November 2006- April 2007. The design was a RCBD with five 5 treatments and 6 replications. Treatments consisted of ad libitum feeding (control), and various restrictions of the same diet corresponding to 90, 80, 70 and 60% of the average amount of feed ingested by the ad libitum treatment group. This was revised weekly to adjust for the increase in body weight of each treatment group. Thirty healthy castrated local "Moolat"pigs aged approximately 5 months and weighing on average 20.3 kg were used for the experiment. High quality commercial feed "Centaco" was purchased in local shops and used for the experiment. Animals were fed twice a day in the morning and late afternoon. The feed contained nutrients in excess of animal requirements. For 7 days prior to the start of the experiment all pigs were fed ad libitum with the commercial diet and voluntary feed intake was measured to determine the level of feed intake at the start of experiment. Animals were housed in an individual pen. They were weighed at the beginning of the trial and at weekly intervals during the experiment. Animals were slaughtered when they reached saleable weight on average of 60± kg for carcass analysis.

Feed refusals were collected daily before feeding time to calculate feed intake. The data of liveweight gain, feed intake, carcass composition of each animal were recoded and were analyzed using ANOVA.

Results and discussion

Feed intake of the ad libitum treatment groups was close to 6% of bodyweight when pigs weighed less than 35 kg with gradual decline to approximately 4% when pigs weighed 50-55 kg. Mean daily liveweight gain of Moolat ranged from 558g for the ad libitum treatment group to 346g for the intake restricted to 60% of the ad libitum group (Figure 41). Weight gains were similar for the ad libitum treatment group and those fed 90 and 80% of ad libitum. Only the 70 and 60% treatment groups had a significantly lower liveweight gain. The daily weight gains recorded in this experiment compare to daily gains of approximately 100 g on farms using traditional feeding systems and 200g for farmers supplementing with Stylo 184. Even the 60% restricted diet had a much higher daily gain than is currently achieved on farms and shows the potential for improvements with better quality diets.

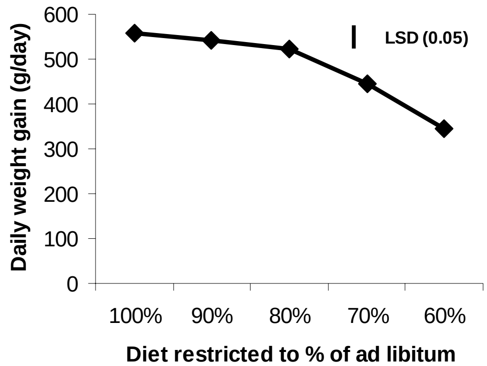


Figure 41. Mean daily liveweight gain (g/day) of Moolat pigs fed ad libitum (100%) or a restricted intake treatment, expressed in % of the ad libitum treatment

The carcass weight of pigs from all treatments was similar at approximately 42 kg. Moolat are a high-fat breed with fat percentage ranging from 59% for the ad libitum treatment group to 48% in the 60% restricted diet treatment group.

The growth performance of native Lao Moolat pigs was impressive as previous indications from farmers were much lower. The experiment clearly showed the potential for improvements in growth rates of village pigs when fed a higher quality diet. Protein is likely to be the most limiting nutrient on farm but other factors such as high levels of fibre may also limit growth of village pigs. This will be investigated in further experiments.

2.1.2 Evaluating ensiled *Canavalia brasiliensis* CIAT 17009 and *Vigna unguiculata* CIAT 9611 cut at different ages alone and mixed with *Ipomoea batatas* roots as alternative feed for swine

Collaborators: S. Martens (CIAT, CIM), P. Avila, L.H. Franco, J.G. Luis (CIAT), A. Alban, L.S. Muñoz (Universidad Nacional de Colombia, Sede Palmira), M. Peters , J. Abello (CIAT)

Rationale

Feeding systems of small and medium scale pig producers in the tropics rely to a growing extend on purchased grains (mainly maize, wheat) and soy, which provide a good source of energy and protein for the animals for whose products there is an increasing demand by consumers. At the same time the worldwide demand for those commodities has risen whereas the production stagnated. Crop failures of exigent wheat for example, increasing transport and synthetic fertilizer costs because of high fuel prices, new demand for raw material for bio-energy and remaining need for direct human consumption with a rising world population has led to reduced supply and increased prices for grains and soy.
To allow higher profit margins for the small and medium scale pig producer in the tropics alternatives such as legumes and starchy plants that can be grown locally shall be examined as the inclusion of legumes in the diet is likely to have a positive effect.

Materials and Methods

In September 2007, 4 plots of *Canavalia brasiliensis* and *Vigna unguiculata* (5*3m²) were established at CIAT Palmira, with 4 harvest times as treatments. Vigna was harvested at 6, 8, 10 and 12 weeks and Canavalia at 8, 12, 16 and 20 weeks after sowing, respectively. 4 replications were employed. The yield of the 4 replicates was measured separately and the dry matter determined in triplicates. Samples were dried at 50 °C for further chemical analysis. A rapid fermentation test, with addition of sugar or/and lactic acid bacteria strains, was performed to evaluate the potential for ensiling of the legumes at different ages. For that small quantities of the plants were chopped up in a kitchen blender. To obtain anaerobic conditions the puree was filled up with distilled water in beakers. The beakers were incubated at 35 °C for two days. The pH was measured at 0, 20, 28, 44 and 52 hours of incubation. Parallel to that the legumes were wilted to a target dry matter of 35 %, then chopped and ensiled in triplicates at lab scale in PVC tubes (20 cm height, Ø 10.8 cm) either alone or in an equal mixture on fresh matter basis with chopped and pre-dried sweet potato roots. As control pure sweet potato silage was produced as well. The silos were stored at 25 °C for 3 months (Table 18).

Table 18. Average DM yield [kg/ha] at different ages and *DM* content [%]

Weeks	***Vigna***		***Canavalia***	
6	1714	*11.1*	-	
8	3457	*11.2*	1124	*21.0*
10	5085	*12.6*	-	
12	8463	*20.6*	3600	*22.9*
16	-		6128	*24.1*
20	-		12243	*39.4*

Results and Discussion

As the harvest took place from October 2007 to February 2008 and the last silos will be opened only in May 2008, some preliminary results are shown here.

The fresh matter yield of Vigna increased rapidly from the pre-florescence stage (6 weeks) to the early post-florescence stage with 10 weeks. The increase in dry matter yield from week 10 to 12 was due to the ripening of the pods and therewith the drying of the plant. Up to 10 weeks age Vigna had a very high water content located mainly in the stem which prolonged the pre-wilting phase for ensiling. It was found out that rolling the harvested plants prior to pre-wilting help diminishing that time considerably.

Canavalia had a much slower biomass production at Palmira until 16 weeks of growth. However, due to a high dry matter content a pre-wilting time of about 4 hours was sufficient for ensiling.

The ensilability of the legumes tested *in-vitro* was variable among varieties and different ages. A rapid and persisting acidulation verified by decreasing pH-values is a main objective for successful ensiling because a fast and high lactic acid production reduces dry matter losses and proteolysis. It prevents the development of undesirable Clostridia and Enterobacteria and guarantees anaerobic stability. The main resource of lactic acid are water soluble carbohydrates. As legumes are generally poor in those the addition of sucrose at 2 % of fresh matter base always improved the fermentability in the test.

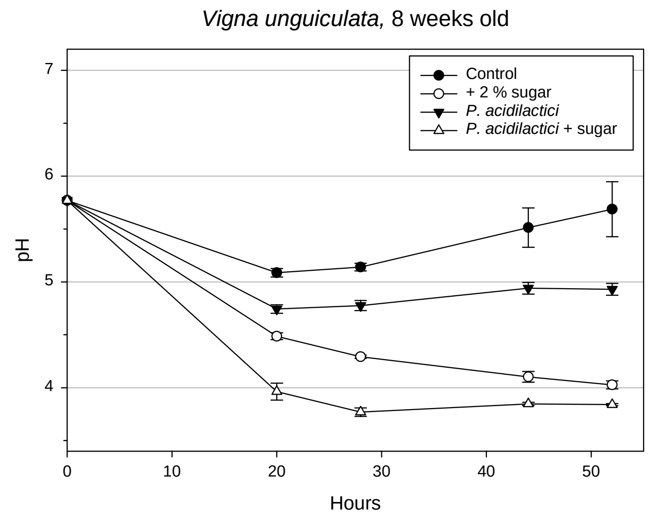


Figure 42. pH development in 8 weeks old *Vigna unguiculata* (exemplary)

The addition of *Pediococcus acidilactici* ($5*10^5$ cfu/g FM) as a lactic acid bacteria strain plus sucrose always led to the best pH development within the 4 treatments. When an effective lactic acid bacteria strain is intentionally added it quickly outcompetes the epiphytic micro-flora and dominates the process, given sufficient nutrients. Regarding the epiphytic micro-flora of Vigna with an additional source of carbohydrates the best fermentation was achieved with 8 weeks age at florescence with a final pH of 4.0 (Figure 42). The only time the control had a pH of below 5.0 after two days was with 12 weeks growth. In general, Canavalia showed harder to ferment, even with the addition of sugar and lactic acid bacteria. That indicates a higher buffering capacity which is the ability to resist a change in pH and is attributed to the anions present, i.e. organic acid salts, orthophosphates, sulfates, nitrates and chlorides, and to plant proteins. However, comparing the 4 different ages, Canavalia fermented best with 12 and 20 weeks age, given additional water soluble carbohydrates.

As for now from the economic point of view *Vigna unguiculata* appears to be more suited for a rapid feed production than Canavalia. However, to give a comprehensive answer on whether one of the two legumes is feasible for pig nutrition and under which condition further results from chemical analysis and on in-vitro digestibility have to be awaited.

2.1.3 *In vitro* characterization of the foliage of six legumes with potential for use in diets of pigs

Highlight

- The potential of six legume species *(Canavalia brasiliensis*, *Cratylia argentea*, *Desmodium velutinum*, *Gliricidia.sepium, Stylosanthes guianensis* and *Vigna unguicuata* for inclusion in pork diets was assessed; among the shrub species *D. velutinum* followed by *C. argentea* and among the herbaceous species *V. unguiculata* and *C. brasiliensis* are the most promising**.**

Contributors: M. Osorio, L. S. Muñoz, P. Sarria, (Universidad Nacional de Colombia - Sede Palmira), M. Peters, L. H. Franco (CIAT**)**

Rationale

Monogastric production in tropical smallholder systems is constrained by high prices of often imported, primary materials, such as grains and cereals. The growing world population and competing demands for these primary materials for human nutrition and as biocombustible affect the sustainability of monogastric production, and thus justify the search for alternative protein feeds which can supplement or replace commercial concentrates.

In pork production, one of the major constraints is the high cost of commercial concentrates which can represent 70% of the total cost of production. In the tropics, there is an array of resilient and productive leguminous forages of high nutritional quality which could potentially be used by pigs; moreover many of these forages can be produced under more marginal conditions where a majority of smallholders are located.

While the protein content in many of these forage legumes is high, their utilization in high percentages in pork diets is often limited by fibre contents and the presence of antinutritive compounds bound to proteins. Information on nutritional quality and digestibility for pigs is scarce.

This study characterizes the potential of hay of six forage legumes *(C. brasiliensis*, *C. argentea*, *D.velutinum*, *G.sepium, S. guianensis* and *V. unguicuata.)* for use in pig diets.

Materials and Methods

In the laboratories of the Universidad Nacional de Colombia – Sede Palmira, Colombia the nutritional composition and *in vitro* enzymatic digestibility for pigs of six forages legumes was measured: *Canavalia brasiliensis* 17009, *Cratylia argentea* 18516, *Desmodium velutinum* 33443, *Gliricidia sepium*, *Stylosanthes guianensis* 184 and *Vigna unguiculata* 961l. Hays were made from material harvested in the rainy season at 9 weeks regrowth.

The following measurements were taken: Dry matter content (%); ash content (%); ether extract (%) using the method of Soxhlet; NDF (%); ADF (%); Lignin (%) and; crude protein (%) and the content of hemicelluloses and celluloses (%) calculated. Brut energy (kcal/kg) was assessed using a calometric bomb and enzymatic digestibility of dry matter and crude protein measured.

The experimental design was a complete randomized block, with the six species as treatments. To determine *in vitro* enzymatic dry matter digestibility (DIVMS), hay was evaluated in three periods, with five repetitions. For the predigestion (method of Leterme and Estrada) samples passing a 0.5 mm mesh were employed. To determine the *in vitro* enzymatic protein digestibility (DIVPC) the method of Kjeldhal was used, measuring de nitrogen content of residues and then multiplying by the factor of 6.25 too obtain crude protein content. The materials were assessed in one period, with two repetitions.

Data was analyzed using ANOVA with means separated using the Duncan multiple range test ($P<0.05$). The correlation between DIVMS and NDF was computed.

Results and Discussion

For better understanding of the results, the species were grouped into shrub and herbaceous materials, taking into account differences in NDF contents between the species due to the contrasting architecture of the plants. In Tables 19 and 20 nutritional values of hays are shown.

Table 19. Nutritional analysis of hays of three shrub legumes species for utilization in pig diets

	Species		
	C. argentea	***G. sepium***	***D. velutinum***
Dry matter %	90.5a	89.8 a	86.9 a
Ash %	11.6 a	8.2 c	10.2 b
Organic matter %	78.9	81.6	76.7
CP %	23.3 a	23.5 a	24.1 a
Brut energy kcal	4424 a	4391 a	4173 a
Ether extract % *	2.2	2.7	2.4
NDF % *	50.6	39.7	46.7
ADF % *	25.9	20.1	24.2
Lignin % *	6.5	7.2	3.6
Hemicellulose	24.7	19.6	22.5
Cellulose	19.4	12.9	20.6

Different letters in a row indicate significant differences. P < 0.05.* Variable measured with one repetition per species.

All legumes had high DM and CP contents and energy values suitable for monogastric nutrition. *G. sepium* had the lowest ADF and NDF contents, however lignin was higher than for *C. argentea* and *D. velutinum*. The higher contents hemicellulose of *C. argentea* and *D. velutinum* in contrast to *G. sepium* indicate a higher quality of fibre of the first two species.

Table 20. Nutritional analysis of hays of three herbaceous legumes species for utilization in pig diets

	Species		
	S. guianensis	***C. brasiliensis***	***V. unguiculata***
Dry matter %	90.6 a	89.9 a	89.6 a
Ash %	8.7 c	14.4 a	12.5 b
Organic matter %	81.9	75.5	77.1
CP %	14.5 c	23.6 a	18.5 b
Brut energy kcal	4113 a	3569 a	3846 a
Ether extract % *	2.6	2.9	4.7
NDF % *	57.8	34.3	31.6
ADF % *	35.3	15.5	16.7
Lignin % *	5.5	2.9	2.1
Hemicellulose	22.5	18.8	14.9
Cellulose	28.9	12.6	14.6

Different letters in a row indicate significant differences. P < 0.05.* Variable measured with one repetition per species.

As for the shrub legumes, CP content and brut energy did not vary between herbaceous legume species, in general the values measured suggest a good potential as alternatives feeds for swine. Fibre content of *Stylosanthes guianensis* was much higher than for *V. unguiculata* and *C. brasiliensis*, indicating the high potential of the latter two species for pig feeding.

Table 21. *In vitro* enzymatic dry matter digestibility (DIVMS) of hay of three shrub legume species

Species	**% DIVMS**
G. sepium	50.6 a
D. velutinum	48.1 ab
C. argentea	43.7 b

Different letters in the same column indicate significant differences P < 0.05

G. sepium had the highest DIVMS among the shrub legumes, followed by *D. velutinum* and *C. argentea*, however differences are lower than may have been expected from differences in NDF values (Table 21). Among the herbaceous legumes *V. unguiculata* had the highest DIVMS, while digestibility of *S. guianensis* was very low.

Table 22. *In vitro* enzymatic dry matter digestibility (DIVMS) of hay of three herbaceous legume species

Species	**% DIVMS**
V. unguiculata	54.3 a
C. brasiliensis	45.7 b
S. guianensis	30.1 c

Different letters in the same column indicate significant differences P < 0.05

In Figure 43 the inverse relationship between NDF content and the enzymatic digestibility of dry matter can be observed, which shows that materials with high fibre contents are more resistant to enzymatic activity in the gastrointestinal tract

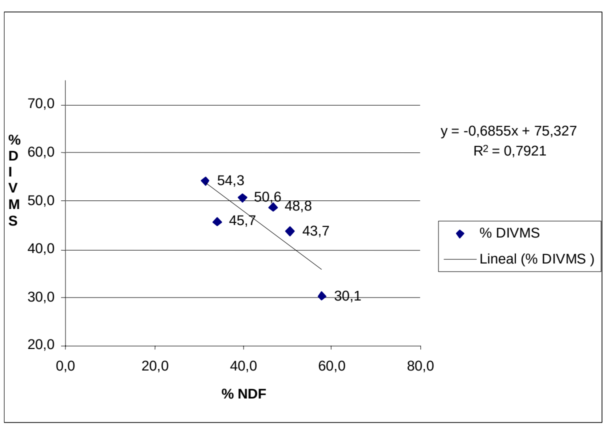


Figure 43 . Relation between enzymatic digestibilty of dry matter of different legume species

Table 23. *In vitro* enzymatic digestibility of crude protein of hay of three shrub legume species

Especie	% DIVPC
D. velutinum	72.0 a
C. argentea	65.9 a
G. sepium	40.8 b

Different letters in the same column indicate significant differences P < 0.05

D. velutinum showed the highest enzymatic digestibility of crude protein among the shrub species, followed by *C. argentea*, which shows the high potential for inclusion as a protein feed in pork diets. In contrast DIVPC of *G. sepium* was low (Table 23).

Table 24. *In vitro* enzymatic digestibility of crude protein of hay of three herbaceous legume species ç

Especie	% DIVPC
C. brasiliensis	66.6 a
V. unguiculata	58.6 a
S. guianensis	44.8 b

Different letters in the same column indicate significant differences P < 0.05

Conclusions

Analyzing three shrub and three herbaceous legumes as protein alternatives for pig alimentation, all legumes tested had suitable crude protein contents, fibre content and fibre quality appearing a more limiting factor.

G. sepium, D. velutium, V. unguiculata and C. brasiliensis all had enzymatic digestibilities of dry matter above 45%, considered suitable for inclusion of these feeds into monogastric diets. In contrast enzymatic digestibilities of protein were highest for *D. velutinum* and *C. brasiliensis* and lowest for *G. sepium* and *S. guianensis* (Table 24).

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

2.2.1 Scaling out of the forage legume Stylo 184 in Southeast Asia

Contributors: Phonepaseuth Phengsavanh (CIAT/NAFRI), Werner Stür (CIAT) and Soukanh Keonouchanh (NAFRI)

Rationale

Scaling out of Stylo 184 is part of an ACIAR-funded project investigating the potential of using forage legumes as a supplement for village pigs. Farmers' feedback suggested that supplementing Moolat pigs with the forage legume *Stylosanthes guianensis* CIAT 184 (Stylo 184) was able to improve daily liveweight gain from approximately 100 to 200g. While a daily liveweight gain of 200g per day is not exceptional (cf. Output 1 – Legume supplementation of village pigs in Lao PDR), it reduces the time needed to fatten pigs in pens from 18 to 9 months. This reduction is considerable and enables farmers to double throughput of fattened pigs and thus increase farm income from village pig production. The scaling out component is based on a 'development alliance' of the research project partners involved in this project and NGOs, government extension services and donor-funded rural development projects. The project supports these development partners through joint workshop, training and mentoring of staff in the scaling out of Stylo 184 in their project areas.

Introduction and methods

NGOs and other development practitioners expressed interest in linking with the research project to improve pig production in their target areas. The project supports this in several ways:

1) Annual planning workshops to review progress, share experiences, discuss implementation issues and develop plans for the next year.
2) Mid-season workshop to discuss implementation issues and training on issues raised by development partners.
3) Linking development project staff with experienced extension staff involved in the project (mentoring) and facilitation of cross visits and training.
4) Development of training and extension materials.

Results

The project works with a range of development partners including NGOs, foreign-funded rural development projects and government extension services:

Development partner organization	**Target area**
Extension services (PAFO and DAFES)	Pek district in Xiengkhuang; Pak Ou and Xieng Ngeun districts in Luangphabang province
CRWRC (Christian Reformed World Relief Committee)	Khoune district in Xiengkhuang province
GAA (German Agro Action)	Three districts in Phongsaly and Oudomxay provinces
World Vision	Two districts in Luangphabang province
CBLSP (Capacity Building in Livestock Systems Project), and the ADB – SULDP	Six districts in four northern provinces
EU - LFSP (Livestock Farmer Support Project)	Numerous districts in six northern provinces

The development or learning alliance started in mid 2006. In the first year of the alliance, development partners worked with a small number of households in their target villages. This increased to 280 households by the end of 2006. Feedback from farmers about the use of Stylo 184 has been positive and by the mid-season review in September 2007, the total number of households that had planted Stylo 184 for supplementation of pigs had increased to over 1,200 households. Feedback from development partners about this type of learning alliance has been encouraging and a study analyzing the process, benefits and suggestions for improvements will be conducted in 2008. Conversely, feed back from developing partner staff about on-farm implementation issues and feedback from farmers in their area has been valuable for researchers.

2.2.2 Enhancing livelihoods of poor livestock keepers through increasing use of fodder – Vietnam Component

Contributors: Truong Tan Khanh (Tay Nguyen University, Vietnam / CIAT); Werner Stür (CIAT); Nguyen Thi Mui (National Institute of Animal Husbandry, Vietnam); and Nguyen Van Giang (National Institute of Animal Husbandry, Vietnam)

Rationale

This 4-year project (2007-2010) is part of the Systemwide Livestock Programme (SLP); it is managed by ILRI and funded by IFAD. CIAT manages the Vietnam component of the project in collaboration with the National Institute of Animal Husbandry (NIAH) and Tay Nguyen University (TNU) in Vietnam. The project is to improve the livelihoods of poor livestock keepers in Ethiopia, Syria and Viet Nam in a sustainable manner through increased access to and adoption of fodder interventions.

With activities in Ethiopia, Syria and Viet Nam and linking with a project implemented in Nigeria and India, the Project aims at better understanding the factors and processes that determine the success of fodder interventions in developing countries. This understanding will be used to strengthen the capacity of poor farmers and service providers to better meet their needs for fodder. Using participatory approaches and considering a range of fodder options in pilot learning sites in the three countries, the Programme will deliver the following outputs:

1. Mechanisms for strengthening and/or establishing multi-stakeholder alliances that can enable scaling up and out of fodder technologies/innovations.
2. Options for effective delivery systems including innovative communication strategies and on farm interventions to improve fodder supply.
3. Enhanced capacity of project partners to experiment with and use fodder technologies through effective communication, technical information and training in diverse aspects placing fodder interventions in the context of systems of innovation.
4. Generic lessons with wide applicability on innovation processes and systems, communication strategies and partnerships that provide an enabling environment to enhance scaling up and out of fodder innovations.

Initial project activities focused on building project teams, selecting pilot learning sites, establishing implementation arrangements and developing workplans for 2007. The team developed a working relationship with the IFAD country office, selected two pilot learning sites, signed agreements with project partners, developed workplans and commenced field activities in the second half of 2007. The selected pilot learning sites are an advanced learning site, Ea Kar district in Daklak province, where managed forages had already been introduced by a previous CIAT project and a new site, Ky Anh district in Ha Tinh province, where the project is embedded in an IFAD investment project – Programme for Improving Market Participation of the Poor, IMPP. Activities commenced at the two pilot learning sites with local project teams, administrative and financial agreements in place. A major activity in late 2007 was a survey of adoption of forages in Ea Kar district, Daklak and preliminary data are summarized in this report.

2.2.2.1 Survey of forage adoption by smallholder farmers in Ea Kar, Daklak, Vietnam

Introduction

Ea Kar district in Daklak was selected as the advanced learning site. Ea Kar was included in a previous CIAT-led project, the Livelihood and Livestock Systems Project (LLSP, 2002-2005 and FSP-2, 2000-2002), and more than 2,000 households had already adopted managed forage plots for cattle fattening, cow-calf production and herbivorous fish production in this district by 2005. At the same time, cattle population expanded rapidly in Ea Kar from 2003-2005 (Figure 44). Ea Kar provides an opportunity for learning lessons about adoption (and non-adoption) and increased market-orientation of smallholder farmers. Ea Kar district is an upland area comprised of mixed crop-livestock smallholder farms with farm sizes ranging from 1-3 ha. The area is undulating, hilly where farmers grow coffee, pepper and annual crops, and only some village have access to small areas of paddy rice. There are villages comprised of migrant Kinh (lowland Vietnamese) people, ethnic minority people and indigenous people. The main project partners in Ea Kar are the district government and Tay Nguyen University with strong links to provincial government agencies and the national level through the National Institute of Animal Husbandry (NIAH).

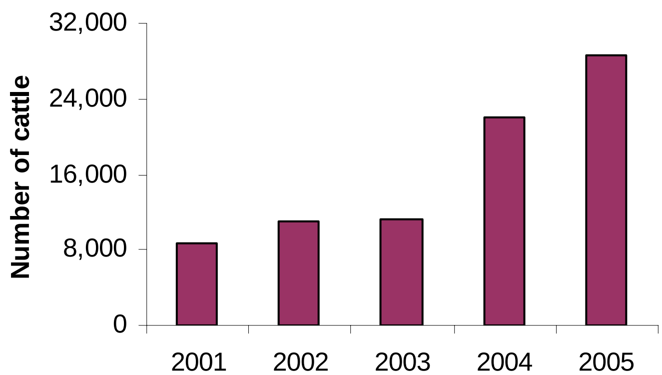


Figure 44. Cattle population expanded rapidly in Ea Kar from 2003-2005.

Methods

In Ea Kar, forage adoption was surveyed in all villages in the district to enable a broad-scale analysis of fodder adoption. The survey instrument was a short, one-page structured questionnaire. District and commune extension workers were trained as enumerators. They visited each village to interview the head of the village on general village characteristics and to obtain a list of households who had planted forages. They then visited each of the adopters to for a short interview. The data were entered into a spreadsheet for analysis. Adoption of forages will be related to a range of factors including social factors, ethnicity, wealth, access to resource, etc. GIS will be used as one tool to assist in the analysis. This survey has been carried out and analysis is in progress. Below is a summary of initial results.

Results and discussion

The number of households growing forage plots increased from 2000-2007 with the most rapid expansion from 2002-2005 (Figure 45).

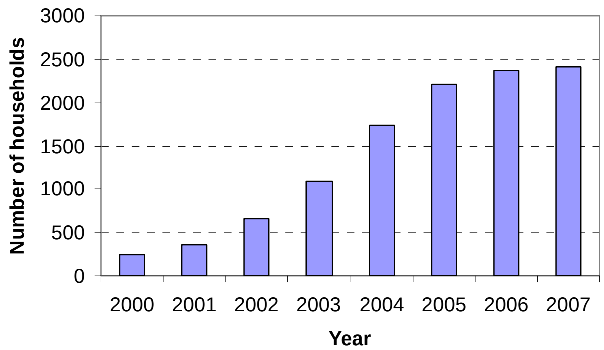


Figure 45. Number of households growing planted forages in Ea Kar, 2000-2007.

Overall adoption rate of planted forage was very high for cattle fattening (96%) and almost half of farmers practicing fattening only started raising cattle after planted forages had been introduced (Table 25). Introducing planted forages encouraged these farmers to start cattle production. In the fattening system almost 70% of the total feed came from planted forages with natural feeds and crop residues accounting the remaining 30%. In cow-calf production system, the adoption rate has been much lower at 19%. This is the traditional way of raising cattle and many farmers have not yet planted forages. For households that have planted forages, the planted forage component accounted for 56% of feed requirements and 19% of households had only commenced cow-calf production after they introduction of planted forages.

Table 25. Forage adoption for cow-calf and fattening production systems

Production systems	No. of households (hh) with cattle in Ea Kar	No of hh adopting forages	Adoption rate (%)	Mean forage area (m^2/hh)	Mean no. of cattle per hh	% of total feed supplied from planted forages	% of hh starting cattle production after planting forages
Cow-calf system	10,134	1,956	19	912	3.4	56	19
Fattening cattle	500	480	96	857	1.8	69	47
Fishery system	3,082	1,306	42	-	-	-	-

Preliminary results show that there has been considerable adoption of forages by Kinh households but not by indigenous households. Other ethnic people adopted forages, but to a lesser extent than Kinh people (Table 26).

Table 26. Number of households (hh), hh with cattle and hh adopting forage plots, stratified by ethnicity in Ea Kar, Daklak

Total number of Households (HH)	31,690
- Kinh (% of total HH)	71%
- Indigenous HH (% of total HH)	10%
- Other ethnic minority HH (% of total HH)	19%
Households with cattle (% of total)	31%
- average number of cattle per HH	2.5
Households with fish ponds (% of total)	9%
Households with planted forages	2,442
- Kinh people (%)	86%
- Indigenous HH with forages (%)	0.1%
- Other ethnic minority HH with forages (%)	14%

A full report of this survey will be available in 2008.

The interim results of the survey were reported to local partners in Ea Kar using GIS maps and summary tables to provide feedback, verify the results with experiences of stakeholders and discuss the implications of the study for future research in Ea Kar. The stakeholder meeting recommended:

- Introducing forage technologies to villages that have not yet been exposed or where adoption rate have been low
  - remote villages in Ea Lang and Ea So communes
  - indigenous and minority villages in Ea Knop, Ea Pal, Ea Sinh and Cư Ni communes
- Improve feeding systems for fattening systems in Ea Dar and Ea Pal communes with particular attention to feeding strategies
  - for different breeds and age of cattle, and
  - protein supplementation
- Improve feeding systems for cow-calf systems in Ea Kmut and Cu Ni communes, with particular attention to feeding strategies
  - for cows at different stages of the breeding cycle,
  - weaning of calves, and
  - dry season feed supply
- Introducing Stylo for pigs in Buon Trung, Ea Bong commune
- Silage making as a way to store feeds for the dry season
- Identify and develop protein sources as a supplement to grass
  - develop legume options for farmers such as the intercrops of forage legumes and maize
  - alternative economic protein sources
- Revisit marketing issues
  - Awareness raising of market opportunities to generate interest in more market-oriented livestock production.
- Improve forage seed production (quality of seed) and delivery systems.

2.3 Benefits from the adoption of 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.

Collaborators: Federico Holmann (CIAT-ILRI), Pedro Argel, Edwin Pérez (ILRI), and Gustavo Guerra (CIAT)

Rationale

The objective of this study was to estimate the benefits of improved forages resulting from the adoption by smallholder farms in Central America.

Material and Methods

Data came from a direct survey to 9 smallholder farmers in Guatemala, 16 farmers in Honduras, 16 in Nicaragua, and 15 producers in Costa Rica which were closely monitored from 2003 to 2007. These farmers participated in the evaluation of new forage options through an ILRI-led, CFC-funded project titled "Enhancing beef productivity, quality, safety, and trade in Central America".

Adoption of improved forages

Table 27 contains the quantity of seed by forage species and country distributed during 2003 to 2007. In addition, Table 28 shows the changes in land use that occurred in these farms as a result of the adoption of improved forages. As shown, the area under improved forages increased from 12% in Guatemala to 105% in Nicaragua. In Guatemala this low adoption rate was due to 2 factors: (a) Hurricane Stan, which passed by Guatemala in late 2005, wiped out the majority of forage adopted by farmers in 2004 and 2005; and (b) the area under improved pastures was already high at the beginning of the project due to the good efforts in technology transfer made by ICTA, the national institution responsible for research and extension. Nicaragua obtained the highest percentage increase in adoption due to the fact that farms in Nicaragua had the least amount of improved pastures. Costa Rica increased the area under improved forages by 96% but in absolute terms it was where adoption was highest, planting an average of 14 ha of improved forages per farm. In Honduras the adoption was moderate (28%). However, Honduras is a country which currently has the highest area per farm under improved forages (50.8 ha/farm) and, like Guatemala, farms had a significant proportion of improved forages when the project started thanks to the effort made by DICTA, the national institution in charge of research and extension.

Impact on herd increase

Table 29 shows the herd inventory by animal category during this period. With the exception of Guatemala (i.e., where animal inventory decreased by 11% due to Hurricane Stan), all farms in remaining countries expanded their herds (between 34% and 41%) not just in mature cows, but in most other categories, which confirms the fact that producers are planning to expand the productive herd not just in the short term but in the medium term as well.

Likewise, Table 29 also shows information on animal mortality. Empirical evidence shows that the adoption of improved forage alternatives for dry season feeding contributed to a better nutrition and thus, reduced animal mortality, which was very significant in Guatemala and Costa Rica (i.e., a reduction in animal mortality by 57% in 2007 compared to 2003) and to a lesser degree in Honduras (24%) and Nicaragua (12%).

Impact on beef and milk production

The adoption of improved forages increased beef production by 15% in collaborating farms in Nicaragua, 46% in Honduras, and 74% in Costa Rica (Table 30). In Guatemala there was no increase in beef production due to Hurricane Stan (Table 31), which passed by in 2005, and forced farmers to sell part of their herd to recuperate their losses in crops. On the other hand, milk production increased significantly in all five countries due to the adoption of improved forages, ranging from 9% in Guatemala, 47% in Honduras and Nicaragua, and 53% in Costa Rica. These increases in milk and beef production were also accompanied by increases in the prices of milk and beef in all countries. Compared to 2003 when the project started, milk price increased from 7% in Nicaragua up to 36% in Costa Rica during 2007. Beef prices increased 9% in Guatemala, 4% in Honduras, 5% in Nicaragua, and 11% in Costa Rica.

Impact on reduction of production costs and farm income

The adoption of improved forages also decreased the cost of producing both milk and beef in the participating farms. As shown in Table 32, milk production costs decreased by 16% in Guatemala, 42% in Honduras, 7% in Nicaragua, and 31% in Costa Rica. Beef production costs decreased by 7% in Guatemala, 46% in Honduras, 9% in Nicaragua, and 23% in Costa Rica.

The increases in production and prices, and the reduction in the production costs generated drastic increases in income. Thus, 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.

Conclusions

The use of seed from improved forages has increased significantly throughout Central America and, as a result, pastures are currently being renovated. Current national policies to liberalize grass seed imports have favored the achievement of project outputs in this area. Extra-regional imports and intra-regional trade have also increased substantially.

The main policy proposals prepared by the project include recommendations for increased support to research activities; identification of improved forage germplasm adapted to high soil acidity conditions and tolerant to drought; reduction of production costs and distribution of improved pasture seed; and improvement of seed supply and marketing systems so that small producers can easily access information obtain planting material. The above can be achieved through small-scale production, involving several local agricultural cooperatives, and the strengthening of producer organizations so they can render different services such as supply of inputs, training, and technical assistance.

Table 27. Amount of seed (kg) of improved forages distributed by the project in the region during the period 2003 to 2007

Specie/Cultivar	Guatemala	Honduras	Nicaragua	Costa Rica	Total
Brachiaria hybrid cv. Mulato	86	133	36	129	384
B. brizantha cv. Toledo	24	55	69		148
B. brizantha cv. Marandú	14		83	36	133
B. decumbens cv. Basilisk	14		76	70	160
Panicum maximum cv. Tanzania		45		20	65
Paspalum atratum cv. Pojuca			47	15	62
Cratylia argentea cv. Veraniega	15	54	39	45	153
Arachis pintoi cv. Porvenir	99	118	18	135	370
Stylosanthes guianensis CIAT 3308	1				1
Pueraria phaseoloides cv. Kudzú				20	20
Leucaena leucocephala CIAT 17263			5		5
Total	**253**	**405**	**37**	**470**	**1,165**

Table 28. Changes in land use with respect to the establishment of improved forges and the number of paddocks.

Parameter	Country							
	Guatemala (n=9)		Honduras (n=16)		Nicaragua (n=16)		Costa Rica (n=15)	
	2003	**2007**	**2003**	**2007**	**2003**	**2007**	**2003**	**2007**
Farm size (ha)	37.5	33.3	57.4	59.9	61.2	69.3	46.1	46.1
Area planted in annual crops	3.4	3.0	1.4	2.9	2.5	2.4	0.1	0.6
Area under forest	0.6	0.5	3.6	0.2	9.4	9.8	5.3	4.8
Area with pastures	33.2	29.2	52.5	57.5	49.3	57.1	36.8	43.0
Brachiaria hybrid mulato	0.0	3.3	0.0	6.4	0.0	0.5	0.0	5.0
Brachiaria brizantha cv. Toledo	0.0	0.6	0.5	4.4	0.1	2.5	1.4	3.2
Brachiaria brizantha cv. Marandú	1.9	3.6	0.3	3.6	0.4	1.5	4.2	10.6
Brachiaria decumbens	3.6	3.6	6.6	8.2	0.2	0.5	1.5	2.0
Brachiaria humidicola	0.0	0.0	9.4	13.3	0.0	0.0	0.0	0.2
Cynodon dactilon	5.6	2.7	12.8	6.9	0.0	0.0	0.4	0.3
Panicum maximun	4.2	3.9	6.6	1.2	0.0	0.0	2.2	2.5
Hyparhemia rufa	0.0	0.1	11.4	6.3	25.0	11.0	11.4	4.2
Aleman	0.2	0.2	0.6	0.6	0.0	0.0	0.0	0.0
Angleton	2.4	1.4	0.0	0.0	1.2	1.2	4.6	3.6
King grass	2.1	1.9	0.3	0.3	0.3	0.7	0.1	0.2
Cratylia argentea	0.0	0.3	0.0	0.3	0.1	0.3	0.0	0.3
Grass-legume mixes	0.0	0.9	0.0	0.8	0.0	0.2	0.0	0.3
Native	13.0	6.5	1.4	0.3	20.3	37.8	10.5	9.8
Other	0.3	0.3	3.1	5.5	1.6	1.0	0.4	0.9
Total area under improved forages	20.2	22.7	39.7	50.8	4.0	8.3	14.9	29.0
Increase in area under improved forages from 2003 to 2007 (%)	NA	12.2	NA	28.0	NA	105.0	NA	96.0
Number of paddocks	18.4	21.0	12.8	22.4	8.6	14.6	4.9	11.1
Stocking rate (AU/ha)	**2.9**	**2.8**	**1.3**	**1.5**	**1.4**	**1.7**	**1.3**	**1.8**

Na = Not Apply

Table 29. Herd inventory by animal category in smallholder dual purpose livestock farms in Central America

Parameter	Country							
	Guatemala (n=9)		Honduras (n=16)		Nicaragua (n=16)		Costa Rica (n=15)	
	2003	**2007**	**2003**	**2007**	**2003**	**2007**	**2003**	**2007**
Mature cows	49.1	44.5	30.4	39.6	25.1	33.0	27.1	33.1
Heifers > 2 years	19.7	15.9	13.4	18.6	19.2	24.7	5.1	8.5
Heifers 1 - 2 years	9.9	11.1	10.6	15.2	8.5	17.1	4.4	8.6
Female calves 0 - 1 year	14.6	10.6	10.4	13.6	7.8	13.3	7.9	12.4
Male calves 0 – 1 year	13.0	9.4	10.0	12.6	6.8	11.9	8.6	10.4
Steers 1 - 2 years	8.7	8.1	2.0	4.0	0.8	0.5	2.3	4.1
Steers > 2 years	0.0	0.1	1.3	0.0	0.2	0.6	5.0	8.8
Breeding bulls	2.3	2.3	1.6	2.3	1.3	1.8	1.1	1.3
Total Animal Units (AU)	83.5	74.4	56.8	76.1	49.2	69.5	43.2	58.8
Herd increase (%)		- 10.9		+ 23.8		+ 41.3		+ 36.1
Animal mortality	2.6	1.1	4.2	3.2	1.6	1.4	2.1	0.9
Mature animals	0.7	0.2	2.1	1.4	1.1	0.9	0.9	0.4
Calves	1.9	0.9	2.1	1.8	0.9	0.8	1.2	0.5
Reduction in mortality (%)		- 57.7		- 23.8		- 12.5		- 57.1

Table 30. Milk production in smallholder dual purpose livestock farms in Central America

Parameter	Season	Year	Country			
			Guatemala (n=9)	Honduras (n=16)	Nicaragua (n=16)	Costa Rica (n=15)
Number of milking cows (#)	Dry	2003	18.1	21.1	17.1	9.6
		2007	17.0	27.4	21.8	13.8
	Rainy	2003	20.1	21.3	21.0	9.3
		2007	18.9	28.1	25.1	13.6
Daily farm milk production (kg)	Dry	2003	66.3	104.1	67.4	35.4
		2007	72.4	152.9	98.8	60.7
	Rainy	2003	108.8	101.3	151.0	51.4
		2007	103.7	149.7	179.7	78.7
Daily Cow milk productivity (kg)	Dry	2003	3.6	4.9	3.9	3.4
		2007	4.2	5.4	4.4	4.4
	Rainy	2003	5.6	4.7	6.5	4.8
		2007	5.4	5.2	6.9	5.2
Milk price (US$/kg)	Dry	2003	0.29	0.28	0.29	0.25
		2007	0.39	0.34	0.31	0.34
	Rainy	2003	0.26	0.22	0.23	0.25
		2007	0.35	0.29	0.24	0.34

Table 31. Beef production in smallholder dualpurpose livestock farms in Central America

Parameter	Guatemala (n=9)		Honduras (n=16)		Nicaragua (n=16)		Costa Rica (n=15)	
	2003	2007	2003	2007	2003	2007	2003	2007
Age at which male calves are sold (months)	9.3	9.3	8.6	8.4	9.8	9.4	13.0	12.9
Weight at which male calves are sold (kg)	208.9	217.8	176.9	188.1	141.0	145.2	227.0	254.0
Males sold annually (#)	16.6	15.0	9.1	12.5	12.2	13.6	13.4	20.9
Amount of beef (live weight) sold per year (kg)	3468	3267	1610	2351	1720	1975	3042	5309
Beef price (US$/kg live weight)	1.27	1.38	1.12	1.16	1.17	1.23	1.23	1.37

Table 32. Feed suplement and labor cost, milk and beef production, income from milk and beef, and farm net income in smallholder dual purpose livestock farms in Central America.

Parameter	Country							
	Guatemala (n=9)		Honduras (n=16)		Nicaragua (n=16)		Costa Rica (n=15)	
	2003	2007	2003	2007	2003	2007	2003	2007
Costs of feed supplements per year (US$/farm)								
Feed concentrates	271	262	974	716	220	102	8	55
Molasses	56	18	196	132	132	144	20	88
Hay	0	0	105	87	0	0	77	128
Others	123	66	129	97	129	144	108	221
Subtotal	607	506	1645	1306	838	829	213	492
Labor force (#)	2.2	2.2	4.9	4.2	2.8	3.6	1.24	1.44
* Family (#)	0.6	0.6	1.6	1.5	1.4	1.4	0.94	0.94
* Hired (#)	1.6	1.6	3.3	2.7	1.6	2.3	0.3	0.5
Cost of hired labor (US/Farm/year)	3636	3731	4028	3715	1389	1920	841	1352
Annual Milk Production (kg/farm)	31938	32143	37470	55229	39863	50121	3884	6088
Annual Beef Production (Kg/farm)	4419	4154	1610	2358	1898	2177	3480	6145
Production cost per kilo of milk (US$) [1]	0.12	0.10	0.26	0.15	0.14	0.13	0.42	0.29
Production cost per kilo of beef (US$) [1]	0.86	0.80	1.15	0.62	0.65	0.59	1.38	1.06
Gross annual income from milk sales (US$/farm)	8835	11913	9355	18088	8816	13996	1941	3489
Gross annual income from beef sales (US$/farm)	4832	4401	1928	2648	2198	2488	3083	5855
Net annual income (US$/farm)	8272	10886	3748	14545	8344	14787	1942	4622
Return to family labor (US$/day)	15.94	32.51	10.11	33.60	18.20	31.44	5.40	13.65
Commercial value of hired labor (US$/day)	5.16	5.29	3.90	3.70	3.17	2.65	8.98	8.67
Return to family labor above hired labor (# times)	3.1	6.0	2.9	9.8	5.5	11.2	0.6	1.8

1. Income over feed and labor cost. It was assumed family labor is equivalent to the commercial value of hired labor. In addition, an extra 20% were added to include other costs such as veterinary inputs and other farm supplies.

2.4 Scaling up dairy production in Honduras: a GIS based regionalization of income indicators.

Highlights

- The regionalization of positive deviances (in Map 7) shows the state of farms that are developing in more intensive cattle management and a better use of forages. Sharp dry season income drops (44 - 53%), as observed on farms with more than 20 cattle can be avoided with a better use of forage technologies and intensification. The even sharper income drops on farms with less than 20 cattle could be mitigated through adequate measures.

- The impact of dry season length on income is great for lowest and low performers. Medium and top performers are able to stabilize their income. Low and medium performers are made up of farms from all herd size classes. Those small farms that are medium performers show that the improvement of cost efficiency is also possible for small and very small herd owners.

Contributors: Lentes, P.; Peters, M.; and Holmann, F. (CIAT)

Rationale

Large parts of Honduras are characterized by a prolonged dry season, varying in length between the moist zones of the North, the central livestock zones and the dry south. This temporal and spatial seasonality is limiting forage and agricultural production gradually.

Milk production systems in Honduras have emerged from extensive ranching systems in times when sufficient land was available. In ranching, the use of labor is considerably less intensive than in other agricultural land use purposes The experience of cattle farmers with low input systems, such as ranching has resulted in a widespread attitude that cattle care for themselves.

During the dry season, Central America’s milk production is about 40 % lower than in the rainy season, when feed resources from green pasture are abundant.. Traditional dry season feed resources are of low quality: Naturalized and native pastures usually dry out at the beginning of the 4 to 8-month dry season and quickly loose nutritive value. Thus, crop residues of maize and beans become important feed sources during the dry season. Low quality and quantity of feed and the low genetic potential for milk production of the commonly used dual-purpose cattle (i.e. cattle for beef and milk production) leads to the sharp decline in milk production during the dry season.

The rising demand for dairy products in Central America has resulted in a general change of farming systems from ranching to dairy production. Yet, cost efficient milk production is much more demanding than ranching.

Regionalization of socio-economic data is used to broaden the information from location-specific surveys to wider areas. Surveys usually use studty areas as their spatial unit and provide punctual information for farms, the survey sites. Regionalization is able to efficiently visualize and present the state of the art as well as to conceptualize target specific research. Policy and development interventions can be planned easier when the situation and possible impact of changes is modeled spatially.

Against this background the objective of this work is to relate the effect of dry season length to the income from milk per cow for farms of distinct cattle herd sizes and resource use efficiency classes and to regionalize these data. A further objective is to assess the average income from milk on district level.

The spatial spread of the profitability of dairy production is mapped and enables regional targeting of forage options considering specific groups of farms in the regions.

Material and methods

In both, traditional and modern farming systems of Honduras, the profitability of dairy production depends on climatic factors. The approaches for regionalization presented in this paper thus uses the length of the dry season as a spatial temporal variable: the returns from milk during the dry season show to be suitable to distinguish different socio-economic systems and the yearly income from milk depends on dry season length. Milk production costs reflect feed availability and costs during the dry and the wet seasons. Moreover, for many farms the incomes from diary production is the only source of a continuous cash flow which allows them to invest in other sectors of the farms like in the cultivation of cash and subsistence crops. Cash at the right time is required for any investment on the farms, like the cultivation of crops, general improvements of the livestock system, the adoption of forage options or the improvement of cattle breeds.

Available socio-economic surveys are limited to certain geographic areas in which farmer's situation is assessed in detail. Study areas usually cover only a few villages. Yet, The necessary study area approach does not tell what happens outside the survey area, although similar systems may exist in other regions. Regionalization of socio-economic data tackles these scale related constraints. The punctual information from surveys is made available for wider areas. Regionalization takes into account that farms act in their spatial setting which is determined by a sum of conditions, making up the frame for production. Many of these factors are physical site conditions, like climate, land cover, soil quality, terrain steepness and water availability throughout the year.

The aim of the approach is to link economic indicators to spatially available variables representing distinct site conditions in order to conduct socio-economic indicators for the coverage area of these spatial variables.

In this paper, the countrywide assessment of the impact of dry season length on dairy production efficiency draws on linking the length of the dry season with socioeconomic indicators that were assessed for the dry and wet seasons. Indicators were generated from farm household surveys and combined with agricultural census data.

Climate data generation and water balance

The minimum of meteorological data required for setting up a water balance model consists of monthly mean temperatures and mean monthly rainfall.

Available climate datasets are designed for continental scale analyses and are thus too coarse for the requirements of this study. Although the Ministry of Natural Resources and the Environment of Honduras published a map of annual rainfall for Honduras, it was not available in a processable form and further data gaps on monthly mean temperatures had to be filled. This was achieved by combining three data sources, which are:

1. Climate station data provided from SERNA and the national meteorological institute
2. Digital elevation data accessible from CSI-CGIAR SRTM
3. Climate data generated for 412 points with the software MarkSim.

Dry season length approximation

The length of the dry season is the period in which evapotranspiration (ET) exceeds precipitation i.e. the period in which the amount of available water is not sufficient for the growth of vegetation. To enable the dry season assessment for livestock holders pastures were selected as reference plants for dry season assessment. For comprehensive descriptions of methodologies to estimate evapotranspiration and definitions for the water balance.

The empirical method of was applied for the countrywide ET assessment, creating calculation routines in Excel and applying them to each location for which the climate data was generated. The Thornthwaite method copes with the minimum data requirements, relying on empirical relations between reference evapotranspiration and air temperature, based on measurements from various climate zones.

$$Et_0 = 16c\left(\frac{10\,T_i}{I}\right)^a \qquad (1)$$

$$I = \sum_{i=1}^{N} \left(T_i/5\right)^{1.514} \qquad (2)$$

$$a = 6.7*10^{-7} I^3 - 7.71*10^{-5} I^2 + 1.79*10^{-2} + 0.49 \qquad (3)$$

$$c = (d/30)*(h/12) \qquad (4)$$

Et_0 reference evapotranspiration mm per month
Ti mean surface air temperature in month i (°C)
I heat index defined in Equation 2
a in Equation 1 is a function of the heat index (I)
c correction factor for month length and daylight duration Equation 4
d length of month in days
h hours of daylight at the 15th of the month

Reference evapotranspiration was corrected using a crop specific correction factor Kc. For the scope of this study the Kc for rotated grazing higher than 15 cm, was used.

$$Et_{crop} = Et_0 * K_c \qquad (5)$$

Water surplus is the difference between rainfall and evapotranspiration of the respective land cover. Whenever water surplus was negative, the month was defined as dry.

Water surplus = Rainfall - Etcrop (6)

Since these calculations deliver data for the sample points that cover Honduras, Kriging interpolation was used to create the climate and dry season length surfaces from the climate sample points. Kriging interpolation, a linear estimation procedure (Matheron, 1963) was used to fill the information gaps between points for which climate data were generated (see below). In Kriging the value of the variable at the location of estimation is calculated from the weighted mean of the surrounding sample points. The weights of the sampled points are calculated to perform optimally to reach the smallest variance in the estimation error. For the interpolation, the Kriging plug-in for ArcView GIS was used. The grids were calculated considering the variance of the 12 neighboring sample points and their distances to the point of estimation. A linear trend in the sample data was assumed for the model.

Sampling and calculation of socio-economic indicators

The sampling plan applied for the collection of micro level farm data covers two study areas in representative zones in the departments of Olancho and Yoro. These areas are typical for the central parts of Honduras. The income indicators used for regionalization were assessed in 2005 and 2006 from the two sub samples A and B.

In sub sample A the economic conditions of the **typical livestock holder** were assessed for randomly selected farms. The sample covers 69 farms in Olancho and 28 in Yoro.

For sub-sample B, 30 farms, referred to in the text as **positive deviances** were selected using expert knowledge provided by local extension staff. On these farms adoption of diverse forage options is more obvious than on the typical farms from sample A. However, the advanced use of forage options does not necessarily mean that the farms take full advantage of the technologies adopted and that this would translate into higher income.
Forage technology adoption is seen as a necessary entry point for cattle farms to improve resource use efficiency but not as the sole technology necessary to reach an integrated development of the farms. Extra large farms (>100 cattle head) were not accepted as positive deviances, because the availability of financial resources is not comparable to the typical Honduran farm.

The focus of the analysis lies on the dairy enterprise, yet other parts of the farming system (beef and crops) were also considered in order to characterize the systems and make the importance of milk production more evident. To obtain the net income of a production system, all production costs were deduced from the gross income. Production costs therefore include all purchased inputs and farm inputs, costs for renting machinery, services and the opportunity cost of family labor. This means that the income for each person working on the farm is valued with equivalent wages like the wages paid for hired labor.

Two indicators were based on the period of one month and one cow in milk during distinct seasons. These indicators are the net income from milk for the dry and for the wet season, respectively. These indicators were chosen to measure production efficiency in both seasons. The production cost per liter of milk in both seasons is used to underline the efficiency per cow more clearly.

Classifications according to cattle herd size and resource use efficiency (performance) serve to make farms comparable throughout systems and sizes. Farms from sample A were classified, compared to each other and to farms of sample B.

Classification procedure

Two classification methods were applied to farms of sub sample A: herd size and performance in dry season milk production.

The herd size classification distinguishes 5 classes, modifying the classes used by SECPLAN and a class of positive deviances, (sub sample B) which contains farms of various herd sizes. Herd size classes were defined as follows:

Very small	1-9 cattle	Large	50-99 cattle
Small	10-19 cattle	Extra large	> 100 cattle
Medium	20-49 cattle		

Performance groups (Table 33), similar to a comprehensive comparative analysis of dry season milk production in Honduras (Lentes et al. 2006 b) were built for farms of sub-sample A. Percentile intervals of the indicator monthly income from milk in the dry season were used to group farms into four classes. Farms that did not benefit from milk production in the dry season and the positive deviances (sub sample B) were considered separately.

Table 33. Performance class definition according to net income from milk /cow/month of dry season US$

Category	Percentile range	Lower bound US$/cow/month	Upper bound US$/cow/month
Lowest performers	No profit obtained	open	0
Low performers	0 - 50	> 0	9.14
Medium	50 - 80	> 9.14	20.23
Top	> 80	> 20.23	open

Regionalization of indicators

For the regionalization of income from dairy production, the seasonality of net income from dairy production plays a crucial role. The income differentiation between seasons and groups of farms is a measure for the efficiency of the resource use and the availability of dry season forage technologies on the farms.

For the performance and herd size groups, the indicator net income per cow per year is calculated using equation (7):

$$Y_{\text{year}} = n * Y_{dry} + (12 - \mathrm{n}) * Y_{wet} \qquad (7)$$

Where:

Y_{year}	Net income per cow per year
n	number of dry months
Y_{dry}	Net income /cow/month of dry season
Y_{wet}	Net income /cow/month of wet season

Average income from milk per cow for each district

The regionalization of the average net income per cow per year in the districts of Honduras uses the last complete agricultural census to determine the share of each herd size class in the each district. The spatial units of this publication are the departments. Five years later, INE published agricultural census for 7 representative regions covering Honduras and thus has the disadvantage that the spatial resolution is coarse, compared to the 1994 census.

The 1994 Census data were collected before hurricane Mitch. In the year after the disaster, cattle population had declined to 82.5% of the 1994 population. Annual growth rates are reported to be 2.58 % for the post Mitch years between 1999 and 2001. Supposing that from 2001 on till 2005, the year of the socio-economic survey undertaken for this study, growth rates have bee similar, the livestock population would have reached the pre Mitch level again by 2005. If we further suppose that this growth has not lead to a shift in herd size composition of farms, the data from 1993 are valid. Although there is uncertainty about this development, the 1993 data are still the best available information on herd size composition in the districts of Honduras.

Together with the result of the productivity assessment from the farming systems survey, census data were used to extrapolate the income situation of the dry and wet season from the survey population to the population of the district.

The district wide average net income/cow/ month was calculated as follows:

$$Y_{dry} = \sum_{i=1}^{N=4} \frac{F_i}{F_{tot}} * I_{idry} \qquad (8) \qquad\qquad Y_{wet} = \sum_{i=1}^{N=4} \frac{F_i}{F_{tot}} * I_{iwet} \qquad (9)$$

Where:

Y_{dry}	Region wide average income / cow / month in the dry season
Y_{wet}	Region wide average income / cow / month in the wet season
F_i	Number of farms in farm size class i
F_{tot}	Total number of farms
I_{idry}	Net income / cow / month of dry season for farm size class i
I_{iwet}	Net income / cow / month of wet season for farm size class i

This yields two average income values, which depend on the proportion each herd size class has in the total population of the district's cattle farmer population. The region wide average income per month of dry season was calculated for each district and two grid themes were created: one with the respective value for Y_{dry} for each district and another one with the respective value for Y_{wet} for each district. These two grid themes were processed with equation (3) to include dry season length in the map of average income yearly income from milk /cow.

Results

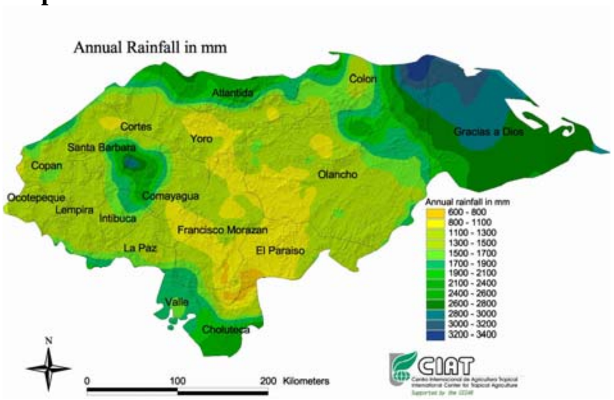
Results are presented in 3 sections: The assessment of the dry season length, the classification of sampled farms according to farm size and the performance indicator and results of the three regionalization approaches.

<u>Dry season length</u>

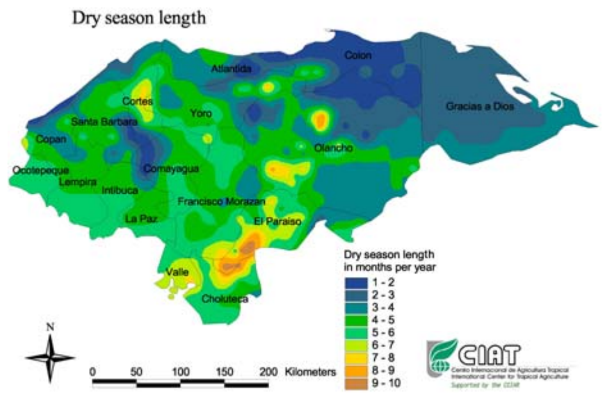
Temperature and rainfall data of stations were compared to the corresponding result for their locations as generated with MarkSim. A set of linear regression models, one for each month, was created with SPSS to correct the MarkSim data with station data. These regressions yielded high explanatory qualities in terms of R-square, since altitude is of major importance when explaining temperatures. On what concerns the rainfall data, the differences between the model results and the measured rainfall are on average small and tolerable. But there was no robust statistical model identified to correct the rainfall output of MarkSim with measured data.

Map 1 shows the annual rainfall distribution for mainland Honduras as modeled with MarkSim, interpolated and mapped with GIS. While the north and especially the northwest receive most rain, the central provinces of Honduras are marked by annual rainfall sums between 1400 and 1000 mm. Moisture islands inside the territory consist of mountain areas shared between Comayagua and Santa Barbara, where higher elevations yield more rain and the area around lake Yohoa. In the slipstream areas behind the coast parallel mountain ranges of the North, there is an abrupt drop of annual rainfall sums. A distinct moisture gradient is to observe in Olancho from the southwest to the northeast and further throughout the departments of Gracias a Dios and Colon to the Caribbean coast. Although favored by high rainfall sums, much of this area is a protected biosphere reserve and most of the unprotected part is inaccessible. In some areas on the Caribbean coast rainfall sums map turned out not reliable, according to field experience. Where this was the case, dry season length was adjusted to surrounding areas using field experience of local experts.

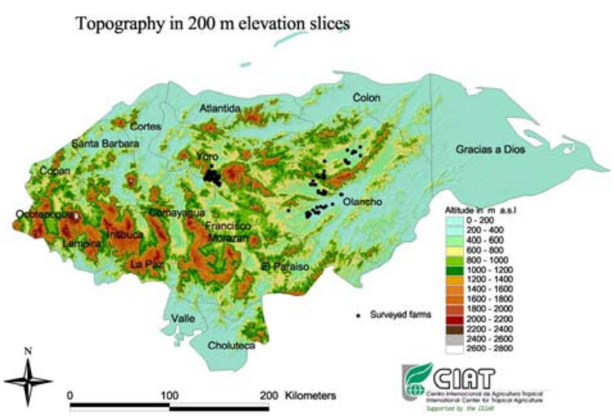
Map 1. Annual rainfall



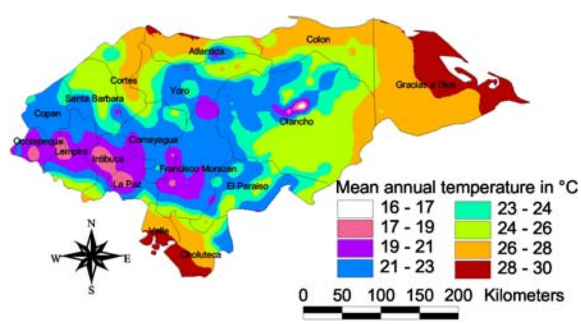
Map 2. Dry season length



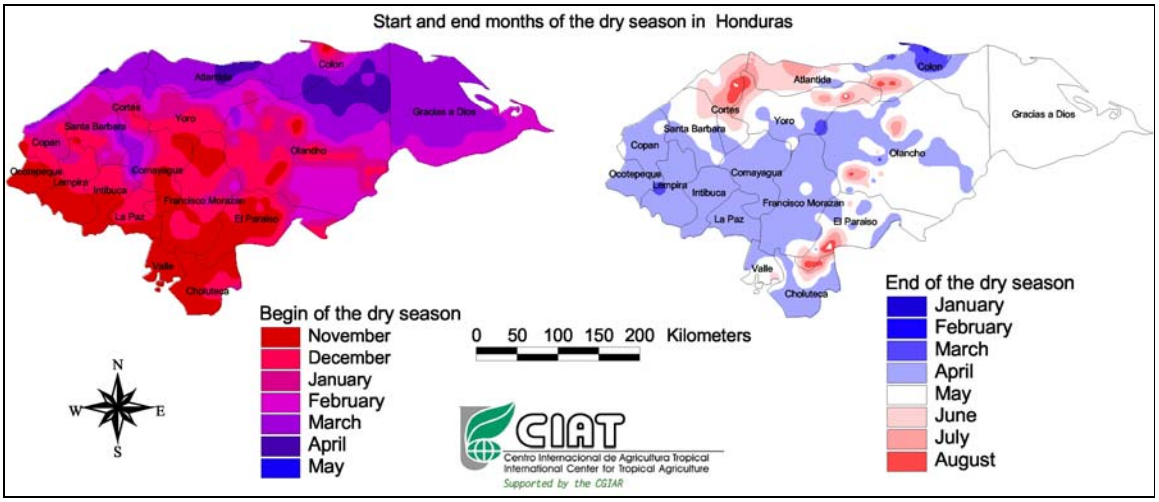
Map 3. Topography



Map 4. Mean temperatures



The dry season lengths (Map 2), were calculated from the difference between evapotranspiration, as assessed with method of Thornthwaite and the annual rainfall.



Maps 5 and 6. Begin and end months of the dry season

Dry seasons shorter than 3 months are characteristic for the northern part of the country near the coast, where elevations are below 200 m. Short dry seasons inside the country are characteristic for mountain areas e.g. those shared between Comayagua and Santa Barbara, where higher elevations yield more rain and the area around lake Yohoa.

In the slipstream areas behind the coast parallel mountain ranges, there is an abrupt drop of annual rainfall sums and an increase of dry season length.

In the central provinces of Yoro, Francisco Morazan, Comayagua El Paraiso and in most of Olancho, as well as in the eastern provinces Ocotepeque, Lempira and La Paz dry a dry season length of 4 to 7 months is most characteristic. Where the dry season is shorter, cooler temperatures and increasing rainfall are due to higher elevations.

The driest areas of Honduras are found in intra mountain valleys, e.g. in the South of El Paraiso, bordering Choluteca, or in rain shadow-influenced environments, such as in the South east of Olancho. Although the South of Honduras shows higher annual rainfall than e.g. the central provinces, it has longer dry seasons, because rainfall is concentrated on short periods of the year, in which heavy rainfall events occur. This region has higher temperatures than the central provinces (Map 4) and a longer dry season.

In order to generate information on where the dry season starts in which month and when it ends, Maps 5 and 6 were elaborated. It can be said generally, that the start of the dry season is spatially more variable than the end of the dry periods. The areas, where the dry season starts first (in November) are located in the south along a strip oriented from south east on the border to Nicaragua to the west of the country on the border to El Salvador and Guatemala. In the central parts of the country dry season starts between December and January. Where dry season is short water balance turn negative from February and March on. In most of the country May and June are the first wet months.

Production efficiency for herd size classes

Within each herd size class, there is a wide range of management and general production conditions, like the characteristics of the land, the genetic potential of the cows, the availability of improved forages and the knowledge available on the farm to manage the farm efficiently under the specific circumstances. These differences make it difficult to characterize herd size groups on with an indicator on resource use efficiency, because the the indicators always include the range of production conditions of the group. Consequently, indicators on herd size are subject to comparatively high variation within groups. The within group variability is great on small farms with less than 20 animals and gets smaller with rising herd sizes. In this paper, farms are characterized only by the indicators used for regionalization. Very small and greater herd sizes differ most in the income per cow / month. This is especially striking in the dry season. The farms with few cattle generate the lowest income from milk per cow and month in both seasons. On very small farms, feed is not available in sufficient quantity and quality and milk production drops sharply. On some farms, commercial concentrates are used to maintain the cows. Milk production of very small farms is not cost efficient in the dry season. Only in the wet season farms with 1 to 9 cattle generate positive income from milk but this does not compensate the losses experienced in the dry season.

Small farms generate little income from milk in the dry season but do not loose on average. In the wet season, small farms generate about half the income of the other farm size classes but only slightly more than one third of what positive deviances gain.

Table 34. Income parameters for milk and beef production in herd size classes, Olancho and Yoro in US$

		Very small 1 to 9 N=16	Small 10 to 19 N=22	Medium 20 to 49 N= 34	Large 50 to 99 N=16	Extra Large > 100 N = 9	Positive deviances N = 30
		A	B	C	D	E	F
Dry season: net income / cow / month	Mean	-7.80	3.14	10.12	11.25	11.95	22.83
	Std. Dev.	13.95	20.70	18.60	10.10	7.70	20.62
	Sig.	B**, C,D,F***	C*,F***	F*	F*		
Wet season: net income / cow / month	Mean	3.47	10.86	21.68	20.95	21.60	29.91
	Std. Dev.	18.55	21.19	16.01	9.94	7.06	15.82
	Sig.	C,D, E,F***	C,D**,E*,F**	F**	F*	F***	
Yearly net income from milk / farm	Mean	-2.51	528.42	1793.70	3324.82	10134.08	5886.40
	Std. Dev.	457.41	942.48	1649.00	2683.39	5101.11	4967.22
	Sig.	C,D, F***	C,D,E,F***,	D**,E,F***	E**,F**	F**	
Yearly net income from beef / farm	Mean	87.72	300.63	460.61	5240.96	10375.74	1982.17
	Std. Dev.	136.54	887.60	769.18	11445.17	7733.00	4017.93
	Sig.	D**E***,F***	C,D*, E,F***	D*,E,F***	E***	F***	

*** The hypothesis of non significant differences between groups was rejected with a probability >= 99 %, according to Mann-Whitney U test

** The hypothesis of non significant differences between groups was rejected with a probability >= 95 %, according to Mann-Whitney U test

* The hypothesis of non significant differences between groups was rejected with a probability >= 90 %, according to Mann-Whitney U test

The concept of economies of scale is applicable to the herd sizes below 20 cattle. When farms get greater, there are no more dramatic differences in the efficiency of milk production. Nevertheless, the seasonality of income is relevant for all farm sizes. Net income from milk per cow on farms with more than 20 cattle drops between 44% and 53 % in the dry season. Dry season incomes per cow are about half the ones in the wet season.

The positive deviances show a comparatively high income from milk per cow in both seasons. Their dry season income is comparable to the wet season income of the farm size classes from 50 cattle upwards. Wet season income differences between positive deviances and the other classes are significant. In the dry season, their income per cow drops by 23 %.

Farms in Honduras are usually characterized as dual-purpose systems, in which milk and beef are produced. Very small farms earn more from beef than from milk. The relation switches to higher income from milk among small farms. Yearly income from milk of medium size farms is about 3.9 times greater than income from beef. Among large farms (ranching systems) there are cases that produce much more beef than milk (see the standard deviation in Table. 34). Extra large farms are in equilibrium between the two products, while positive deviances have a clear focus on milk.

<u>Production efficiency for performance classes</u>

To characterize farms according to resource use efficiency, four performance classes were built, using the indicator net income per cow per month of dry season. Table 33 shows the limits of the classes, derived from percentiles of the net income /cow/month of dry season (p-value <0.01). The socio economic and production conditions of performance classes are presented in Table 35. All farms that experience losses in the dry season were joined in the class of the lowest performers. Even in the wet season, lowest performers do only recuperate their expenses marginally. Wet season production cost/liter of milk is very high, compared to the other performance groups. As much as 75 % of very small farms perform lowest. Milk production on these farms is low because few cows of low genetic potential are milked and cost efficient feed is not available in the dry season. The low volumes result in an under exploitation of family labor force: Farmers on many very small farms earn less than a workers salary. While some low performers have negative yearly incomes but are close to the breakeven cost, others lose more. Dry season production costs of milk decline, as the performance level gets better. So does the variability of production costs. Those farms at the bottom of the performance scale lack of cost efficient farm feed and need higher milk production volumes to produce efficiently.

Small farms (10 to 19 cattle) have equal presence in lowest and medium performers categories (36 %). A few small farms perform low (9.1%) and some more perform top (18.2%). Cost efficient milk production is more often achieved with herd sizes between 10 and 19 than with fewer animals.

Low and medium performers generate nearly the same net income/cow during the months of the wet season, however in the dry season there is a marked income difference between those two groups. Low performers show deficiencies in dry season herd management such as inadequate provision of feed and exaggerated use of purchased supplements. In forage technology adoption, medium performers are one step ahead of low performers. Medium performers use more low cost farm feed and are better prepared for the dry season with conserved forage.

Positive deviances lie between medium and top performers in the income and production cost parameters in both seasons. The inclusion of positive deviances in the analysis does not necessarily demonstrate what can be achieved with an appropriate use of forage technology. The analysis rather shows that an integrated change of the livestock production system is the key to success. More factors than the availability of forages have influence on the economic success of dairy production e.g. the genetic quality of the milking cows.

Table 35. Income parameters and costs for milk production in performance groups, Olancho and Yoro in US$

		Lowest N=31 A	Low N=17 B	Medium N=29 C	Top N=20 D	Positive Deviances N=30 E
Dry season: net income / cow/ month	Mean	-15.31	5.54	14.29	27.08	22.83
	Std. Dev.	11.57	3.41	2.51	5.41	20.62
	Sig.	B,C,D,E***	C,D,E***	D***,E*		
Wet season: net income / cow / month	Mean	0.95	19.59	18.57	33.01	29.91
	Std. Dev.	16.22	10.26	9.61	15.24	15.82
	Sig.	B,C,D,E***	D***,E**	D,E***		
Dry season milk production cost / liter	Mean	0.53	0.19	0.13	0.09	0.18
	Std. Dev.	0.34	0.07	0.05	0.05	0.06
	Sig.	B,C,D,E***	C,D***	D**,E***	E***	
Wet season milk production cost / liter	Mean	0.22	0.07	0.07	0.03	0.10
	Std. Dev.	0.16	0.06	0.05	0.02	0.05
	Sig.	B,C,D,E***	D,E**	D,E***	E***	
Net income milk / farm / year	Mean	-89.39	3699.43	3273.46	3096.26	5886.40
	Std. Dev.	545.69	3961.11	4646.34	1531.33	4967.22
	Sig.	B,C,D,E***	E**	D**,E***	E**	

*** The hypothesis of non significant differences between groups was rejected with a probability >= 99 %, according to Mann-Whitney U test

** The hypothesis of non significant differences between groups was rejected with a probability >= 95 %, according to Mann-Whitney U test

* The hypothesis of non significant differences between groups was rejected with a probability >= 90 %, according to Mann-Whitney U test

Countrywide income regionalization

The indicators of milk productivity used for the countrywide regionalization are the net income/cow/ month in the dry season and in the wet season. The spatial variables used for regionalization are the length of the dry and wet seasons. For the regionalization of the income indicators, income values for the categories were inserted in equation 3. The income grid surfaces were created with GIS.

Countrywide income assessment for herd size classes

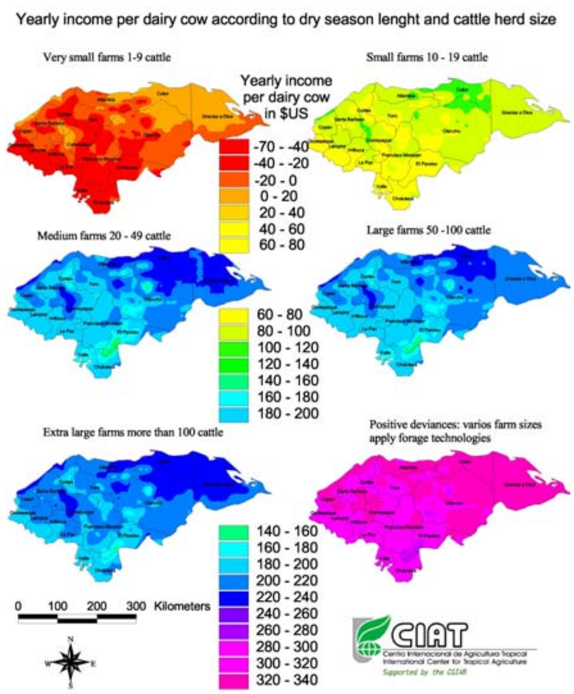
The yearly income from milk per dairy cow was mapped for five farm size classes and the category of positive deviances. Table 36 presents the income characteristics of the dairy enterprise for these farm categories.

Table 36. Grid statistics for income and dry season maps in suitable areas

Months of dry season	9.6	4.6	0.96
Net income / cow / year US$			
	Minimum	Mean	Maximum
Very small	-67.25	-10.23	30.76
Small	52.19	89.58	116.47
Medium	148.46	209.96	249.01
Large	157.67	206.76	242.04
Extra Large	165.95	214.79	249.90
Positive deviances	290.51	326.33	352.09

Very small farms up to 9 cattle head are usually resource poor farms, which do not put much emphasis on dry season milk production. As shown in Table 34, there is a high variability in the income per production unit among this farm size class. The model designates only areas with dry seasons shorter than 3 months as zones, in which very small livestock herd owners can make profit form milk production (Map 7). These areas are mainly located in the Northern part of the country and in a few mountain areas inside the country. For the drier parts of Honduras the model outputs losses in milk production for the whole year.

The owners of small herds of 10-19 animals can produce milk profitably in all regions of Honduras. Corresponding to dry season lengths small cattle farms earn between 52.2 and 116.5 US$ /year per cow in milk.



Map 7. Income regionalization for cattle herd size classes

On those farms with more than 20 cattle, income between the driest and wettest areas varies between 148 and 249 US$. As in the surrey results (Table 34) the model did not state dramatic income differences for those groups with more than 20 cattle.

The vulnerability of farms to income depressions in the dry season is great on very small and small farms. In the driest parts of Honduras, farms with more than 20 cows have a greater income/cow/ month than smaller farms in the wettest parts. It is apparent, that a better dry season herd management would help farms to generate more income per cow. Very small farms would need to improve their dry season feed base and increase the number of milking cows to be able to work profitably in areas with more then 3 months of dry season. When compared to the average Honduran farmer of different herd sizes, positive deviances yield the highest incomes per cow per year in the whole country.

Countrywide income regionalization for performance classes

In the countrywide maps (Map 8) on the income /cow/year for performance classes, income is a function of dry season length and the dry and wet season incomes for each performance class (Table 37). The degree to which yearly income depends on the dry season length differs between the performance groups and is determined by the difference in incomes between the dry and the wet season.

Lowest performers show the highest dependency on climatic factors. Although the income of low performers also traces the spatial pattern of dry season length in Honduras, their income is always positive.

The maps for medium and top performers show that these groups generate comparatively high incomes in all areas of Honduras. The income range of medium performers is about 15 $ lower than for top performers.

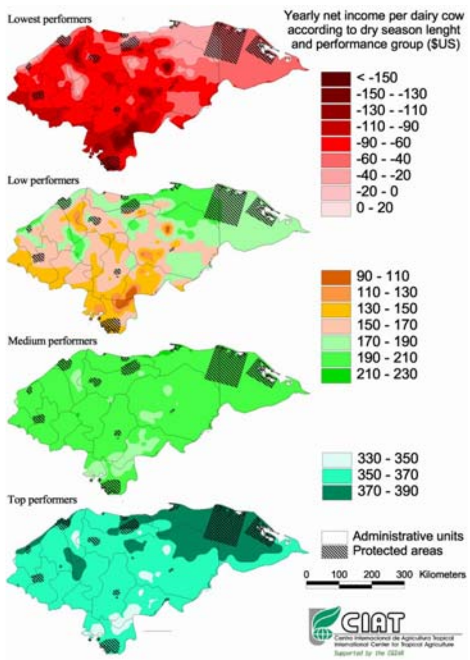
Table 37. Grid statistics

Dry season length (months)	10.11	4.52	0.67	
Net income / cow / year US$				
	Minimum	Mean	Maximum	Range
Lowest performers	-152.97	-62.16	0.58	152.3
Low performers	93.05	171.52	225.73	132.68
Medium performers	179.58	203.48	212.0	40.42
Top performers	336.18	369.29	392.18	55.98

The grid statistics calculated from the maps show, that there is only a small area mapped in Honduras, where lowest performers are predicted to recuperate costs of milk production. The break-even point is reached with a dry season length of 0.7 months. The maps and Table 37 show that the income range between areas with short and long dry season is the highest in the lowest and low performers categories. Medium and top performers are considerably less affected by dry season length.

The income gradients, as shown in equations (6-7) of lowest and low performers are considerably steeper than for the other performance classes. This means, that these two classes are affected more seriously by dry season length than the others. This can also be seen from the income range between the wettest and driest parts of the country.

Low and medium performers would generate nearly the same income under conditions without dry season constraints (Figure 46). For each month of dry season, the gradient of low performers is nearly 10$ steeper than the one of the medium performers. Medium performers income per cow declines 4.28 $ for each month of dry season. Top performers show the highest base income but the decline per month of dry season is a little steeper than among medium performers. Positive deviances showed comparatively higher costs during the dry season than top performers. Their yearly income /cow declines more rapid/steeply for each month of dry season (8).



Map 8. Income regionalization for performance classes

Using the average values of income per farm, the regionalization of income parameters according to climate yields the equations and graphs shown in Figure 46:

Lowest performers:	Y= 11.4	–	16.26 x	(6)
Low performers:	Y= 235.08	–	14.05 x	(7)
Medium performers:	Y = 228.84	–	4.28 x	(8)
Top performers:	Y = 396.120	–	5.93 x	(9)
Positive deviances	Y= 358.909	–	7.079 x	(10)

Where: Y = net income /cow/year
x = months of dry season

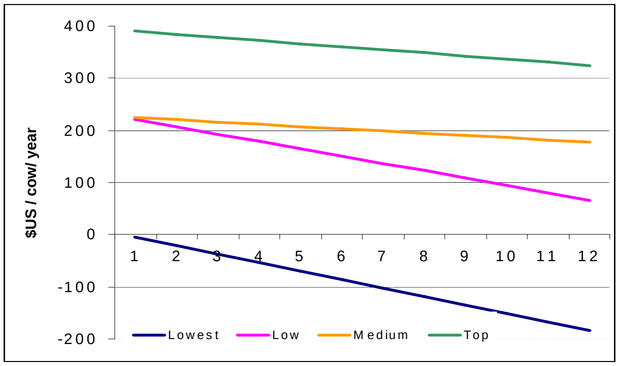


Figure 46. Yearly income per cow in milk for performance groups with variable dry season length.

3. Average income assessment for farm size class proportions for each district

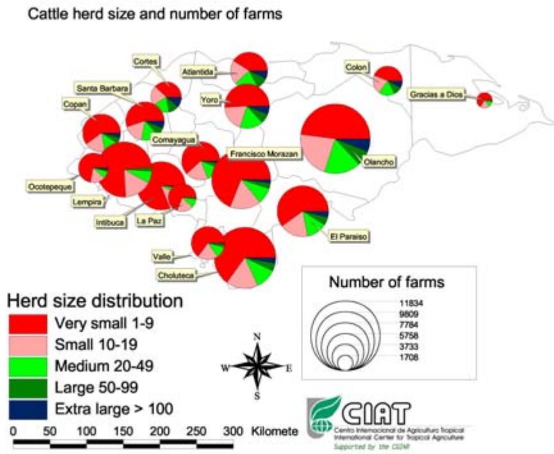
According to SECPLAN, the distribution of herd size classes is uneven throughout the country (Map 9). The Western and Southern provinces have a high share of farms with very small herd sizes of less than 10 cattle. The maximum share of very small herds is found in Intibuca with 81 % of the farms. On country average the majority of cattle farms have very small herds. These are the farms that are affected most by a prolonged dry season and which are least developed forage options.

The average income per cow per district is dependent on the herd size composition given for each district. As it was shown in Table 34 and Map 7, each herd size class has distinct incomes from milk for the dry and wet seasons.

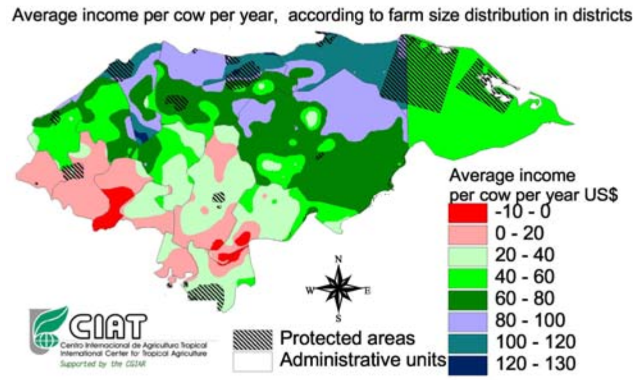
The corresponding average distribution of these classes in each district and their respective efficiency were used to calculate the average yearly performance of the dairy enterprises per district. This regionalization approach is suitable to compare the profitability of milk production districts in districts. Based on the presence of cattle herd sizes, the income per cow of the average farm in this district is calculated and the dry season length is considered.

The applied model estimates the lowest incomes per cow per year for the areas in the south of the country and in the southwest, where the share of very small herds is high and the dry season is between 6 and 10 months according to Map 1.

As it can bee read from Map 10, the central part of Honduras shows incomes between 20 and 40$ in the areas with 4 to 5 months of dry season, but drops to 0 to 20$ /cow/year in much of the Northern part of Francisco Morazán. For most of the mountainous areas of e.g. Olancho and Yoro, which have between 3 and 6 months of dry season, the model estimations are between 20 to 80 $ /cow/year. In most parts of Honduras, like in the North along the Caribbean or in the east of Olancho, incomes per cow rise to values between 80 and 120 US$/cow/year, while in some areas income may reach up to 130 US$. Although Gracias a Dios is one of the areas with most rainfall in Honduras, the income level of livestock keepers is estimated low, because of a very high share of very small farms in the population.



Map 9: Cattle herd size distribution in districts



Map 10. Income distribution derived for districts

Discussion and conclusions

Dry season length was calculated from evapotranspiration generated with the method of Thornthwaite. The weather simulation software, MarkSim provided the input data Temperature and Rainfall. Temperatures were corrected with station data. The resolution of the dry season assessment is one month. It is known that the Thornthwaite method tends to underestimate Eto under arid conditions and that it overestimates ETo under the equatorial humid climate of the Amazon region. Since only monthly averages were used for the regionalization, the inaccuracy of the method was tolerated. Experienced local experts agreed with the final dry season map produced.

With the income regionalization maps we localize gradual changes from low to high income for herd size and performance classes on country scale.
When based on herd size classes, income indicators have the inevitable disadvantage of comparatively high standard deviations (Table 34). The standard deviations represent a measure for the representativeness of mean values. It shows that within each herd size class, there are more- and less successful farms. The reason why the classification in herd size classes was used despite the high variability of the indicator is that it can be easily assessed in the field and is convincing for farmers, extension workers and policy makers.

The classification on performance yields more representative mean values and is more precise for regionalization. Performance or efficiency indicators are beneficial tools for assisting effective decision making aimed at improving business performance. The disadvantage the performance indicator used in this context is that it is not as quickly accessible in the field as herd size. The maps show clearly, that the impact of the dry season length on income of lowest and low performers is greater than for medium and top performers.

A more precise regionalization of average income /cow/year per district would be possible with a new agricultural census. The paper made use of the available data to demonstrate the methodology, estimating total livestock population for 2005 from annual growth rates in the post Mitch period. This presumes that herd size class compositions of 1993 are still valid.

All regionalization of the indicators for the categories of farms shows clearly, that the length of the dry season has a tremendous impact on yearly income per cow in dairy production. When classified to farm size small and very small farms are the worst hit by a long dry season. In the performance classification, lowest and low performers are most seriously affected. When the average herd size composition of districts is considered, regions with a high share of small herd sizes show low incomes per cow.

The regionalization of positive deviances (in Map 7) shows the state of farms that are developing in more intensive cattle management and a better use of forages. Sharp dry season income drops (44 - 53%), as observed on farms with more than 20 cattle can be avoided with a better use of forage technologies and intensification. The even sharper income drops on farms with less than 20 cattle could be mitigated through adequate measures.
Interpreting the maps on the performance classes as stages of intensification, it can be demonstrated to farmers and policy makers how much and where in Honduras an upward movement between efficiency classes increases income per cow. Intensification of production may be the only solution for resource-poor farmers and for a self sufficient milk production in Honduras. Between 2001 and 2003 milk production in Honduras staggered 14% behind milk consumption.

The adoption of new crops and improved technologies is constrained substantially where the availability of working capital is limited. Financial bottlenecks are important constraints for adoption of forage technologies and genetic improvements of the herds on small and very small farms. These farms lack of capital at the end of the dry season and their priority is to invest in subsistence crop production. Without an increase of working capital it is unlikely that resource poor farms in such a situation invest in forages of better nutritive value and their conservation during the rainy season, because their crop production requires the investment for crop production. Without investments or efforts for intensification, these farms remain on low-income levels. More off farm employment would help alleviate the lack of capital since the additional income could be invested in more capital-intensive technologies. Such opportunities are rare and far from being available for the rural poor in Honduras. Nevertheless some innovative and motivated individuals undertake low cost efforts and improve slowly.

On farms with more than 20 cattle head, the probability for change is higher. These farms are able to accumulate some capital to reinvest in the farm e.g. in forages, their conservation or in cow breeds with better genetic potential for milk production.
The resource use efficiency of farms is related to the length of the dry season and the technological level of the farms. Where the dry season is very long, farmers with low technological level generate little to reinvest and are thus cash constrained. Whereas more dry season technology is required to sustain production and income the drier it gets.
The impact of dry season length on income is great for lowest and low performers. Medium and top performers are able to stabilize their income. Low and medium performers are made up of farms from all herd size classes. Those small farms that are medium performers show that the improvement of cost efficiency is also possible for small and very small herd owners.

2.5 Field evaluation of a collection of the forage legumes shrubs *Leucaena diversifolia* and *Leucaena trichandra*

Contributors: M. Peters, L.H. Franco (CIAT), R. Schultze-Kraft , Katrin Zöfel (University of Hohenheim), B. Hincapié, P. Ávila (CIAT), Nelson Vivas (Universidad del Cauca) statisticians G. Ramírez and G. Guerra (CIAT).

Rationale

Previous research had shown *Leucaena diversifolia* and *Leucaena trichandra*, two very closely related species, to be well adapted to acid and infertile soils and mid altitudes (up to 2000 m.a.s.l.), in contrast to the widely used *Leucaena leucocephala* that does not perform well under these conditions. However, the evaluation of *L. diversifolia* and *L. trichandra* up to now has been restricted to only few accessions. A comprehensive collection of the two species was put together in order to screen for diversity in agronomic traits and nutritive value. Furthermore, the study aims to describe morphological differences both between the two species as well as among accessions.

Materials and Methods

A collection of 61 accessions of *L. diversifolia* and *L. trichandra* was planted in jiffy pots in the green house (50 accessions of *L. diversifolia* and 11 of *L. trichandra*). After eight weeks seedlings were transplanted (June 2005) to the CIAT station in Santander de Quilichao. CIAT accession 17503 was included as control as there is data available from previous evaluations, including regional evaluations. A randomized block was employed, with three replications for agronomic and forage quality evaluation, and one for morphological characterization. Each replication consisted of five plants per accession. The plants were spaced 1 m, with 1.5 m between rows. Fertilization was (kg/ha) P40, K50, Mg20, and S20. *Rhizobium* inoculum was applied in the field in a mixture with water, given to each plant directly into the soil. During the first eight weeks after transplanting, plants were irrigated when necessary to safeguard the establishment of the trial. Equally insecticides were applied when pests appeared to threaten the survival of the plants.

Agronomic evaluation included regular assessment every four weeks of plant vigor and symptoms of nutritional deficiencies, pests and diseases. Three months after planting, plant height, diameter and growth habit were recorded. The first cut was done in October 2005 at a height of 0.5 m above the ground. In the fourth replication, morphological evaluation was carried out four months after transplanting and comprised the assessment of leaf morphology (form, color, pubescence, presence of glands, leaf area, flowering and growth habit.

Results and Discussion

All accessions showed good vigor under field conditions in Quilichao (Photo 1). Three months after transplanting to the field, plant height and diameter ranged from 0.2 to 1.7 m and 0.1 to 1.8 m, respectively. Four months after transplanting, they reached 2.3 m and 2.4 m for height and diameter, respectively. Growth habit showed great variability. Erect to decumbent forms were found. Angles between main bole and branches ranged from up to 90° to around 20°. Also the number of branches below 0.5 m (height of standardization cut) fluctuated greatly among accessions, indicating differences in regrowth capacity.

Photo 1. Collection of *L. diversifolia* and *L. trichandra* planted at Quilichao

The morphological data confirm the large genetic variability within the two species as reported in the literature. Features like colorof the pinnule border, pubescence, length and width of leaves and length and width of pinnules varied greatly within one species. Main morphological differences between *L. diversifolia* and *L. trichandra* are length and width of the pinnules (4.0 to 8.0 vs. 0.8 to 1.4 mm and 5.2-12.6 vs. 1.6-3.2 mm, respectively), number of pinnae per leaf and number of pinnules per pinna, both being distinctly lower for *L. trichandra*.

Several accessions, for which information to which species they belong was not available in the pertinent databases, could not be assigned to one of the two species based on their morphological characteristics.

Across the dry and wet seasons, significant ($P<0.05$) differences between accessions were measured for DM yield, height, diameter and number of regrowing points. Mean dry season yields were only half of yields achieved in the wet season (259 g/plant versus 127 g/plant). Height and diameter were also higher in the wet season, while the number of regrowing points was higher in the dry season. Accessions CIAT 17271, ICRAF 46/87/15, CIAT 21242, ILRI 16507, CTAHR K782, CIAT 17249, ILRI 15551, CTAHR K787, ILRI 505, ICRAF 45/87/09, CIAT 22192, ICRAF 45/87/05, CIAT 17248, ICRAF 46/87/08, 46/87/14 and CTAHR K779 had DM yields higher than 300 g/plant in the wet season, while in the dry season accessions with highest DM yields above 170 g/plant were CIAT 17268, CTAHR K779, K782, CIAT 21142, CTAHR K787, ILRI 15551, CTAHR K781, CIAT 17249, ILRI 16507, CTAHR K780, ILRI 505 and CIAT 17248. (Table 38).

Three years after planting some plants did not persist due to attacks of nematodes (a known problem in Quilichao) and leaf sucking insects. There was also incidence of infestation with the fungus *Camptomeris leucaenae*.

There do exist very early flowering accessions; however 22 accessions did not reach flowering 18 months after planting.

Table 38. Agronomic evaluation of a collection of *Leucaena diversifolia* and *L. trichandra* in Quilichao. Data of six evaluation cuts (three cuts in the wet season and dry season each).

Species * and accession No.	Height	Diameter	Regrowing points	DM yield	Height	Diameter	Regrowing points	DM yield
	Wet				Dry			
	(cm)		(No.)	(g/pl)	(cm)		(No.)	(g/pl)
Ld 17271	166	150	52	440	107	118	52	159
Ld 46/87/15	160	122	45	403	86	113	50	162
Ld 21242	191	124	52	368	111	120	50	197
Lt ILRI 16507	169	126	40	357	110	107	38	174
Ld K 782	163	130	51	352	98	122	54	202
Ld 17249	187	121	63	336	134	107	53	182
Ld ILRI 15551	164	116	46	334	92	112	45	185
Ld K 787	167	124	43	332	105	118	44	191
Ld ILRI 505	169	134	44	329	98	120	42	173
Ld 45/87/09	152	115	39	325	76	103	42	96
Ld 22192	156	129	43	324	92	105	41	128
Ld 45/87/05	164	121	55	323	79	106	46	104
Ld 17248	195	128	56	323	145	102	45	170
Ld 46/87/08	157	128	46	317	87	122	58	139
Ld 46/87/14	156	126	34	310	90	109	39	109
Ld K 779	163	121	42	306	102	120	49	208
Ld K 780	167	111	37	297	106	122	42	106
Ld K 781	166	113	44	294	114	123	49	183
Ld 46/87/02	164	110	41	287	99	102	46	107
Ld 45/87/17	187	112	36	285	101	114	43	160
Ld 46/87/04	171	117	39	284	90	101	42	105
Ld 45/87/14	171	103	32	274	100	105	42	124
*Ld*46/87/12	152	107	44	269	85	105	41	164
Ld 46/87/01	156	116	46	269	97	102	48	117
Ld 45/87/20	168	131	43	267	102	118	45	137
Lt ILRI 523	156	106	37	267	118	104	35	138
Ld 45/87/10	178	121	39	267	101	113	46	169
Ld 45/87/18	170	120	32	260	97	114	47	131
Ld K 784	139	108	34	259	97	111	41	149
Ld 83/92	156	114	40	258	88	110	42	120
Ld 17485	155	108	39	258	103	98	39	125
Lt CPI 46568	156	119	41	258	86	90	31	76

Continues…

Table 38. Agronomic evaluation of a collection of *Leucaena diversifolia* and *L. trichandra* in Quilichao. Data of six evaluation cuts (three cuts in the wet season and dry season each)

Species * and accession No.	Height	Diameter	Regrowing points	DM yield	Height	Diameter	Regrowing points	DM yield
	Wet				Dry			
	(cm)		(No.)	(g/pl)	(cm)		(No.)	(g/pl)
Ld 46/87/09	167	110	31	254	104	100	34	139
Ld K 778	170	112	34	247	104	100	39	112
Ld 45/87/01	178	119	33	237	91	99	43	92
Ld 45/87/07	167	110	40	236	93	96	37	109
Ld 46/87/06	162	106	26	236	98	96	36	116
Ld 46/87/10	149	112	44	234	79	112	50	117
Ld 17497	139	114	47	234	106	95	43	122
Ld K 793	155	111	30	232	92	115	40	137
Ld CPI 33820	148	107	41	230	91	115	42	100
Ld ILRI 515	163	101	32	229	92	92	32	106
Lt 4/91/17	172	93	31	222	120	95	29	86
Ld 46/87/07	178	117	38	222	103	96	36	95
Lt 4/91/04	176	121	45	220	114	109	44	96
Lt 17268	167	104	28	217	134	106	37	213
Lt 4/91/12	177	98	27	217	113	95	35	94
Ld 17461	162	15	30	214	106	104	35	153
Ld ILRI 14193	157	95	28	209	92	97	32	91
Ld 17388	169	99	22	207	118	100	23	125
Lt 17264	127	115	35	207	80	98	36	134
Ld 45/87/13	145	112	32	203	80	95	36	84
Ld 45/87/02	149	91	26	200	86	95	38	108
Ld 45/87/06	129	93	39	192	74	87	35	62
Ld 45/87/12	149	108	31	188	81	97	36	72
Lt 4/91/13	146	101	27	174	86	96	31	69
Ld 17503**	149	97	29	170	108	80	25	97
Ld 45/87/11	126	106	36	161	74	88	30	63
Ld 82/92	136	92	27	133	76	85	30	54
Ld 17247	163	84	23	109	115	61	23	70
Lt 4/91/06	110	88	26	95	74	81	28	38
Mean	160	112	38	259	98	104	40	127
LSD(P<0.05)	32.89	28.77	13.70	128.12	22.48	21.560	13.94	126.73

- *Ld = L. diversifolia, Lt = L. trichandra*
- ** CIAT 17503 control

Forage quality (*in vitro* dry matter digestibility, IVDMD and crude protein content, CP) varied significantly (P<0.05) among accessions in the wet season, mostly in respect to IVDMD (Table 39). Accessions CIAT 17247, ICRAF 4/91/12, CIAT 17249, CIAT 17264, CIAT 17248, ICRAF 4/91/13, 4/91/17, 4/91/06, 4/91/04, CIAT 17268 and CPI 33820 had IVDMD and CP above 60% and 22%, respectively. In contrast, the high yielding accessions ICRAF 46/87/15, CIAT 21242, and ILRI 16507 had IVDMD below 51%. Similar to wet season results, forage quality differed among accessions also in the dry season (P<0.05), with higher values than in the wet season. The same accessions with high forage quality in the wet season (> 60% IVDMD and > 22% CP) had 70% IVDMD and 23% CP, respectively.

Table 39 . Forage quality of accessions of *Leucaena diversifolia* and *L. trichandra* in the wet season in Quilichao, 2005-2006.

Species and accession No.	IVDMD	CP	Species and accession No.	IVDMD	CP
	%			%	
Ld 17247	71	23	*Ld* K781	51	22
Lt 4/91/12	70	23	*Ld* ILRI-515	50	22
Ld 17249	70	25	*Ld* 45/87/08	50	21
Lt 17264	69	23	*Ld* 45/87/05	50	24
Ld 17248	69	23	*Lt* CPI-46568	49	22
Lt 4/91/13	69	24	*Ld* 17485	49	24
Lt 4/91/17	68	23	*Ld* 45/87/07	49	21
Lt 4/91/06	68	24	*Ld* ILRI-505	49	23
Lt 4/91/04	67	24	*Ld* 17497	49	22
Lt 17268	66	22	*Ld* 45/87/18	48	23
Ld CPI-33820	63	22	*Ld* 17388	48	21
Ld 45/87/20	58	21	*Ld* ILRI-15551	48	22
Ld K787	57	22	*Ld* 45/87/14	48	23
Ld 46/87/08	56	23	*Ld* K778	48	22
Ld K779	56	20	*Ld* 45/87/01	47	23
Ld K784	55	24	*Ld* 45/87/11	47	22
Ld 83/92	54	20	*Ld* 46/87/04	47	25
Lt ILRI-523	53	22	*Ld* 45/87/10	47	24
Ld K782	53	22	*Ld* 21242	47	22
Ld 45/87/06	53	22	*Ld* 45/87/12	47	22
Ld 17271	53	23	*Ld* 46/87/01	47	25
Ld 17503*	52	24	*Ld* 46/87/07	46	21
Ld 46/87/10	52	25	*Ld* 82/92	45	21
Ld 45/87/17	51	23	*Ld* 17461	45	24
Lt ILRI-16507	51	25	*Ld* 45/87/13	45	23
Ld K780	51	22	*Ld* 46/87/14	45	23
Ld 46/87/09	51	22	*Ld* 46/87/06	44	23
Ld 22192	51	23	*Ld* 46/87/12	44	22
Ld 45/87/02	51	23	*Ld* 45/87/09	44	23
Ld K793	51	21	*Ld* 46/87/02	43	22
Ld ILRI-14193	51	22	*Ld* 46/87/15	41	22
Lt 4/91/13	75	29	*Ld* K 787	59	24
Lt 4/91/12	79	28	*Ld* 45/87/07	54	24
Lt 4/91/06	79	28	*Ld* 83/92	66	24
Ld 17249	80	28	*Ld* 46/87/10	63	24
Lt 4/91/17	79	27	*Lt* CPI 46568	59	24
Lt 4/91/04	76	27	*Ld* 21242	51	24
Ld 17248	79	27	*Ld* 17388	59	24
Ld 17247	79	26	*Ld* ILRI 505	52	24
Ld 22192	64	25	*Ld* 45/87/18	53	24
Ld K784	58	25	*Ld* ILRI 14193	65	24

Continues…

Table 39 . Forage quality of accessions of *Leucaena diversifolia* and *L. trichandra* in the wet season in Quilichao, 2005-2006.

Species and accession No.	IVDMD	CP	Species and accession No.	IVDMD	CP
Lt 17268	74	25	*Ld* 45/87/17	53	23
Ld 46/87/07	63	25	*Ld* 177461	48	23
Ld 46/87/08	59	25	*Ld* 45/87/09	54	23
Ld 45/87/05	59	25	*Ld* K 780	55	23
Ld 17503*	62	25	*Ld* 46/87/02	51	23
Ld 46/87/09	55	25	*Lt* 17264	74	23
Ld ILRI 515	59	25	*Ld* K 781	57	23
Ld 46/87/06	49	25	*Ld* 46/87/14	54	23
Ld K 782	58	24	*Ld* 45/87/12	55	23
Ld K 793	60	24	*Ld* 45/87/10	50	23
Lt ILRI 16507	61	24	*Ld* 45/87/01	55	23
Ld 17271	67	24	*Ld* 82/92	49	23
Ld K 779	60	24	*Ld* 46/87/04	49	23
Ld 45/87/20	63	24	*Ld* 46/87/15	49	23
Ld 45/87/02	57	24	*Ld* 45/87/11	51	23
Ld 45/87/14	55	24	*Ld* 46/87/12	49	23
Ld K 778	54	24	*Ld* 46/87/01	49	22
Ld CPI 33820	70	24	*Lt* ILRI 523	57	22
Ld 17497	59	24	*Ld* 45/87/13	55	20
Ld 45/87/06	57	24	*Ld* 17485	54	20
Ld ILRI 15551	57	24	*Ld* 45/87/08	54	19
Mean				60	24
LSD(P<0.05)				9.237	4.350

* CIAT 17503 control

In Table 40 tannin contents of accessions selected on the basis of yield and forage quality are presented. Depending on seed availability, these accessions will be tested in Genotype by Environment trials.

Table 40 . Tannin content of selected accessions of *Leucaena diversifolia* and *L. trichandra* in the wet and dry season in Quilichao, 2005-2006.

Species and accession No.	Wet			Dry		
	Tannins, soluble	Tannins, insoluble %	Tannins, total	Tannins, soluble	Tannins, insoluble %	Tannins, total
Lt 4/91/17	19.8	5.8	25.6	19.3	5.3	24.6
Lt 4/91/04	13.8	5.9	19.7	15.0	5.9	20.9
Ld K 779	16.3	3.1	19.5	16.4	3.2	19.6
Ld 17248	15.1	4.0	19.1	17.2	2.7	20.0
Lt 4/91/12	13.9	4.9	18.8	15.6	4.9	20.5
Lt 17264	15.1	3.5	18.7	11.5	4.3	15.8
Ld 45/87/20	15.2	3.1	18.4	16.2	3.9	20.1
Ld CPI 33820	14.8	3.0	17.8	16.2	3.3	19.5
Lt 17268	14.2	3.3	17.6	9.9	4.6	14.5

Continues…

Table 40 . Tannin content of selected accessions of *Leucaena diversifolia* and *L. trichandra* in the wet and dry season in Quilichao, 2005-2006.

Species and accession No.	Wet			Dry		
	Tannins, soluble	Tannins, insoluble %	Tannins, total	Tannins, soluble	Tannins, insoluble %	Tannins, total
Ld 17503*	12.6	4.6	17.2	24.4	3.8	28.3
Ld 46/87/08	14.0	2.7	16.7	14.8	4.1	18.9
Ld 21242	14.2	2.4	16.6	18.3	3.1	21.5
Ld 17271	13.7	2.7	16.5	13.8	3.4	17.3
Ld 22192	12.9	3.2	16.1	16.9	4.6	21.4
Ld 17388	12.3	3.5	15.8	12.6	2.6	15.2
Ld K 780	12.1	3.3	15.4	11.7	2.4	14.1
Ld K 787	12.6	2.4	15.1	9.3	4.8	14.1
Lt ILRI 16507	12.1	2.9	15.1	16.4	3.2	19.6
Ld 17249	11.4	3.2	14.6	6.4	2.2	8.6
Ld 83/92	11.5	3.0	14.6	13.0	3.9	16.9
Ld K 781	11.8	2.6	14.4	12.0	3.3	15.3
Lt ILRI 523	10.9	3.3	14.2	6.7	3.5	10.2
Ld 17497	9.4	2.9	12.4	12.1	1.8	13.9
Ld K 784	6.8	3.2	10.0	8.1	6.0	14.1
Ld K 782	4.7	3.2	7.9	10.8	4.2	15.0
Mean	12.8	3.4	16.3	13.8	3.8	17.6
LSD($P<0.05$)	10.67	3.53	12.80	10.28	3.31	11.33

* CIAT 17503 control

In a preliminary cafeteria trial, consumption of the accessions was low; with CIAT 17264, ILRI 523, ILRI 515, CTAHR K 787, ICRAF 46/87/08, UQ 83/92, ILRI 15551, CIAT 17249, CIAT 17247, CIAT 14193, control CIAT 17503, CIAT 17248, CIAT 17268, ICRAF 46/87/12, 46/87/01, 45/87/08 and ILRI 16507 consumed at a low level. The cafeteria test will be repeated in a drier period and treatments such as wilting will be tested.

2.6 Field evaluation of a collection of the forage legumes *Dendrolobium* spp

Contributors: M. Peters, L.H. Franco, R. Schultze-Kraft (University of Hohenheim), B. Hincapié, P. Ávila, and statisticians G. Ramírez and G. Guerra.

Rationale

To ensure a continuous forage supply in stressed environments CIAT is researching novel high quality shrub legumes with adaptation to acid low fertility soils: In continuation of previous efforts a collection of *Dendrolobium* is being evaluated for agronomic and morphological parameters.

Materials and Methods

A collection of 60 accessions of *Dendrolobium* spp was planted in jiffy pots in the green house (18 accessions of *D. lanceaolatum*, 34 of *D. triangulare*, 4 of *D. rugosum,* 2 of *D.* sp and 2 of *D. umbellatum*). After eight weeks seedlings were transplanted (November, 2005) to the CIAT station in Santander de Quilichao. A randomized block with four replications was employed; three replications were used for agronomic and forage quality evaluation, and one for morphological characterization. Each replication consisted of five plants per accession. The plants were spaced 1 m, with 1.5 m between rows. Fertilization was (kg/ha) P40, K50, Mg20, and S20. Six evaluation cuts were done, three in the dry and three in the wet season.

Results and discussion

Stands were considered fully established five months after planting. At this time , plants were morphologically differentiated, with little branching of the majority of accessions. Height and diameter varied between 0.1 m and 2.1 m and 1 m to 1.77 m, respectively. Three growth habits were identified, erect, semi-decumbent and decumbent or prostrate. Though initial establishment was slow possibly due to late planting, no pest and disease problems were observed (Table 41).

90% of accessions produced seed, with CIAT 22004, 13705, 23105, 23934, 13546, 23933 and 23106 being early flowering and providing high seed yields. Flowers were mostly white or pale rose.

Table 41. Vigor, height, diameter and branches of a collection (2006) of *Dendrolobium* spp. in Quilichao.

Accession No. CIAT	Ha *	Vigor	Height	Diameter	Branch	Accession No. CIAT	Ha	Vigor	Height	Diameter	Branch
		1-5	cm		No.			1-5	cm		No.
Dt 22004	P	3	56	89	3	Dt 23419	E	2	73	59	2
Dt 22005	P	3	42	128	4	Dt 23422	E	3	62	87	2
Dt 23733	P	4	63	136	3	Dt 23932	E	4	61	131	3
Dt 23933	P	3	45	93	2	Dl 23937	E	3	159	65	1
Dt 23935	P	4	35	165	4	Dt 33115	E	3	68	85	1
Dt 23936	P	3	38	118	3	Dt 33116	E	4	64	124	5
Dt 33515	P	3	36	78	3	Dr 33118	E	2	46	45	1
Dl 13258	E	3	88	59	2	Dr 33383	E	2	49	33	1
Dt 13259	E	2	67	70	3	Dl 33398	E	2	77	22	1
Dl 13260	E	3	77	43	1	Dt 33402	E	2	45	65	1
Dl 13261	E	3	96	54	1	Dr 33403	E	2	61	39	1
Dt 13262	E	3	73	78	2	Dr 33407	E	2	93	42	1
Dl 13528	E	2	87	67	2	Dl 33455	E	2	59	31	2
Dt 13529	E	3	53	98	5	Dl 33467	E	2	57	21	2
Dl 13546	E	2	60	49	2	Dl 33480	E	2	48	28	1
Dl 13705	E	3	83	34	2	Dt 35518	E	2	41	70	2
Dl 13706	E	2	43	52	2	Dt 23107	SE	2	46	39	2
Dl 13707	E	3	105	56	1	Dt 23239	SE	3	47	93	5
Dt 13710	E	4	79	119	2	Dt 23421	SE	2	37	88	2
Dl 13711	E	3	103	85	4	Dt 23734	SE	3	62	109	3
Dt 23104	E	2	50	52	2	Dt 23735	SE	4	75	135	5
Dt 23105	E	2	51	76	2	Dt 23934	SE	4	41	135	4
Dt 23106	E	2	63	51	2	Dt 33117	SE	2	53	87	3
Dt 23108	E	3	62	84	3	Dt 33119	SE	3	58	107	3
Dt 23412	E	3	75	93	1	Dt 33391	SE	3	49	95	3
Dt 23413	E	2	66	61	1	Dt 33508	SE	2	48	35	1
Mean								2.6	62.4	76.3	2.6
Rango								1-5	0.1-2.1	6-1.77	1-7

***** Ha. Habit: e=Eerect, SE=Semi-Erect, P=Postrate

The collection was classified into the species *D.lanceolatum*, *D. triangulare* (*triangulare* var 1, *triangulare* var 2) and *D. rugosum*.

DM yields differed significantly (P<0.01) between species, both in the wet as in the dry season, with *D. triangulare* v2 having the highest yields, followed by *D. tringulare* v1, *D. lanceolatum* and *D. rugosum* (Table 42). Across species, dry season yields were in average 33% lower than wet season yields. Equally, differences (P<0.01) between species were observed for height, diamtera nd number of regrowing points. In the dry season there were slightly more regrowing points(39) than in the wet season (34).

In Table 42 the results of the agronomic evaluation of *Dendrolobium triangurare,* separted for dry and wet season are shown. Significant differences (P<0.01) between accessions were found for DM yield, however mean yields were low (120 and 86 g/plants for the wets and dry season, respectively) when compared with other shrub legumes evaluated under the same conditions. Accessions CIAT 23239, 13259, 23413, 13710, 13262, 23934, 23412 and 23932 had DM yields above 150 g/plant in the wet season, but in the dry season only CIAT 23239 y 13262 had yield above 150g/plant. In average dry season yields were 39% lower than wet season yields. While regrowing points increased in the dry season, height and diameter decreased.

Table 42. Agronomic evaluation of a collection (2006) of *Dendrolobium triangulare*. in Quilichao. Data of 6 evaluation cuts (three in the wet season and three in the dry season).

Accession No. CIAT	Height	Diameter	Regrowing points	Mean DM yields	Height	Diameter	Regrowing points	Mean DM yields
	Wet				Dry			
	(cm)		(No.)	(g/pl)	(cm)		(No.)	(g/pl)
23239	67	130	60	264	57	113	70	199
13259	77	119	43	217	71	105	56	142
23413	68	110	35	216	61	105	47	139
13710	65	115	50	203	65	108	59	142
13262	66	110	41	197	62	100	49	164
23934	60	121	57	177	52	119	66	122
23412	69	109	54	176	64	100	51	124
23932	49	94	36	151	48	93	45	85
23735	62	114	52	146	57	114	68	118
13529	65	112	43	145	53	108	50	142
33115	57	114	49	141	51	101	51	102
23936	55	111	44	135	52	108	48	102
23108	59	98	33	132	55	107	42	101
33116	63	108	39	127	60	98	48	110
23935	55	119	43	126	45	112	47	92
23733	60	111	38	125	61	113	44	105

Continues…

Table 42. Agronomic evaluation of a collection (2006) of *Dendrolobium triangulare*. in Quilichao. Data of 6 evaluation cuts (three in the wet season and three in the dry season).

Accession No. CIAT	Height	Diameter	Regrowing points	Mean DM yields	Height	Diameter	Regrowing points	Mean DM yields
	Wet				Dry			
	(cm)		(No.)	(g/pl)	(cm)		(No.)	(g/pl)
22005	49	93	52	125	49	94	60	89
33402	50	87	36	107	46	87	66	88
23421	55	99	31	106	44	86	38	46
23734	55	140	45	94	54	89	56	79
33119	52	94	41	86	52	97	45	69
23933	49	99	40	85	46	110	45	88
23106	59	88	32	83	51	79	36	48
23419	62	86	29	81	54	77	30	43
33117	56	79	30	78	48	79	39	50
33391	52	80	46	76	50	81	47	67
33515	44	83	40	71	45	84	47	55
23105	64	80	33	70	42	76	33	37
23422	55	75	29	70	46	70	33	38
23107	52	68	25	56	46	66	27	32
23104	50	72	25	54	41	71	27	32
33518	50	78	24	53	44	73	22	29
22004	37	79	24	50	35	76	37	49
33508	48	60	18	37	50	72	22	39
Mean	57	98	39	120	52	93	45	86
LSD(P<0.05)	16.280	36.562	20.992	99.748	9.908	21.473	21.707	69.856

As for *D. triangulare,* though differences between accessions were found in *D. lanceolatum* (P<0.01), however mean yields were even lower, in this case without variation between dry and wet season (Table 43).

Table 43. Agronomic evaluation of a collection (2006) of *Dendrolobium lanceolatum*. in Quilichao. Data of 6 evaluation cuts (three in the wet season and three in the dry season).

Accession No. CIAT	Height	Diameter	Regrowing points	Mean DM yields	Height	Diameter	Regrowing points	Mean DM yields
	Wet				Dry			
	(cm)		(No.)	(g/pl)	(cm)		(No.)	(g/pl)
13261	79	110	33	127	81	107	35	105
23937	87	91	33	121	89	102	39	112
13705	78	86	31	113	74	89	38	107
13528	75	86	31	96	69	81	40	86
13546	72	82	32	93	76	77	37	84
13711	73	88	24	89	80	99	33	93
13707	76	97	28	78	82	103	36	74
13258	71	86	33	77	78	87	40	71
13260	65	76	29	65	77	88	32	70
13706	67	88	24	57	70	83	33	47
33398	75	81	20	41	82	83	19	34
33455	60	55	26	41	62	52	32	40
33467	53	55	20	34	79	58	26	25
33480	54	59	18	33	63	67	20	19
Mean	70	81	28	77	76	84	33	70
LSD(P<0.05)	18.660	25.701	17.464	77.209	36.125	24.225	15.099	47.502

No differences between accessions were encountered in *D. rugosum,* having in general the lowest DM yields among the *Dendrolobium* species (Table 44).

Table 44. Agronomic evaluation of a collection (2006) of *Dendrolobium rugosum* in Quilichao. Data of 6 evaluation cuts (three in the wet season and three in the dry season).

Accession No. CIAT	Height	Diameter	Regrowing points	Mean DM yields	Height	Diameter	Regrowing points	Mean DM yields
	Wet				Dry			
	(cm)		(No.)	(g/pl)	(cm)		(No.)	(g/pl)
33383	53	53	7	58	46	55	10	26
33118	59	63	8	43	50	62	10	34
33407	55	59	9	36	50	59	10	26
33403	57	53	7	34	50	55	9	26
Mean	56	57	8	43	49	58	10	28
LSD(P<0.05)	8.772	13.105	4.440	37.840	5.761	8.992	3.403	12.716

IVDMD and CP content varied significanltly (P<0.01) between accessions in both the wet and dry season (Tables 45 and 46). Accessions CIAT 33518, 33383, 13259, 33119, 23239, 13262, 33508 and 23735 had digestibilities and crude protein contents above 50 % and 17 %, respectively in the wet season.

Table 45 . Forage quality of accessions of *Dendrolobium* spp. evaluated in the wet season in Quilichao.

Accesion No.	IVDMD %	CP	Accesion No.	IVDMD %	CP
Dt 13259	52	23	Dt 23412	40	19
Dt 23107	41	22	Dt 33515	44	19
Dt 13262	51	22	Dt 23936	43	19
Dt 23422	44	22	Dt 33116	44	19
Dt 23104	43	22	Dt 23933	44	19
Dt 23108	43	21	Dt 33518	59	19
Dt 23239	52	21	Dt 33508	51	18
Dt 23421	44	21	Dr 33403	42	18
Dt 23106	43	21	Dt 13529	45	17
Dt 23105	42	21	Dr 33407	42	17
Dt 23413	44	21	Dl 13706	47	17
Dt 33117	47	21	Dr 33383	53	17
Dt 33115	44	21	Dr 33118	45	17
Dt 22004	48	20	Dl 33480	37	16
Dt 23934	47	20	Dl 33455	36	16
Dt 23419	40	20	Dl 23937	37	16
Dt 33391	45	20	Dl 33398	38	16
Dt 33402	49	20	Dl 13546	37	16
Dt 23735	50	20	Dl 33467	34	16
Dt 23734	48	20	Dl 13528	36	16
Dt 22005	45	20	Dl 13711	39	15
Dt 33119	52	19	Dl 13705	39	15
Dt 23935	44	19	Dl 13260	35	15
Dt 23932	48	19	Dl 13707	41	15
Dt 13710	40	19	Dl 13261	36	14
Dt 23733	47	19	Dl 13258	37	14
Mean				44	19
LSD(P<0.05)				6.952	2.793

In the dry season accessions CIAT 33119, 33518, 23734, 13262, 33402, 23239, 13733, 23735, 23934 and 33117 had digestibilities and crude protein contents above 53% and19%, respectively.

Table 46 . Forage quality of accessions of *Dendrolobium* spp. evaluated in the dry season in Quilichao.

Accesion No.	IVDMD	CP	Accesión No.	IVDMD	CP
	%			%	
Dt 13262	57	24	Dt 33119	59	20
Dt 13259	52	24	Dt 22004	50	20
Dt 23239	54	23	Dt 22005	52	20
Dt 23421	46	23	Dt 23733	54	19
Dt 33115	49	22	Dl 33467	38	19
Dt 23734	57	22	Dl 23937	31	19
Dt 33391	51	22	Dt 13261	34	19
Dt 23422	47	22	Dt23933	47	19
Dt 23412	41	22	Dt23936	47	19
Dt 13710	44	22	Dt 13705	37	18
Dt 23932	52	22	Dt 33508	43	18
Dt 23413	50	21	Dl 13546	37	18
Dt 23735	54	21	Dt 13529	51	18
Dt 23104	43	21	Dr 33383	50	18
Dt 33515	49	21	Dl 33398	42	18
Dt 23107	43	21	Dl 33455	33	18
Dt 23106	41	21	Dl 13260	44	18
Dt 33518	58	21	Dl 13706	43	18
Dt 23934	53	21	Dl 13528	34	18
Dt 23419	40	21	Dl 33480	40	17
Dt 33116	48	21	Dr 33407	44	17
Dt 33117	53	21	Dl 13711	40	17
Dt 23108	49	21	Dr 33118	51	17
Dt 33402	56	21	Dr 33403	42	17
Dt 23105	46	21	Dl 13258	34	17
Dt 23935	51	20	Dl 13707	33	16
Mean				46	20
LSD(P<0.05)				12.642	4.084

In a preliminary cafeteria trial cows only consumed accessions CIAT *D. lanceolatum* 13711, Dl 13707, and *D. lanceolatum* 23937 of low quality and accessions CIAT *D. triangulare* 23734 and Dt 23735 of better quality.

Photo 2. Collection 2005 of *Dendrolobium spp*. in Quilichao.

2.7 Evaluation of selected accessions of *Canavalia brasiliensis* and *Canavalia* sp. for multipurpose uses in Santander de Quilichao, Colombia

Contributors: M. Peters, R. Schultze-Kraft (University of Hohenheim), L.H. Franco, B. Hincapié, and statistician G. Guerra

Rationale

Canavalia brasiliensis Mart. ex Benth. ("Brazilian jackbean") is a weakly perennial, prostrate to twining herbaceous legume with a wide natural distribution in the New World tropics and subtropics. In comparison with *C. ensiformis* ("jackbean"), 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 consequently 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 a 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.

Materials and Methods

Out of larger collections evaluated in 2004 and 2005, the most promising nine and four accessions of *Canavalia brasiliensis* and *Canavalia* sp, (taxonomic determination pending), respectively, were selected to be tested in experimental plots (3 x 3 m) across several seasons. A Randomized complete block design with three replications was employed. Criteria for selection were DM yield and forage quality.

Photo 3. Selected *Canavalia brasiliensis* accessions in Quilichao

Results

Plants established quickly with very little incidence of pest and diseases. Soil cover nine weeks after planting revealed significant (P<0.05) differences among accessions, with CIAT 905, 19038, 7969, 17462, 17009 and 808 having soil covers >70%. Twelve weeks after establishment there were no more differences among accessions, with a mean soil cover of 87%. Vigor of all accessions was high 12 weeks after establishment (Table 47). Data on DM yield and forage quality will be presented in future reports.

Table 47. Vigor and soil cover (%) during establishment of selected *Canavalia brasiliensis* and *Canavalia* sp. accessions in Quilichao..

	9 weeks		12 weeks	
Species* and accession No. CIAT	Vigor 1-5	Soil cover %	Vigor 1-5	Soil cover %
*C*sp* 19038	4	83	5	100
Cb 7969	4	78	5	100
Cb 17009**	4	72	5	97
Cb 7648	4	67	5	97
Cb 17462	4	77	5	93
Cb 905	4	87	4	90
*C*sp 21013	4	67	5	88
Cb 7971	3	65	5	88
Cb 808	4	70	4	82
*C*sp 21012	3	45	4	80
Cb 20303	3	55	4	80
Cb 7972	3	53	4	78
*C*sp 21014	2	20	4	63
Mean	3.5	64	4.5	87
LSD (P< 0.05)		21.634		7.285

* *Csp* = *Canavalia* sp., *Cb* = *C. brasiliensis*
** Control

2.8 Genetic analysis and taxonomic implications for the genus *Cratylia* Mart. ex Benth. (Fabaceae)

Contributors: H G. Suárez; M. S. Andersson; G. Gallego; M. Peters; R. Schultze-Kraft; and J. Tohme (CIAT)

Rationale

Multipurpose leguminous shrubs have a great potential for the improvement of livestock-only and mixed crop-livestock production systems, mainly in the tropics. Some species within the genus *Cratylia* are particularly promising for multi-purpose uses and as forage supplement.

The genus *Cratylia* belongs to the family Leguminosae, subfamily Papilionoideae, tribe Phaseoleae and subtribe Diocleinae. In recent years there has been increased interest in *C. argentea* and *C. mollis* for their potential as forage for tropical regions. Both species are drought-tolerant, multipurpose shrub legumes well adapted to acid soils of the sub-humid and humid tropics with relatively high nutritional value.

Recently, the genetic diversity of a collection of *C. argentea* (accessions collected mainly in Brazil) was studied using RAPDs. The results showed low genetic diversity and relatively high genetic similarity among (Brazilian) *C. argentea* accessions. In contrast, the *C. mollis* accessions included as outgroup and the only Bolivian *C. argentea* accession ('Yapacani') were genetically (and morphologically) strongly different from the rest of the collection, suggesting that the *C. argentea* specimen from Bolivia might be a different taxon or even a different species.

The objective of the present work is to clarify the genetic relationships between *Cratylia argentea* germplasm from Brasil and Bolivia to further elucidate the taxonomic status of the Bolivian genotypes, thus supplementing previous results about a germplasm collection assembled from the wild-legume flora mainly in Brazil, and contributing to taxonomic efforts currently underway for the genus *Cratylia*.

To achieve this, molecular markers (RAPDs and ITSs) are used to compare representative accessions of the *Cratylia argentea* prototype (from Brazil) to a set of 'Yapacani-type' *C. argentea* accessions collected recently in Bolivia. Several accessions of the closely related species *C. mollis, Dioclea virgata* and *D. guianensis* are included as outgroup to evaluate the hypothesis that the 'Yapacani-type' might be a different taxon or species.

Methodology

Plant material and DNA extraction

This study included 17 accessions of *Cratylia argentea*, of which 13 are collections from Brazil and the remaining 4 in Brazil (states of Mato Grosso and Goias) (Table 48); 2 accessions of *Cratylia mollis* collected in Bolivia; 3 accessions of *Dioclea virgata* (2 Colombian, 1 Brazilian) and 3 accessions of *Dioclea guianensis* (Colombia). The species *C. mollis*, *D. virgata* and *D. guianensis*, were included to establish inter-specific genetic relationships with *C. argentea.* Accessions are bulked samples representing natural populations of their respective collection sites in Bolivia. Seedlings were grown under greenhouse conditions (CIAT) and transplanted to the field in the CIAT-Quilichao Experimental Station. Young leaves were harvested from greenhouse just before reaching a fully developed size. Genomic DNA was isolated from fresh leaves.

RAPD Markers

Amplification of RAPDs was done and PCR reactions were carried out in a final volume of 25 µL as follows: 25 ng of genomic DNA were added to a mix containing 2.5 m*M* MgCl2, 1X PCR buffer (50 m*M* KCl; Tris-HCl pH 8.8 10 m*M*, 0.1% Triton X-100), 0.2 m*M* of each dNTPs, 0.2 µ*M* of primers: OP-D15 (5'-CATCCGTGCT-3'), OP-G12 (5'-CAGCTCACGA-3'), OP-I07 (5'-CAGCGACAAG-3'), OP-J06 (5'-TCGTTCCGCA-3'), OP-J07 (5'-CCTCTCGACA-3'), OP-J12 (5'-GTCCCGTGGT-3') (Operon Technologies, Alameda, CA, USA), and one unit of *Taq polymerase* (CIAT). The amplified DNA fragments were visualised in agarose gels 1,5% stained with ethidium bromide.

ITS Amplification, cloning and DNA sequencing

Amplification reactions of ITS regions were performed in a final volume of 25 µL as follows: 5,6 ng of genomic DNA were added to a mix containing 1.5 m*M* MgCl2, 1X PCR buffer (50 m*M* KCl; Tris-HCl pH 8.8 10 m*M*, 0.1% Triton X-100), 0.2 mM of each dNTPs, 0.1 µ*M* of primers: ITS1 (5'AGAAGTCGTAACAAGGTTTCCGTAGG-3') and ITS 4 (5'-TCCTCCGCTTATTGATATGC-3') and one unit of *Taq polymerase*. Products were cleaned with the Wizard SV Gel and PCR Clean-Up System (Promega). The cleaned products were ligated into pGEM – T Easy Vector carrying ampicillin resistence gene and transformed into *E. coli* competent *DH5-α* cells. Sequencing was performed using a Big Dye kit (*PE Applied Biosystem, Warrington, Cheshire, UK*) and run on an ABI *Prism* 377 (*Perkin Elmer/Applied Biosystem*).

Analysis of DNA sequence data

The sequence data (electropherograms) were edited with the Sequencher 4.6 software program (*Gene Codes Corporation, Ann Arbor, MI*). The obtained ITS sequences were initially aligned with Clustal W (EMBL-EB: http://www.ebi.ac.uk/Tools/clustalw/) applying the default parameters and then manually adjusted for indels otherwise not properly recognized by Clustal W.

Results

The RAPDs fragments generated show a high level of polymorphism (93.2%) and total reproducibility in the repetitions performed, besides a good discrimination relative to the bands generated for the different genotypes (Fig. 47). 25 complete ITS sequences of ITS1-5.8S-ITS2, varying between 716 and 728 bp, were obtained. The total aligned length of the ITS sequence, excluding the 5.8S gene, is 567 positions, corresponding to 289 bp in ITS1 and 278 bp in ITS2 (Fig. 48).

Currently, the respective phylogenetic, similarity and genotyping analyses are being developed with the results obtained from RAPDs and ITS data of the two different *C. argentea* types ('Yapacani' and *C. argentea* type) and the other species included as outgroup (*C. mollis*, *D. virgata* and *D. guianensis*) in this study.

Table 48. Origin of the *Cratylia argentea*, *Cratylia* sp., *Cratylia mollis*, *Dioclea virgata* and *Dioclea guianensis* used in the present study.

	Species	ID (CIAT)	Country	Latitude	Longitude	Observations
1	*Cratylia argentea*	18516	BRAZIL	13°22'S	46°25'W	*argentea* type
2	*Cratylia argentea*	18668	BRAZIL	15°22'S	56°13'W	*argentea* type
3	*Cratylia argentea*	18674	BRAZIL	14°38'S	52°22'W	*argentea* type
4	*Cratylia argentea*	22406	BRAZIL	14°15'S	46°30'W	*argentea* type
5	*Cratylia argentea(?)*	22397	BOLIVIA	17°24'S	63°56'W	'Yapacaní' type
6	*Cratylia mollis*	7940	BRAZIL	n.a.	n.a.	Outgroup
7	*Cratylia mollis*	8034	BRAZIL	n.a.	n.a.	Outgroup
8	*Dioclea virgata*	828	COLOMBIA	8°04'N	72°27'W	Outgroup
9	*Dioclea virgata*	8008	BRAZIL	n.a.	n.a.	Outgroup
10	*Dioclea virgata*	8196	COLOMBIA	4°12'N	70°19'W	Outgroup
11	*Dioclea guianensis*	7799	COLOMBIA	4°20'N	70°01'W	Outgroup
12	*Dioclea guianensis*	8193	COLOMBIA	4°31'N	71°16'W	Outgroup
13	*Dioclea guianensis*	9311	COLOMBIA	4°28'N	70°35'W	Outgroup
14	*Cratylia* sp.	Pto Grether(a)	BOLIVIA	n.a.	n.a.	'Yapacaní' type
15	*Cratylia* sp.	Pto Grether(b)	BOLIVIA	n.a.	n.a.	'Yapacaní' type
16	*Cratylia* sp.	Yacapani Sra.	BOLIVIA	n.a.	n.a.	'Yapacaní' type
17	*Cratylia* sp.	Yacapani Sda	BOLIVIA	n.a.	n.a.	'Yapacaní' type
18	*Cratylia* sp.	GPS-039	BOLIVIA	17º03'S	63º53'W	'Yapacaní' type
19	*Cratylia* sp.	GPS-042	BOLIVIA	16º59'S	65º26'W	'Yapacaní' type
20	*Cratylia* sp.	GPS-043	BOLIVIA	17º00'S	65º33'W	'Yapacaní' type
21	*Cratylia* sp.	GPS-044	BOLIVIA	17º05'S	64º49'W	'Yapacaní' type
22	*Cratylia* sp.	GPS-046	BOLIVIA	17º15'S	64º14'W	'Yapacaní' type
23	*Cratylia* sp.	Arroyo Dolores	BOLIVIA	17º26'S	63º37'W	*argentea type*
24	*Cratylia* sp.	Laguna Madrejon	BOLIVIA	17º26'S	63º39'W	'Yapacaní' type
25	*Cratylia* sp.	Naranjal	BOLIVIA	17º25'S	63º56'W	'Yapacaní' type

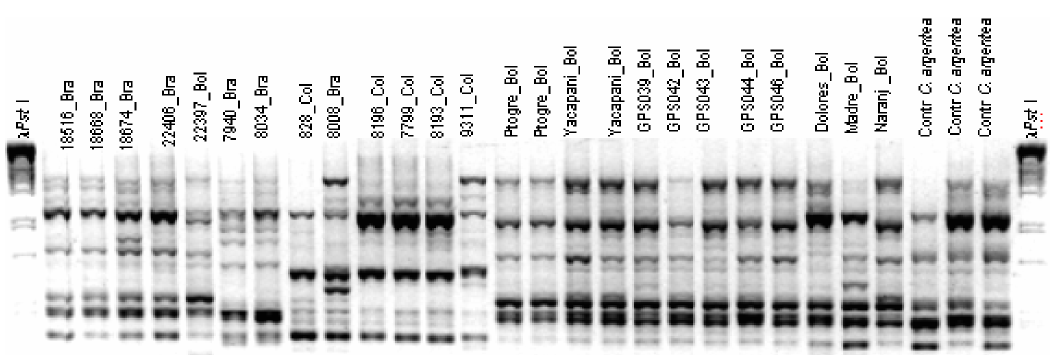


Figure 47. RAPD profile obtained using the primer OPD15 for the 25 accessions. Size markers (λ-DNA/*Pst* I, Invitrogen, USA) for assessing base pair lengths are shown in the first and last lane of picture.

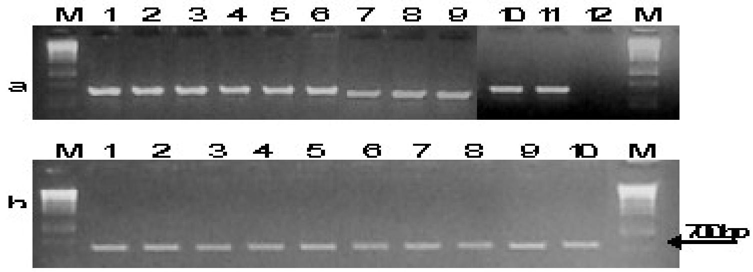


Figure 48. Gel electrophoresis of the amplified rDNA internal transcribed sequence (ITS1-5.8S-ITS2) region of the (1) *Cratylia argentea* (18516); (2) *C. argentea* (18668); (3) *C. argentea* (18674); (4) *C. argentea* (22406); (5) *Cratylia* sp. (Yacapani type); (6) *Cratylia* sp. (Yacapani type); (7) *Cratylia mollis* (7940); (8) *Dioclea virgata* (828); (9) *Dioclea guianensis* (7799); (10) Positive control (*Phaseolus lunatus*); (11) *Oryza sativa* (12) Negative control, b: ITS region cleaned with the Wizard SV Gel and PCR Clean-Up System (Promega). Size markers (□-DNA/Pst I, Invitrogen) are indicated by M.

Outcome 3: Benefits of multipurpose grasses and legumes realized in crop/livestock system through adaptation, innovation and adoption

3.1 Early adoption of forage conservation technologies in Honduras

Highlights

- In areas of prolonged dry seasons, continuous promotion of forage conservation represented by the extension strategy ‘promotion of adoption’ resulted in high levels of technology diffusion under favourable conditions

- Silage making proved effective to facilitate overcoming dry season feed constraints and to improve livestock production. Most suitable technologies for small-scale farmers are hay from improved grasses, sorghum hay/straw and sorghum silage using earth and heap silos. Legumes such as cowpea, supplemented fresh, in form of hay, silage or concentrate, proved efficient as partial substitute of commercial concentrates.

Contributors: C. Reiber (CIAT, University of Hohenheim), M. Peters, R. Schultze-Kraft, P. Lentes (CIAT), and V. Hoffmann (University of Hohenheim)

Rationale

Forage conservation in form of hay and silage is a promising measure to alleviate dry season feed constraints. However, adoption has been limited in the tropics and subtropics, particularly in small-scale farms. In collaboration with national partners, farmer trainings have been conducted in different areas of Honduras during 2004 and 2005 following the overall strategy to encourage innovation and adoption processes of hay and silage technologies among smallholders. At the beginning of the project manual hay making was new to all farmers whereas silage technology had already been adopted in some project regions as result of earlier extension activities. Advantage was taken of those areas where first silage adopters had already experience with the technology prior to the start of the project, to investigate the effect of continuous promotion activities on the adoption and diffusion of silage technology. In the case of silage, two different extension strategies adapted to different adoption stages and ‘knowledge groups’ are distinguished: (a) ‘promotion of innovation’ (PI) was applied with groups of smallholders in locations where silage was not used or known in order to test and adapt new silage and hay technologies; and (b) ‘promotion of adoption’ (PA) was applied in locations where at least one innovator had already experience with silage making. Prototype farm(er)s were involved in the demonstration and promotion activities (farmer-to-farmer approach) (Figure 49).

The research reported here seeks (a) to compare the effect of the above strategies on innovation, adoption and diffusion processes of silage making methods, (b) to reveal farmer criteria for silage adoption or rejection, and (c) to determine favouring and inhibiting factors, at local, farm and technological levels, for hay and silage adoption by Honduran small-scale farmers. It serves the purposes of investigating the potentials and constraints of silage and hay technologies for smallholders in order to derive recommendations for further research and development activities.

Methods

Characterization and classification of research and extension groups

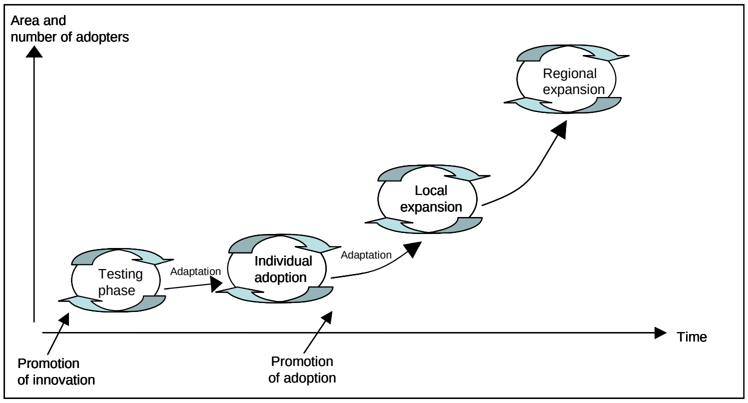


Figure 49. Illustration of the adoption stages in which the project intervened with the two extension strategies.

Table 49 shows the main differences of the target groups and extension strategies.

Table 49. Main differences of the target groups and strategies.

	Promotion of innovation	**Promotion of adoption**
Desired effect	Adapted technology for smallholders	Wider impact, diffusion
Characterization of the target groups		
Pilot farms with silage	No	Yes
Awareness of silage technology	No	Yes
Know-how	No	No
Strategies applied		
Target groups	Groups of smallholders	Interested individual farmers and groups
Type of knowledge transfer	Trainings	Demonstrations, field days
Use of little-bag silage (LBS)	As entry point	As a training tool and alternative for smallholders
Transfer agents	Technicians, extensionists, researchers	Technicians, extensionists, researchers, and farmers
Number of case studies	7	6

Table 50 shows the case studies, which are grouped into the two different extension strategies and three different extension intensities. The grouping of case studies into different extension intensities reflects the number of trainings, the presence of a technician to directly support farmers, and the number of farmers reached whereas the grouping in extension strategy implies the time period of extension.

Table 50. Characterization of case studies.

No. of case study	Location of farmer groups	Depart-ment	Promoters/ Collaborators	No. of trainings[1]	Personal technical assistance	Partici-pating farmers	Extension intensity	Extension strategy[2]
1	Victoria	Yoro	CIAT/DICTA	>3	Yes	29	High	PA
2	Sulaco	Yoro	CIAT/DICTA	>3	Yes	19	High	PA
3	Yorito	Yoro	CIAT/DICTA	>3	Yes	23	High	PA
4	Yoro	Yoro	CIAT/DICTA	3	Yes	21	High	PA
5	Las Vegas	Yoro	CIAT/Ayuda en Acción	2	No	14	Medium	PI
6	Alauca	El Paraíso	CIAT/DICTA	2	Partly	10	Medium	PI
7	Jamastrán1	El Paraíso	CIAT/DICTA	3	Partly	24	Medium	PA
8	Jamastrán2 (NITs[1])	El Paraíso	Fondo Ganadero	2	Partly	40	Medium	PI
9	SP de Catacamas	Olancho	CIAT/UNA	1	No	18	Low	PI
10	SF de Becerra	Olancho	CIAT/DICTA	1	No	21	Low	PI
11	SF de la Paz	Olancho	CIAT/DICTA	1	No	17	Low	PI
12	Candelaria	Lempira	FAO/CIAT/ ITC	2	Yes	15	High	PA
13	Jesús de Otoro	Intibuca	CIAT/FHIPA (CIAL)	2	Partly	8	Medium	PI

[1] Including field days
[2] Code extension strategy: PI: Promotion of innovation; PA: promotion of adoption

Trainings were carried out by project staff except for case 8 representing the NITs (Núcleos de Integración de Tecnología). NITs were established and supported by the 'Fondo Ganadero'; the case includes eight farmer groups of five smallholders each which were trained in silage production using a heap silo.

Grouping of farmers

Farmers are first grouped into silage adopters, non-adopters, potential adopters (farmers who reliably intended to adopt) and rejecters.

For simplification purposes, 'rejecters' are considered as non-adopters and 'potential adopters' as adopters at a later stage of the analysis. Further, small-, medium- and large-scale farmers are classified according to their herd size (small: 1-20 head of cattle; medium: 21-50; large: 51-100; extra large: >100). Figure 50 shows the share of the different farms size categories considered in this study.

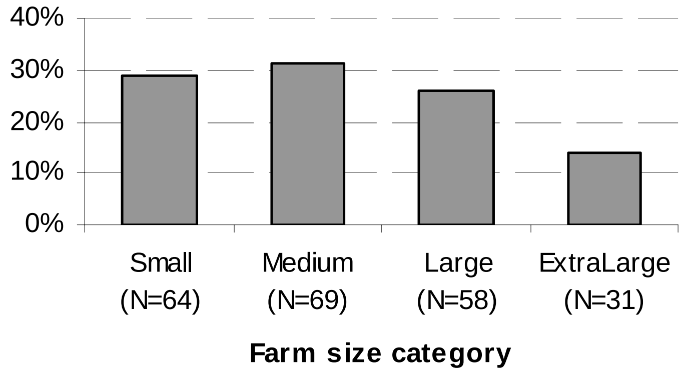


Figure 50. Share of small-, medium-, large-, and extra-large farms

Data collection

In total, about 250 farmers participated in trainings. Basic farm data (e.g. farm size and number of animals) could be gathered from 222 participants (89%). As a continuous process, innovation, adoption and diffusion processes were monitored in the research regions. By the end of the project, structured interviews were applied with trained farmers in order to gather data on adoption factors including farmers' perceptions. Key-person semi-structured interviews, e.g. with prototype farmers and group leaders as well as extensionists/technicians served to derive information on the local adoption status and technological potentials and constraints.

Data analysis

Data were analyzed using Excel and SPSS statistical software. Methods applied for the comparative analysis of grouped farms include descriptive statistics (averages, standard deviations, frequencies), simple linear regression, and non-parametric tests (Mann-Whitney test).

Results

Results are divided into local and extension level, technological level, and farm(er) level.

Local and extension level: Silage (and hay) adoption for each location

Table 51 gives an overview of the adoption of silage (and hay) technology for each research location. The strategy 'promotion of innovation' resulted in total adoption between 0% and 29% with adoption increases between –5% and 24%. In contrast, 'promotion of adoption' shows adoption rates between 13% and 79% with adoption increases between –40% and 57% between 2003/2004 and 2006/07.

Table 51. Effect of farmer trainings on adoption.

	Extension strategy	No. of farmers participating in trainings	No. of silage users in 2003/04	No. of LBS testers after 2004[1]	No. of adopters in 2006/07 of participants	% silage adoption[2]	% silage adoption increase[3]	Number (and %) of hay adopters
Victoria	PA	29	7	6	20	69	45	4 (14%)
Sulaco	PA	19	7	1	15	79	42	3 (16%)
Yorito	PA	23	4	3	12	52	35	1 (5%)
Yoro	PA	21	3	2	15	71	57	11 (52%)
Las Vegas	PI	14	0	2	3	21	21	5 (36%)
Alauca	PI	10	0	3	2	20	20	2 (20%)
Jamastrán1	PA	24	5	3	11	46	25	5 (21%)
Jamastrán2 (NITs)	PI	40	12	1	10	25	-5	4 (10%)
SP de Catacamas	PI	18	0	2	2	11	11	6 (33%)
SF de Becerra	PI	21	1	3	6	29	24	10 (48%)
SF de la Paz	PI	17	0	0	0	0	0	4 (24%)
Candelaria	PA	15	8	1	2	13	-40	0 (0%)
Jesús de Otoro	PI	8	0	1	1	13	13	0 (0%)

[1] LBS testers are not considered as adopters if LBS was only used one year
[2] Total adoption of farmers who participated in trainings and/or were supported by technician
[3] % adoption increase between 2003/04 and 2006/07 = (No. of silage adopters 06/07 – no. of silage users until 2004 who participated) / (no. of participating farmers)

The case study Candelaria, which is described below in detail, indicates that promotion over a longer time period does not necessarily lead to higher adoption, if conditions are not favourable. In case of the NITs (case Jamastrán 2), no further adoption occurred after the initial trainings on silage production in heap silos in 2004/2005. The majority of non-adopters mentioned the non-availability of chopping equipment as the main limitation. The two cases of rejection are due to the fact that male farmers emigrated outside of Honduras. In Alauca, San Pedro de Catacamas, San Francisco de la Paz and Jesús de Otoro where nobody elaborated silage in 2004, adoption increased by 20%, 11%, 0%, and 13%, respectively, after three years.

In the following, results are presented for silage adoption whereas hay production and its adoption are presented separately under ‘innovations’.

Adoption as effect of extension strategy and intensity

When the locations are grouped according to extension strategy, 27% of 85 farmers adopted silage technology as result of the strategy ‘promotion of innovation’ whereas 53% of 135 farmers adopted as result of the strategy ‘promotion of adoption’. The difference between the strategies is highly significant ($p<0.001$). Moreover, more farmers intended to adopt (‘potential adopters’) with adoption-promotion (Figure 51).

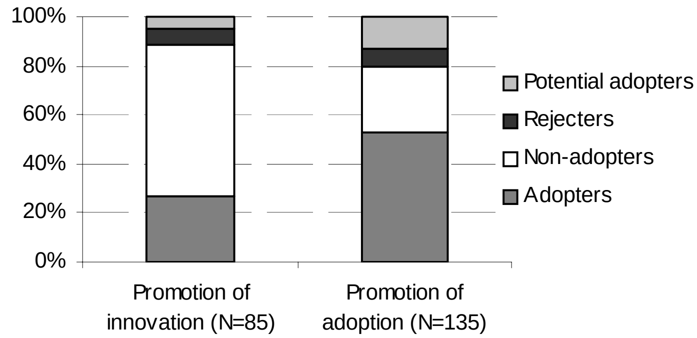


Figure 51. Adoption as affected by different extension strategies

Figure 52 shows adoption rates of 21%, 40% and 53% for low, medium and high extension intensity, respectively. This partly reflects the above results since ‘PI’ was largely applied with low intensity whereas ‘PA’ was largely applied with higher intensity depending on the availability of technical assistance. However, there are 57 cases of medium intensity across both strategies.

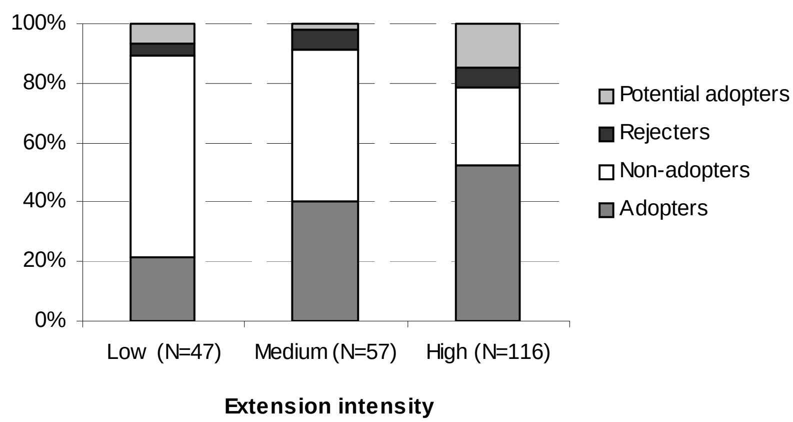


Figure 52. Adoption as affected by different extension intensities

In the following, ‘potential adopters’ are grouped with ‘adopters’ and ‘rejecters’ with ‘non-adopters’. Figure 53 shows the effect of the two strategies on the adoption for each farm size category. From a total of 64 small-scale farmers, 24 (38%) have adopted silage technology, with 31% as result of ‘PI’ and 48% as result of ‘PA’. The ‘smallest’ farmer who adopted silage had seven head of cattle. For medium-scale farmers, in average, 42% adopted silage with 23% of ’PI’ and 60% of ‘PA’. In average, 63% of large-scale farmers adopted silage technology with 34% more adoption when promoted with ‘PA’ compared to ‘PI’.

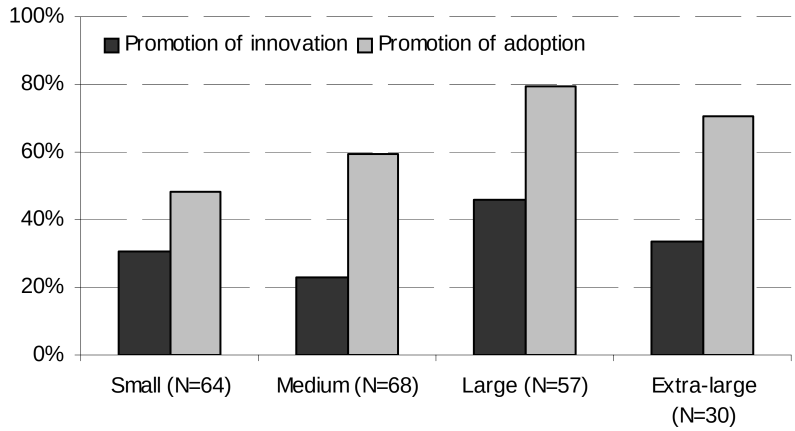


Figure 53. Silage adoption for different extension and farm size categories

Case studies of adoption and rejection

The following two case studies both have used the 'PA' strategy with the first one ending in 'rejection' while the second one led to 'diffusion' of the technology.

1. Case study: Small-scale silage production in the hillsides of Candelaria
Candelaria is situated at an altitude of 660 m.a.s.l in the southern part of the department of Lempira in Western Honduras. It is considered one of the poorest areas in Honduras. Topographically it is dominated by steep hills. Annual precipitation is 1400 mm with a distinct dry season that lasts about 6 months from November to May. Physical and social infrastructure for the region is poor, as reflected by a lower Human Development Index as compared to other parts of Honduras. Local markets are limited and demonstrate low integration with the rest of Honduras. Cheese, in Honduras often locally produced is coming from the other side of the border, El Salvador. Small farms account for approximately 80% with less than five hectares. Seventy-five percent of producers in the region plant maize and beans as subsistence crops; 10% grow coffee and 5% extensively manage livestock. It is estimated that 80% of cattle farms have less than five animals, mainly Brahman cattle for meat production. Old cows are sold to El Salvador, calves of 1-2 years to Guatemala.

The most limiting factor mentioned by farmers was feed shortage in the dry season. In the rainy season, milk production is greater than the demand and not all milk produced can be sold. In the dry season, on the other hand, demand is greater than supply. Price for milk ranges from about 7 Lempiras (0.37 $US) per liter in the rainy season up to 12 Lempiras (0.63 $US) per liter in the dry season. Six of 11 farmers (55%) ceased milk production at least for some time in the dry season, partly due to the lack of forage and partly due to dry cows (relatively more calves are born in April and May). Dry season feed is based on crop residues from maize and sorghum ('maizillo', *Sorghum vulgare*) which is called 'guate' or 'guatera'. In case of guatera, 'maizillo' is planted with high density and used whole for forage. In case of guate, the panicle is harvested in January for concentrate feed or tortillas and the straw, either stored or left in field, is used for forage. Purchased concentrate is hardly used.

In Candelaria, the FAO promoted silage already in 1998/99 without the use of machinery. However, none of the five farmers participating continued to prepare silage by hand-chopping. Since 2003/04, two extensionists from a local institute promoted the conservation of cut and carry grasses and supported eight smallholders with chopping equipment and technical assistance. Farmers had to pay the gasoline, oil and about 5 US$ per day for the chopper service. Small earth (also called pit) silos ('agujero', 'horno forrajero') of about 6m³ with plastic at all sides and at the bottom were promoted.

After three years, six farmers rejected to produce silage, partly due to poor silage fermentation, and partly due to chopping equipment constraints. Farmers complained about disgusting smell of silages produced from the grasses *Brachiaria brizantha* and *Pennisetum purpureum* (King Grass and Camerún), which led to a bad reputation of silage in general. Malfermentation was ascribed to be result of inappropriate ensiling management, in particular the high moisture content in the silos. This is caused partly by grasses ensiled without prewilting, and partly by diluting molasses, as an additive, by too large quantities of water; moreover, molasses is used at levels lower than the recommended 5%. In order to train farmers in principles of silage making, a participatory evaluation was conducted with differently treated *Brachiaria brizantha* cv Toledo little bag silages (LBS) as experimental units. It was demonstrated to farmers that short wilting and the addition of 5% molasses resulted in acceptable silage qualities (see Annual Report 2006). LBS was appreciated for the possibility to ensile small quantities and for less problems of spoilage losses during feed out.

Ceasing the support with chopping equipment, silage likely will be produced only by few smallholders with chopper, as commented by the local extensionists. It was argued that improved pasture varieties will substitute silage making due to their drought tolerance and ability to regrow rapidly after sporadic heavy rain events in the dry season. *Brachiaria brizantha* cv Toledo seed is now produced on more than 40 hectares and rapid diffusion is presently taking place.

<u>2. Case study: Adoption and diffusion of silage technology in the area of Yoro</u>

In the Yoro area, CIAT/DICTA initiated the promotion of silage making in 2002. Subsequently, prototype farms were established in Victoria (2), Yorito (2) and Yoro (1). In addition to farmer trainings and field days, farmers were assisted by a technician who was a 'prototype' farmer himself. Although there were already few large-scale silage adopters since the early 90s, technology did not spread until 2002/03. Since then, the total number of farmers employing silage as dry season feeding strategy in the area increased from 11 in 2002/03 to presently about 102 farmers with 26 farmers from Yoro, 15 from Yorito, 28 from Sulaco and 33 farmers from Victoria. The dashed lines in Figures 54 and 55 represent the minimum diffusion course based on the intention of contacted farmers to produce silage for the dry season 2007/08.

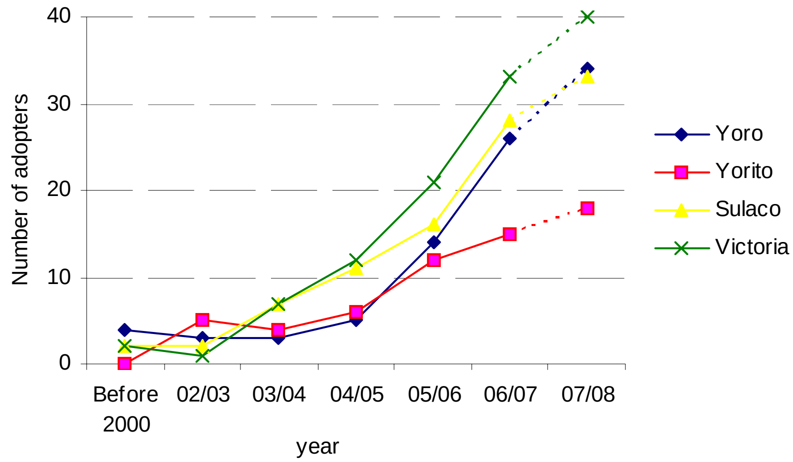


Figure 54. Adoption progress of silage technology over years

The present (2007/08) share of silage adopters of all livestock farmers in the four locations is estimated to be 23% (34 from 150) in Yoro, 36% (18 from 50) in Yorito, 37% (40 from 109) in Victoria, and 41% (33 from 80) in Sulaco.

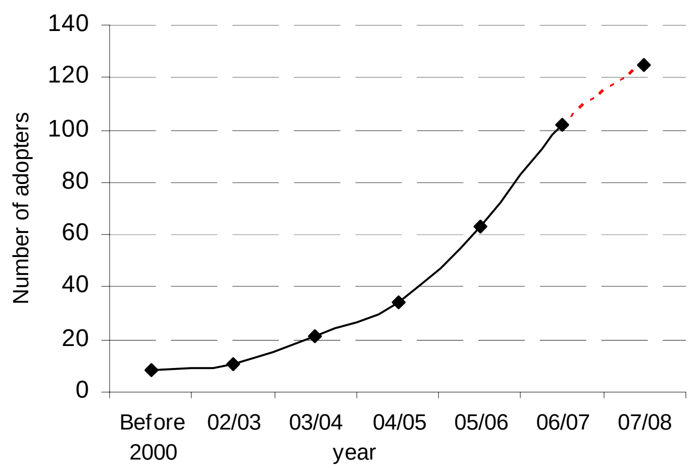


Figure 55. Accumulated adoption in the Yoro area

The spread of silage in Sulaco was mentioned to be fostered by the long dry season whereas in Yorito it was fostered by the existence of the 'milk group' (CREL, spanish acronym for milk collection and cooling center).

Influence of CRELs on silage adoption

With the membership in CRELs, the purchase of any quantity of milk at a reasonable and constant price throughout the year is guaranteed. In Yoro, the CREL group delivers milk to the processing enterprise SULA since June 2003, in Yorito and Victoria since February 2004. In

Yorito, similar to Victoria and Yoro, the price paid per liter of milk has increased steadily from 4.59 Lempiras (0.24 $US) in January 2005 to 6.20 Lempiras (0.33 $US) in April 2007. In Sulaco, many livestock farmers are affiliated to a group called AGASUL (Asociación de Ganaderos y Agricultores de Sulaco, founded in the late 80s). Milk is sold at the local market at a price of about 4 Lempiras (0.22 $US) in the rainy and up to 6 Lempiras (0.32 $US) in the dry season. Some larger farmers of the group deliver their milk to a private entrepreneur in Yoro.

Pioneer silage farmers were almost all CREL group members whereas many non-CREL farmers recenty adopted silage. Figure 56 shows that relatively more farmers being affiliated to CRELs, and in case of Sulaco to the group AGASUL, use silage than the total share of silage users for the locations. In Sulaco, even about 80% of the group members have a silo, in Victoria more than 60% and about 40% in Yorito and Yoro.

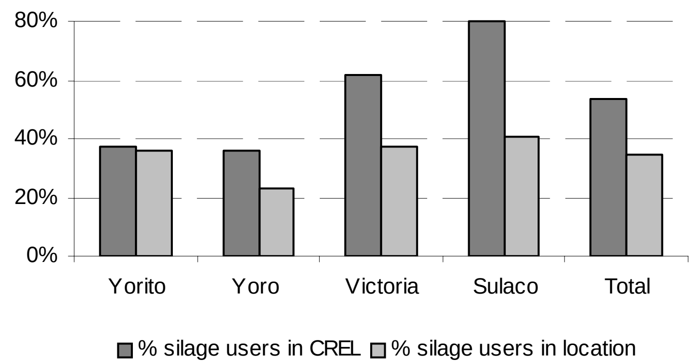


Figure 56. Silage use in CRELs compared to local adoption

As corroborated by three independent key informants pertaining to a CREL in Jamastrán (El Paraíso), about 80% of group members feed silage whereas total adoption in the region is estimated to be less than 20%.

Although these results indicate that the good milk market represented by CRELs motivated farmers to adopt silage technology, this may not have been the decisive factor for the spread of silage since i) the diffusion process in Victoria and Yorito initiated already before the existence of CRELs, and ii) high adoption was also documented for Sulaco where no CREL exists. Therefore, factors such as farmers' attitude towards the milk business as well as the group membership as such (e.g. referring to information exchange) are considered to be important for the adoption and diffusion of silage technology.

Technological level: Characterization of used forages and silo types

Over all locations, the typical ensiling process is to cut forage with machete whereas tractors are not used. Maize and sorghum are usually cut in the doughy stage of maturation. Cut forage is brought to the silo where it is chopped using motor-driven choppers. Apart from some farmer trainings, manual chopping was not practiced by farmers. Compaction is usually done by rolling a water-filled barrel over the bulk or if available, by a car. Usually, molasses is not used as additive in case of maize and sorghum.

Ensiled forages

In 2007, of 80 farmers interviewed, about half (39) ensiled a single crop whereas the rest ensiled at least two different crops. Regarding the ensiled forages, 66% of silage users ensiled maize, 61% sorghum, 20% cut and carry grasses (*Pennisetum purpureum* 'King Grass' or 'Camerún'), 6% sugarcane, 4% *Brachiaria brizantha* cv. Toledo and 4% cowpea (*Vigna unguiculata)*. Figure 57 presents the share of ensiled forages for different farm size categories. It shows that small-scale farmers ensile relatively more sorghum and King Grass/Camerún compared to medium- and large-scale farmers. However, this tendency is not valid for extra- large farms.

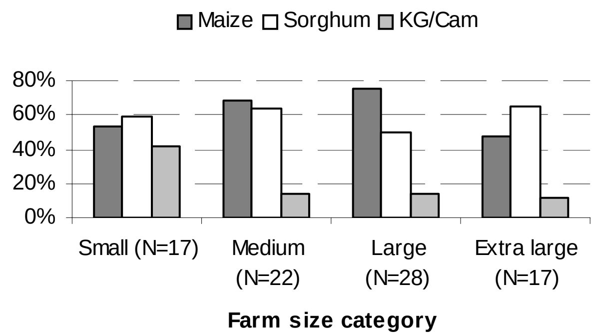


Figure 57. Forages used for silage in different farm size categories

The average area dedicated to silage production is 1.9 ha for maize, 1.6 ha for sorghum, 0.7 ha for sugarcane and 0.6 ha for cut and carry grasses. Figure 58 shows the average area that is dedicated to silage production for each farm size category. It is obvious that the area for maize and sorghum silage becomes larger with increasing farm size category.

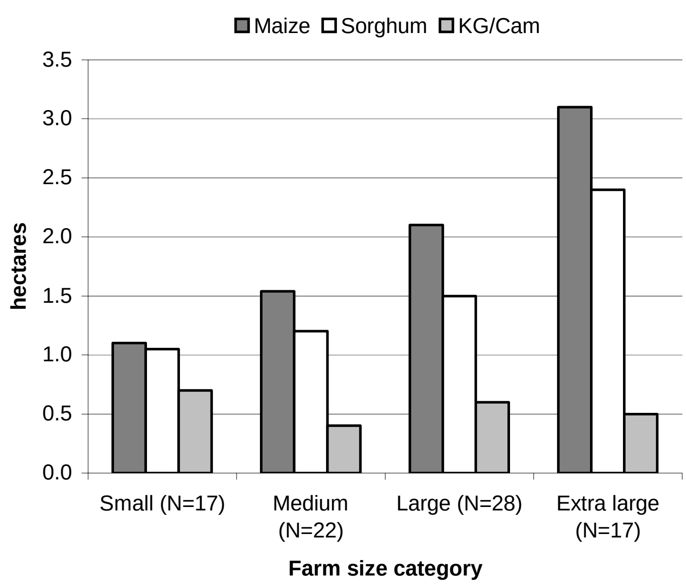


Figure 58. Area dedicated for silage production in different farm size categories

Both, maize and sorghum are considered as quality silages supplemented for milk production purposes to crossbred cows. However, sorghum silage is preferred to maize silage regarding drought tolerance and silage costs. Many farmers from the area of Yoro cultivate maize in the 'primera' planting season and sorghum in the following 'postrera' season. Sorghum planted in September can still be cut once or twice for silage and finally be grazed or cut to be supplemented directly (fresh) or dried. With respect to the silage fermentation qualities, even without any additive, there was generally no problem with maize or sorghum silages as corroborated by evaluations of organoleptic characteristics of silages. However, even when molasses was used, frequent fermentation problems have occurred with grasses such as Pennisetum purpureum and, to some extent, Brachiaria spp., which affect nutritional quality and palatability. These problems are ascribed mainly to lower ensilability concerning the content of water-soluble carbohydrates (WSC) of grasses in combination with a lower dry matter content when harvested compared to maize and sorghum. Therefore, grass silages, similar to hay made from pastures, are perceived rather for maintenance feed than for milk production. Mixtures of grasses and/or legumes with maize or sorghum silages resulted in acceptable qualities.

Forage innovations

Innovation with forage technologies such as *Vigna unguiculata* (cowpea), *Cratylia argentea*, *Brachiaria brizantha* cv Toledo, and sorghum conserved as silage and/or hay has been stimulated. These technologies were tested onfarm as supplements, e.g. by comparing them to other technologies such as commercial concentrates and maize silage, respectively (see also CIAT Annual Report 2006). With respect to Toledo silage, results of participatory experimentations indicated acceptable silage fermentation in four cases (including twice in LBS) and even 'competitivity' with maize silage because of a better cost-benefit ratio (see CIAT Annual Report 2006) whereas in three trials, malfermentation was a problem.

<u>Innovation with cowpea (*Vigna unguiculata*)</u>

Cowpea seeds were distributed to farmers during trainings. About 50 farmers tested the accessions Verde Brazil, FHIA, 284/2, 9611 and CIDICCO. In 17 cases, cowpea production failed due to reasons such as non-cultivation ('didn't plant'), 'cowpea didn't germinate' (e.g. due to drought), or cowpea was lost due to production constraints, such as water logging or drought. Farmers planted between 0.1 and 1 ha. Two farmers who had conducted feeding experiments continued to produce cowpea. In total, at least 11 farmers from different areas used ground cowpea mixed with maize as concentrate. The residues are grazed by the animals. At least six innovators used cowpea for silage and at least five farmers for hay. In six cases, cows directly grazed on it.

In general, farmers are enthusiastic about cowpea, which is appreciated for its high drought tolerance, high biomass and grain production, low incidence of pests and diseases, multiple uses, high palatability, and its effect on animal production. A farmer observed a milk production increase of 2-5 liters per cow (of high genetic potential) when 2.3 kg of cowpea was supplemented to 2.3 kg commercial concentrate. In view of increasing costs for commercial concentrates, cowpea concentrate evolved to a promising 'by-product' of promotion activities.

<u>Cowpea silage supplementation</u>: Cowpea accession 'Verde Brazil' was cut for silage in the flowering stage after eight weeks of growth in the dry season. It was wilted in the field for 4 to 5 hours to a DM content of about 35%. Then, it was chopped in small pieces using a machete. A

total of 360 kg was ensiled in 13 tubular plastic bags (seven bags of 18 kg each and six bags of 36 kg each) with different additives, i.e. molasses (5%) and/or chopped citrus fruits. The sealed bags were stored for nine weeks.

Although stored in a closed room, high total spoilage loss (total 39%) occurred due to plastic perforations caused by mice. Bags with perforations had been placed directly upon a wooden floor, through which mice could have entered. Smaller bags placed upon the big ones had no perforations with losses ranging from 1% to 15% with an average of 5%. For intact bags, the parameters pH (<4.5), smell and palatability indicated good quality little bag cowpea silage. Wilting to 35% DM in combination with the addition of, i.e. molasses (5%), and molasses (2.5%) + chopped orange (5%) proved effective for cowpea silage preparation.

Two crossbred cows (Brahman-Holstein) were selected to be supplemented with daily 5 kg of cowpea silage each during one week to 1 kg per cow of concentrate and maize stubble grazing. Milk production of the two cows increased from average 4.5 and 2.5 liters/cow, respectively to average 4.9 and 3.9 liters/cow, respectively. Supplementation of 5 kg of cowpea silage for lactating cows showed a milk production increase of average 0.9 liters/cow (26%) corresponding to 0.24 $US. Considering only the milk production increase and a cost of 0.22 $US/kg (1.1 $US for 5 kg) of cowpea silage, the slightly higher income through cowpea silage supplementation would not pay its costs.

Results indicate that the tested innovations could be suitable feeds if used as i) a substitute for more expensive technologies such as commercial concentrates and maize silage, and ii) a supplement for cows of higher milk production potential with restricted feed base.

Silo types

Regarding the type of silos used in the Yoro area, Figure 59 shows that within the last years, the share of bunker silos has decreased from about 90% in 2003 to about 50% in 2006. Heap silos have become more popular and are increasingly being adopted by silage novices.

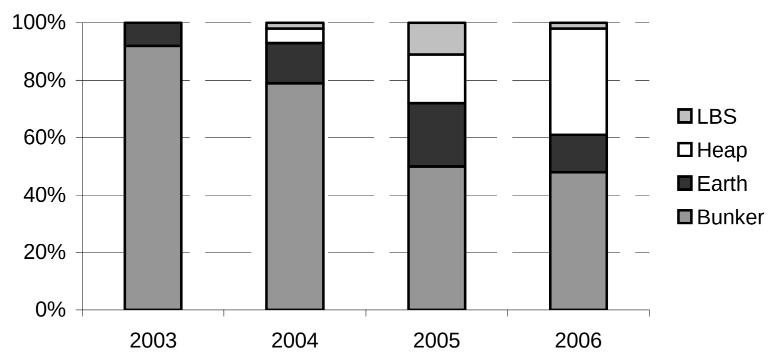


Figure 59. Silo types used over years in Yoro area

Regarding the type of silo being presently used in the different locations, a preference for a specific silo type evolved (Figure 60). In Yorito, for example, all farmers use the costly bunker silo built of bricks and mainly with roof (Photo 4) whereas in Yoro, heap silo became the most widely used (75%) silo type. Heap silos are also the main silo type used by silage novices in Olancho and Jamastrán (Danli). It is considered as ‘silo for the poor’ since it does not require any initial investments in infrastructure. Moreover, it is flexible in size and location, and the bulk can be compacted by car, which is not possible with the bunker silos. And, in comparison to little bag silage, less plastic is used, reducing the cost per unit of silage. The ‘earth’ silo has earth walls and is usually below ground level. However, differently to the earth ‘pits’ in Candelaria, excavated slopes are used in Victoria, Sulaco, Danli and Olancho. In contrast to the ‘pits’, these silos have an ‘open’ front (Photo 4) facilitating compaction (e.g. by car) and silage extraction, and are slightly inclined to avoid water accumulation. Moreover, no plastic is used at the sides and at the bottom to guarantee drainage. A layer of earth is put on top of the plastic to support air tightness and protect plastic from direct sunlight.

Photo 4. Bunker silos in ‘prototype’ far, (Yorito) Sorghum silage in earth silo (Victoria)

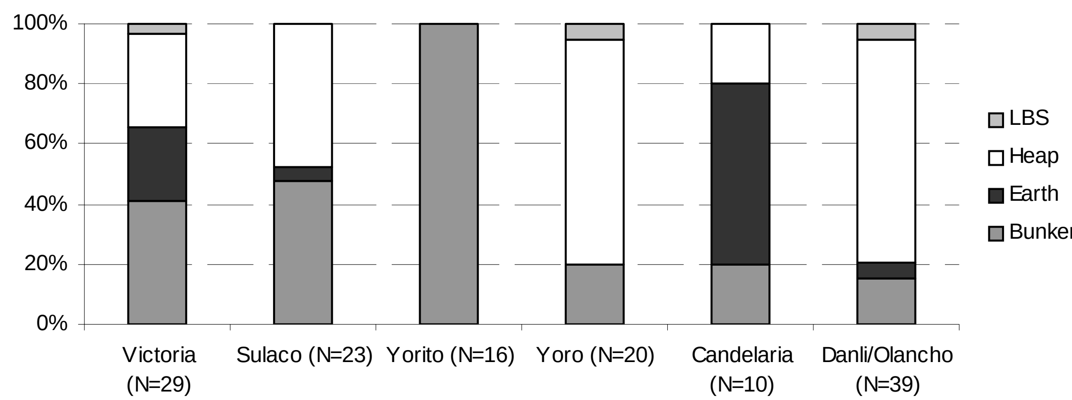


Figure 60. Silo types used in the different locations

Potentials and constrains of ‘little bag silage’ (LBS) for smallholders

Little bag silage (LBS) is a low-cost alternative for resource-poor smallholders. Innovation around LBS has been encouraged during farmer trainings and field days. LBS has been socialized with about 200 farmers from 10 different locations.

As a result, about 25 farmers had personally tested LBS. Nineteen percent of testers were small-, 31% medium-, and 50% large-scale farmers with more than 50 head of cattle. About 10 farmers, (mainly with more than 10 cows) are likely to continue to use plastic bags (mainly tubular plastic and double system) as an additional silage conservation alternative whereas the rest of the farmers has rejected LBS. Of all LBS testers, 12 farmers had already adopted silage technology and used LBS as additional silo type, mainly to make use of a) surplus forage that did not fit in their silo, b) small amounts of cultivated legumes, i.e. *Cratylia argentea* and *Vigna unguiculata* (cowpea), ensiled together with, e.g., maize, sorghum, sugarcane or *Pennisetum purpureum*, and c) paid labour resources in times of less workload. Silage novices who had tested LBS adopted or were about to adopt other silo types of higher capacity (such as heap and earth silos), mainly after having had negative experiences with LBS. Based on farmer observations, about 30% had spoilage losses below 10% whereas about 20% had 100% loss. Reasons are high vulnerability of LBS to pests, mainly mice. Further constraints to larger adoption include lack of (i) suitable and affordable plastic bags, and (ii) appropriate storage facilities and chopping equipment in smallholder farms.

However, LBS proved to be useful and could play an important role in participatory research, extension and development activities as a demonstration, experimentation and learning tool that can be used to get small-scale silage novices started with a low-risk technology. In order to reduce the risk of losses, LBS production requires good management consisting of (a) the use of resistant, high-density plastic material of at least 100 µm (caliber 4), preferably double bagged; (b) ensiling forages with a DM content of 30-40%; (c) chopping; (d) addition of sugar additives, e.g. molasses, when forage is low in WSC; (e) good compaction; (f) hermetical sealing; (g) careful handling to avoid plastic perforations; and (h) sheltered storage protected from pests and excessive temperatures and sunlight (Photo 5).

Photo 5. Hand-chopping of sorghum, sealing of plastic bag and storage of LBS

Farm(er) level: Comparison of adopters with non-adopters

Table 52 shows that farmers using silage, in average, enjoyed higher education, have more cattle, cultivated more improved pasture and cut and carry grasses, possess cows of higher value and produce more milk in the rainy as well as in the dry season. Differences between adopters and non-adopters are highly significant ($P<0.001$) for the factors education, number of livestock, and milk production in the dry season; very significant for the factors improved pasture use, cut and carry grasses and milk production in the rainy season; and significant for the value of cows. No significant differences were found for the factors farmers' age, total farm area, number of animals/pasture area and concentrate use in the dry season. Milk production in the dry season is 1.8 liters/cow higher for farms using silage compared to farms of non-silage users whereas the difference in rainy season is 1.2 liters/cow.

Table 52. Comparative analysis of adopters and non-adopters.

Factors	Silage	N	Average	Std. Deviation	p	Significance
Age	No	22	54.5	12.8	0.183	ns
	Yes	49	49.5	13.7		
Education (years)	No	31	4.9	5.2	0.000	***
	Yes	52	10.7	5.6		
No. of cattle	No	103	52.7	70.4	0.000	***
	Yes	110	71.5	76.5		
Area (ha)	No	103	39.9	51.2	0.389	ns
	Yes	117	52.4	67.4		
Improved pasture (ha)	No	105	4.6	9.3	0.006	**
	Yes	117	10.3	20.9		
Cut and Carry (ha)	No	105	0.9	2.6	0.008	**
	Yes	117	1.1	1.6		
Number of cattle/ha pasture	No	99	1.9	1.7	0.087	ns
	Yes	103	2.3	1.7		
Concentrate dry season (kg/cow/day)	No	105	0.8	1.4	0.163	ns
	Yes	117	1.0	1.2		
Value of cows ($US/cow)	No	62	780	301	0.022	*
	Yes	77	857	229		
Milk rainy season (liters/cow)	No	61	4.8	2.4	0.007	**
	Yes	58	6.0	2.8		
Milk dry season (liters/cow)	No	78	3.4	2.6	0.000	***
	Yes	77	5.2	2.8		

ns: not significant
* significant: the hypothesis of non-significant differences between groups could be rejected with a probability of >=95% according to Mann-Whitney U test
** very significant: the hypothesis of non-significant differences between groups could be rejected with a probability of >=99% according to Mann-Whitney U test
*** highly significant: the hypothesis of non-significant differences between groups could be rejected with a probability of >=99.9% according to Mann-Whitney U test

Reasons for non-adoption and rejection

A total of 75 non-adopters and rejecters consisiting of 37% small-, 29% medium-, and 33% large-scale farmers were asked for reasons for not using silage (any more). Some farmers mentioned two reasons, e.g. ‘No chopper’ and ‘No forage’ which resulted in a total of 109 answers. Figure 61 presents most mentioned reasons for each farm size category. ‘No chopper’ was stated by 46% of small-scale farmers and still by 32% of medium-scale farmers. ‘No need’ integrates reasons such as ‘no feed scarcity’, ‘sufficient pasture’, ‘has irrigation’ and ‘has floodplane’ (‘*vega*’). Larger farms seem to have less need for forage conservation than smaller farms probably due to higher availability of grazing land or feed resources and access to water. ‘Wants to make’ is no direct reason for non-adoption but reflects the decision of farmers to adopt (potential adopters). About 32% of medium-scale and 11% of small-scale farmers regard silage as expensive for what they may not have financial resources (‘No money’). ‘Bad experience’ was mainly mentioned by rejecters but also by their neighbours, i.e. by farmers who were not convinced or were afraid of silage making due to previous failure, e.g. high losses in the first implementation. It is noticable that farmers had bad experience mainly with ensiled cut and carry grasses. ‘Lack of forage’ was mentioned by about 14% of small-scale farmers. Other reasons mentioned only three times or less are not listed in the figure such as ‘lack of labour’, ‘bad cows’, ‘low milk price’, ‘lack of knowledge’, ‘lack of time’, ‘very labour-intensive’, and ‘low number of cows’.

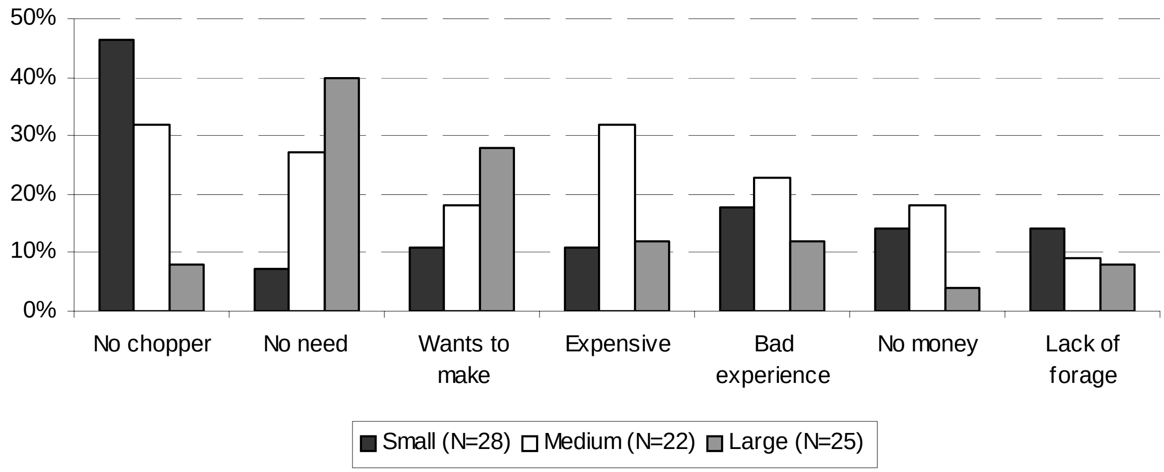


Figure 61. Reasons for non-adoption of silage making for small-, medium, and large-scale farmers

Reasons for silage making

Adopters were asked what motivated them to adopt, or why they started to make silage. From 52 answers, ‘Lack of feed’ (29%) including ‘need’ (6%), and ‘to avoid losses’ (6%) was the most frequently mentioned reason for adoption (Figure 62). In this context, three farmers indicated the uncontrolled burning of pasture in April and May to be the reason for feed shortage and for silage use, respectively. ‘Positive example’ implies the neighbouring silage ‘innovator’ (15%) as well as the ‘positive effects’ (about 12%) on livestock production that can be observed on the innovators’ farm (effects are presented below).

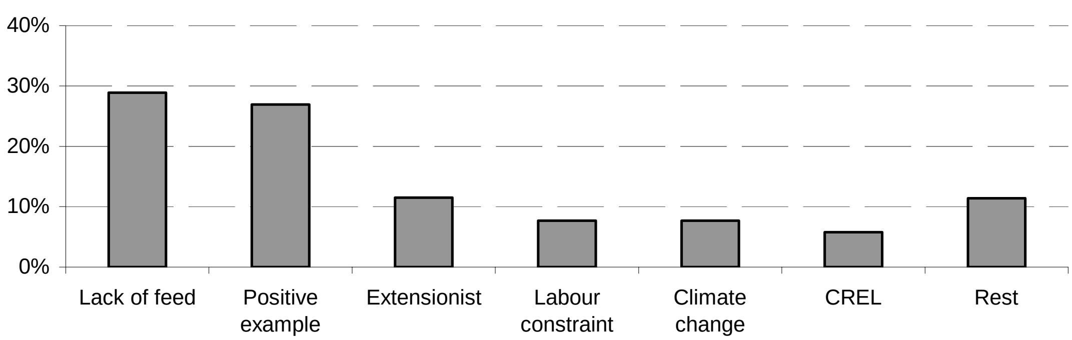


Figure 62. Reasons for silage adoption

The ‘extensionist’, incorporating a prototype farmer who provided technical assistance, was seen as motivating factor, mainly in Victoria and Sulaco. ‘Labour constraint’ refers to the dry season when labour, e.g. to cut forage daily, becomes scarce. In this context, a farmers’ statement: “*...people go to the States or don’t like to work, it is easier to find young labour for one week* (e.g. to prepare silage) *than for the whole dry season…*” (e.g. to cut and carry grass or to accompany animals to a grazing area). Migration of young men to the United States is a severe problem not only in the Yoro area. ‘Climate change’, e.g. the perceived longer and unpredictable dry season, was mentioned by four farmers. Beside ‘CREL’ and ‘Need’ other reasons such as ‘pressure on pasture’, ‘the meeting’, ‘the better milk breed’, and the ‘higher number of animals’ need to be taken into consideration as reasons for adoption. The following statement is noteworthy: “*…in the dry season farmers suffer and they see that farmers with silage don’t suffer…*”.

Innovators’ assessment of the effect and advantages of silage use

Silage users were asked about dry season milk production before/after and during (with and without) silage supplementation. Table 53 shows a highly significant difference of about 2.5 liters/cow. This refers to silage produced mainly from maize and/or sorghum.

Using an open question, farmers were asked what kind of effects they noticed with the use of silage. Beside the effect on milk production, farmers observed a range of advantages. Out of 64 responses, about 26% mentioned the cows to be in good shape (e.g. “gorda” and “bonita”) including a faster development and growth of calves. This is seen as an important factor since well-shaped cows in the dry season are not only a sign for higher production but also an attribute a farmer is proud of. ‘Feed security’ in times of severe drought accounted for 13% of responses.

Table 53. Dry season milk production with and without silage as perceived by adopters.

Silage	Average	N	Std. Deviation	Significance
No	5,0	34	3,6	***
Yes	7,5	34	5,2	

*** highly significant: the hypothesis of non-significant differences between groups could be rejected with a probability of >=99.9% according to Mann-Whitney U test

As consequence of silage availability, ‘cows can be managed close to the farm’ and ‘do not need to walk long distances’ or being maintained in the hillsides where they are exposed to risk of losses due to death (cows falling down the hill) or theft (10%). Improvements of fertility (cows enter in heat earlier after the dry season) (9%) and health conditions (5%) including less incidence of ticks were observed. Moreover, the use of silage was perceived to have positive effects on pasture recuperation and production due to reduced grazing pressure (13%). Reduced labour requirement (compared to the use of cut and carry grasses and sugarcane) during the silage supplementation period when labour availability is often a constraint accounted for 8% of responses. Some silage users stated to be free of any worries about feed shortages which is reflected by a farmers’ comment as follows: “…nowadays, I’m pleased when the dry season is coming, in the past I was crying…”. And “…for many farmers, silage is regarded as solution to the problem of forage scarcity…”.

Milk production of farms with and without silage

Figure 63 shows the course of average milk production (liters/cow) from June (beginning of rainy season) 2005 to May (end of dry season) 2006 of 21 farms with silage and 25 farms without silage. Highest milk production of about 6.5 liters/cow was registered in the first half of July, decreasing until December to a minimum of 4 liters/cow. During this period, cows graze on pasture grasses and are supplemented at most with a low level of concentrate and mineral salt. Milk production is similar for both groups indicating similar genetical potential of cows. During the feed supplementation period, from December to May, higher milk production was registered for farms using silage compared to non-silage users.

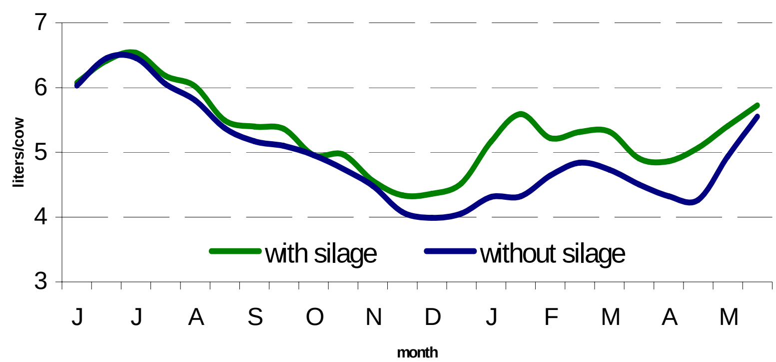


Figure 63. Milk production (liters/cow) in farms with (N=21) and without (N=25) silage

Milk production influenced by share of European dairy breed and silage use

Linear regression analysis showed that the value per cow is linearly correlated with very high significance ($p<0.001$) with (i) the share of European dairy breed, (ii) milk production in the rainy season as well as (iii) milk production in the dry season. Figure 64 shows milk production with and without silage for two breed categories. Regarding the first category, cows with less than 50% dairy breed produce significantly ($p<0.005$) more milk with silage (4.5 liters/cow) than without silage (2.2 liters/cow). In this analysis, six farmers who do not milk in the dry season are involved in the first group. Taking out these farmers, average milk production is 2.8 liters/cow, which is still 1.7 liters/cow less ($p<0.05$) than for the group with silage. Regarding the category of cows of 50% and more dairy breed, they produce one liter/cow more with silage than without silage.

These results do not mean that milk production is influenced by silage use and dairy breed only since other factors such as the use of commercial concentrate need to be taken into consideration. Regression analysis revealed that dry season milk production increases with increasing concentrate use ($p<0.001$). Further analysis is required to determine the effect of silage-only supplementation on milk production.

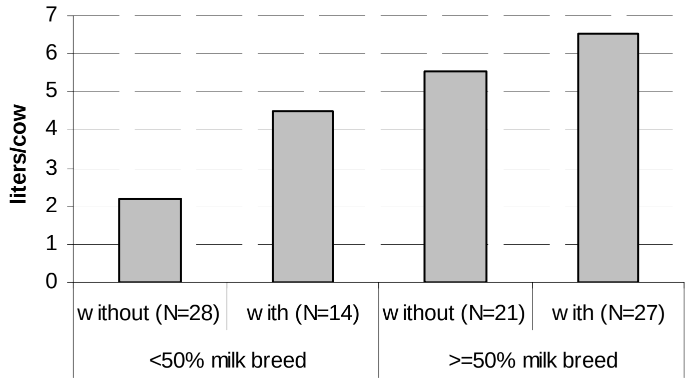


Figure 64. Milk production with and without silage for two breed categories

Hay production from pasture grasses

At the beginning of the project, contrary to silage, hay was only used by few farmers operating mainly with tractors and balers in Yoro and Olancho. In contrast, in Yorito, Sulaco, Victoria and other research locations, hay was not used and often not even known. Similar to the diffusion of silage as result of continuous promotion, a 'hay boom' is presently occuring around Yoro and in some areas of Olancho where about 50% of participating farmers used hay in the dry season 2006/07. From 53 adopters, 49% had less than 50 head of cattle with 19% small-scale farmers; 51% of adopters are large and extra-large farmers with more than 50 head of cattle.

Brachiaria species are used by 82% of hay adopters with 33% using *B. brizantha* (mainly cv. Toledo), 27% *Brachiaria* hybrid (cv. Mulato), and 22% *B. decumbens*. Estrella grass (*Cynodon nlemfuensis*) was made to hay by 20% of adopters, *Digitaria swazilandensis* ('suazi') by 11%, and *Panicum maximum* by 7%. Other forages used for hay were *Vigna unguiculata* and *Cratylia argentea*.

Around San Francisco de Becerra, Juticalpa and Catacamas (Olancho), hay production became a good business for some large-scale farmers with balers. Many small-scale farmers now purchase hay in the market at a price ranging from 15 to 35 Lempiras (0.8-1.8 $US) per bale of about 8-13 kg. Differently to Yoro, in Olancho farmers can now contract for the service of mechanized hay production. They usually pay the service with 50% of the quantity of bales produced or 10-15 Lempiras per bale (about 0.05-0.08 $US/kg). Manual hay production costs (mainly labour costs) ranged from 0.01 to 0.05 $US/kg of hay. Some farmers mentioned the recent availability of machines as reason for increased hay production in the area. An innovator mentioned that about 60% of farmers in the area feed hay but nobody cuts hay using machete. In fact, only six farmers who participated in the training in Olancho were registered who cut grass using machete. Around Yoro, only one farmer produces hay by using a tractor. In many research locations such as Victoria, Yorito and Candelaria, tractors would not be suitable due to small pasture areas and slopy terrain.

Beside manual cutting with machete, there is an increasing use of motor-scythes ('*chindagua*') accelerating the process of cutting grass by about three times as noticed by farmers and corroborated through measurements. Grass is usually cut during the dry season and, under dry and hot conditions, needs two to three days to get dry. Hay production during the rainy season was practiced but farmers complained about high losses due to frequent rains. Hay making during the dry spell in August (‘*veranillo’*) may be a favourable time-frame. Most farmers baled hay using a wooden frame in which it is compacted and formed and tied up by two crossed cords.

Only eight farmers used pasture hay to feed lactating cows whereas the large majority used hay for calves, heifers and dry cows. For lactating cows, hay is usually offered sprinkled with molasses. Without this, cows refuse to feed on it as stated by many farmers. This may be due to the fact that lactating cows, in contrast to calves and dry cows, are ‘spoilt’ with green and sappy grasses; a long adaptation period with production losses would be required. Another problem may be the quality of hay that is usually produced during the dry season when grasses are in an advanced stage of maturity. Moreover, cut drying grass is in general not turned involving an extended drying period with losses in quality and palatability.

All four farmers who tested cv. Mulato hay complained about the difficulty to find workers for its elaboration. Production of Mulato hay is disliked and refused by workers due to its fine hairs itching on the skin when manipulated (note: this is not valid for the new cv. Mulato 2). A farmer from Victoria who conducted a feeding experiment comparing maize and cv. Toledo silage, produced cv. Toledo hay the subsequent year. He prefers cv. Toledo hay (‘*less costs*’) for calves and maize or sorghum silage for cows.

For a feeding trial, about 1 ton of cv. Toledo hay was produced to be fed to lactating cows. The hay was supplemented at 6.8 kg/cow/day to 0.9 kg of concentrate and pasture grazing to eleven cows. Farmers’ observation was that milk production of some cows increased slightly while that of other cows decreased. Data were taken only for some days, which showed a slight decline from, in average, 3.7 liters/cow to 3.5 liters/cow. A problem was seen in the long adaptation period required until cows feed on hay. The farmer commented hay to be suitable for supplementation when feed is scarce and serving rather for maintenance than for milk production. The farmer, as many others, preferred silage to hay due to higher palatability and stronger effect on milk production. However, another innovator from Olancho used maize silage earlier but now feeds cv. Mulato hay from his pasture, which was said to be more comfortable, cheaper, and easier with the availability of machinery. With cv. Mulato hay, his cows maintained milk production.

Conclusions

In areas of prolonged dry seasons, continuous promotion of forage conservation represented by the strategy ‘promotion of adoption’ led to technology diffusion under favourable conditions such as a) availability of positive examples (e.g. ‘prototype farms’); b) presence of motivated farmer groups; and c) a favourable milk market (i.e. guaranteed purchase at an acceptable price).

At farm(er) level, compared to non-adopters, silage adopters enjoyed higher education, have higher number of cattle, cultivated more improved pasture, and have cows of higher milk production potential. Poor small-scale farmers are constrained by lack of machinery, i.e. chopping equipment for silage making, financial and forage resources. However, this study indicates that once technologies are increasingly being used within a location, small-scale farmers can benefit from the increased know-how and access to technologies (i.e. choppers) by simply copying.

At technological level, silage making proved effective to facilitate overcoming of dry season feed constraints and to improve livestock production. Most suitable technologies for small-scale farmers are hay from improved grasses, sorghum hay/straw and sorghum silage using earth and heap silos. Legumes such as cowpea, supplemented fresh, in form of hay, silage or concentrate proved suitable as partial substitutes for commercial concentrates.

For future development activities, it is recommended to initiate innovation processes with innovators through participatory experimentation and/or to make use of already existing positive examples and incorporate small-scale farmers early on. Once positive examples are present, technologies can be scaled-out through 'promotion of adoption'.

3.2 Improved feeding systems for smallholder dairy cattle with emphasis on dry season feeding and its effects on milk production and quality

Highlights

- Introduced forage species *Brachiaria brizantha* "Toledo" and the *Brachiaria* hybrid Mulato II show promising results in dry season adaptability and milk production in Nicaraguan hillsides

- Improved crop residues i.e. (annual) legumes intercropped with cereals like maize and sorghum contribute significantly to higher milk yields during the dry season

Contributors: R. van der Hoek, M. Mena (INTA), A. Benavidez (INTA), A. Schmidt, H.D. Hess (ETH) and M. Peters (CIAT)

Rationale

The objective of this project jointly carried out by ETH (Eidgenössische Technische Hochschule - Zürich), CIAT and INTA (Instituto Nicaragüense de Tecnología Agropecuaria) is the participatory development of alternative and environmentally sound dry season feeding options in different agro-ecological zones in the hillsides of Latin America, which contribute to sustained milk production and improved milk quality during the dry season and reduce the dependence on purchased supplements.

Availability and quality of local and introduced forages

To assess seasonal variations in dry matter production and feeding value of local and introduced forage species, in Las Segovias (in El Tule and at an experiment site of UCATSE – Universidad Católica del Trópico Seco, situated between Estelí and Condega) data were collected from plots with eight grasses (four local and four introduced; Las Segovias is a dry region with 1200 mm annual rainfall and a six months dry season. Figure 65 shows the results of the grass plots in El Tule at the beginning of the dry season of 2006/2007. Regrowth between 10th October and 1st December was vigorous without a significant difference between local and introduced species ($p=0.118$). The second (drier) period showed a much lower production, but the introduced species performed significantly better ($p<0.001$), suggesting a better drought adaptation than the local ones. Among the individual species, both *Andropogon gayanus* and *Brachiaria brizantha* 26110 "Toledo" produced significantly more biomass than *Panicum maximum* ($p<0.05$). Fertilizer and block effects were not found. The data from the UCATSE site, as well as on the feeding value of the different grasses will become available in the beginning of 2008.

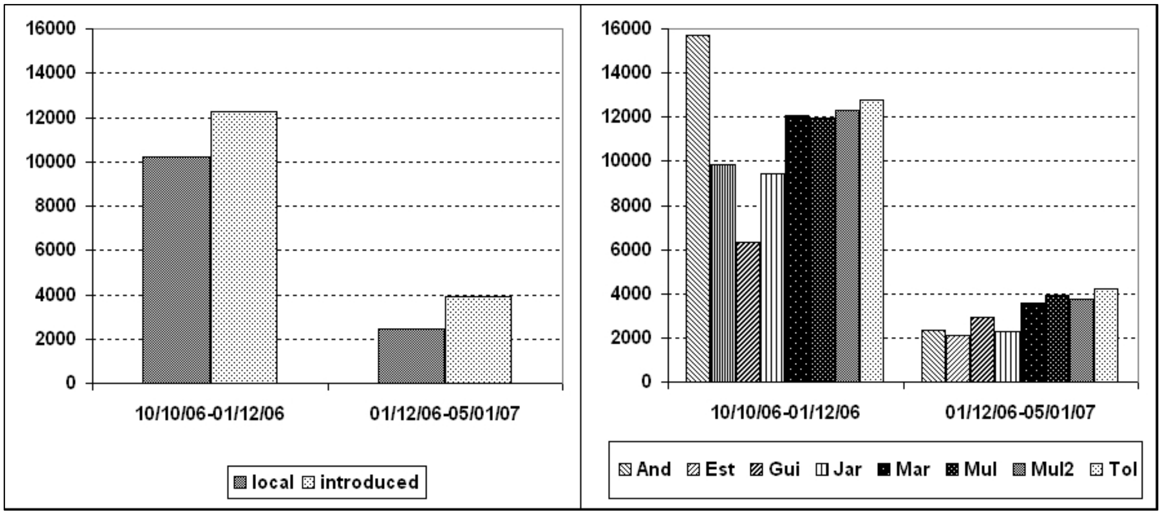


Figure 65. Biomass production (kg DM/ha) of local and introduced pastures (left: total; right: per species) during two periods at the beginning of the dry season of 2006/2007

And: *Andropogon gayanus*; Est: *Cynodon* spp.; Gui: *Panicum maximum*; Jar: *Hyparrhenia rufa*; Mar: *Brachiara brizantha* 6780; Mul: *Brachiaria* hybrid 36061; Mul2: *Brachiaria* hybrid 36087; Tol: *Brachiaria brizantha* 26110 "Toledo"

A participatory evaluation with farmers in El Tule showed a preference for Mulato, followed by Mulato 2 and Toledo. Positive traits were palatability, texture, resistance to grazing and biomass production. Least preferred grasses were *Cynodon, Hyparrhenia rufa* and *Andropogon gayanus.* The associated negative traits were (low) palatability, reproduction, feed quality and resistance to grazing. (Figure 66)

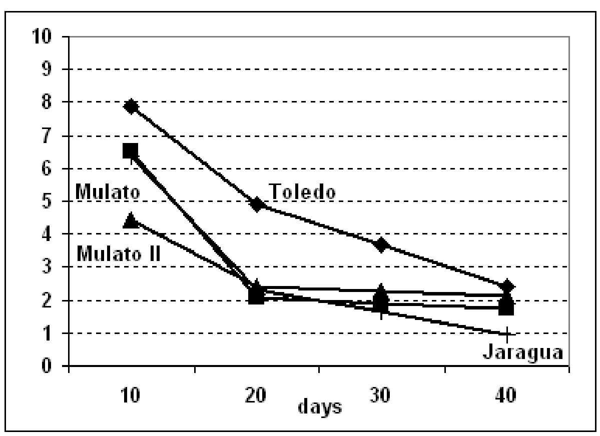


Figure 66. Development in pasture biomass availability (t DM/ha) in El Tule (dry season, beginning 2007)

<u>Determination of feeding value of locally available feeds and supplements</u>

Samples were taken of locally available feed used to fill feed gaps during the dry season, including sugar cane, "Taiwan" (*Pennisetum* spp.), maize cob leaves, rice straw, "vaina de carbón" (pods of *Acacia pennatula*), leaves of *Gliricidia sepium, Brachiaria brizantha* 6780

"Marandú", *Andropogon gayanus*, *Cynodon* spp., *Hyparrhenia rufa* and chopped sorghum ("guate"). The feeding value is determined at CIAT (Cali).

Improved forage management and supplementation strategies for the dry season

In 2007, experiment cycles with introduced (i.e. *Brachiaria* hybrids, *Brachiara brizantha* "Toledo") and local (i.e. *Hyparrhenia rufa*) pastures were continued in El Tule (cross-over design with four groups of two cows rotating simultaneously between four pastures, 12 days per pasture) Figure 64 shows the development in biomass availability in El Tule in the beginning (Jan-Feb) of 2007. As also shown by the data in Table 54, "Toledo" performed best in terms of biomass production and resisting grazing pressure. The results of this experiment were similar to the earlier ones, without any significant effects of pasture type on milk production and milk quality.

Table 54. Pasture yields, milk production and milk quality, El Tule, dry season beginning 2007.

	Average DM yield (t/ha)	Milk production (lt/cow/day) (n=8)	Fat (%) (n=8)	Protein (%) (n=8)	Lactose (%) (n=8)	Total non-fat solids (%) (n=8)
Hyparrhenia rufa ("Jaragua")	2.8	2.44	4.29	3.42	5.12	9.31
Brachiara hybrid 36061 "Mulato"	3.1	2.45	4.83	3.46	5.19^{q}	9.43
Brachiara hybrid 36087 "Mulato II"	2.8	2.49	3.89	3.26	4.87^{p}	8.88
Brachiaria brizantha 26110 "Toledo"	4.7	2.45	4.18	3.28	4.92	8.94

within columns different superscripts (pq) denote significant differences ($p<0.1$)

The same experiment was repeated during the rainy season (Table 55) and the subsequent dry period at the end of the year (Table 56), applying a similar cross-over design with a group of five cows rotating between the four pastures, 12 days per pasture.

In both periods, pasture production was relatively low. This was mainly due to an unusual drought during the rainy season, in which especially Mulato II showed a low biomass of just over a tonne per hectare. However, the milk production in this pasture was significantly higher than of the other pastures ($p<0.05$). Toledo showed also a relatively high production, especially when compared to Mulato ($p<0.1$). While producing the lowest milk yields, grazing of Jaragua and Mulato resulted in significantly higher fat contents ($p<0.05$).

Table 55. Pasture yields, milk production and milk quality, El Tule, rainy season 2007.

	Average DM yield (t/ha)	Milk production (lt/cow/day) (n=5)	Fat (%) (n=5)	Protein (%) (n=5)	Lactose (%) (n=5)	Total non-fat solids (%) (n=5)
Hyparrhenia rufa ("Jaragua")	4.3 (5.3)	3.54^{a}	6.77^{b}	3.32	4.98	9.04
Brachiara hybrid 36061 "Mulato"	3.5 (5.2)	$3.50^{a\ p}$	6.26^{b}	3.18	4.93	8.96
Brachiara hybrid 36087 "Mulato II"	1.1 (2.6)	4.26^{b}	5.12^{a}	3.35	5.02	9.12
Brachiaria brizantha 26110 "Toledo"	3.7 (6.2)	$3.78^{a\ q}$	5.03^{a}	3.28	4.90	8.90

within columns different superscripts (ab, pq) denote significant differences ($p<0.05$, $p<0.1$)
DM yields between brackets: total biomass including other pastures, legumes and weeds

Table 56. Pasture yields, milk production and milk quality, El Tule, dry season end 2007.

	average DM yield (t/ha)	Milk production (lt/cow/day) (n=5)	Fat (%) (n=5)	Protein (%) (n=5)	Lactose (%) (n=5)	Total non-fat solids (%) (n=5)
Hyparrhenia rufa ("Jaragua")	0.7 (0.9)	3.14	6.39	3.34	5.02	9.12
Brachiara hybrid 36061 "Mulato"	1.2 (1.6)	3.14	6.52	3.42	5.08	8.98
Brachiara hybrid 36087 "Mulato II"	1.9 (3.1)	3.14	6.72	3.23	4.83	8.81
Brachiaria brizantha 26110 "Toledo"	1.8 (2.2)	3.14	6.28	3.26	4.89	8.90

within columns different superscripts (ab, pq) denote significant differences ($p<0.05$, $p<0.1$)
DM yields between brackets: total biomass including other pastures, legumes and weeds

The effect of the drought continued in the dry season, showing in general low pasture biomass availability. The only exception was Mulato II showing even a higher biomass production than in the rainy season, although without any effect on milk production and quality.

During the dry periods, the lack of effect on milk production despite the differences in dry matter availability was probably due to the limited genetic potential of the animals in the trials. Apart from this, Mulato II is the most promising introduced pasture, showing a significantly higher milk production during the rainy season and remarkable high biomass availability in the dry season after prolonged periods of drought.

Differences in live-weight gain and other production characteristics were not taken into account in these measurements. As yet no detailed information on nutritional value is available, but representative samples will be analyzed in the beginning of 2008.

Assessment of the effects of improved maize and sorghum fallows on milk production and quality during dry season

In 2007, a follow-up cross-over experiment to a similar experiment in 2006 was conducted in La Trinidad (Estelí) with three cows confirmed these results (Table 57). In comparison with traditional crop (maize) residues and crop residues with molasses, improved crop residues with *Lablab purpureus* increased daily milk production by 0.6 and 0.8 l respectively ($p<0.05$). There was also a positive effect on fat percentage, although not statistically significant.

Table 57. Effect of use of improved crop residues (with *Lablab purpureus*) on milk production and quality.

Treatment	Traditional crop residues	Crop residues with molasses	Improved crop residues
Milk production (l/day)	3.58[a]	3.31[a]	4.19[b]

within rows different superscripts (ab) denote significant differences ($p<0.05$)

These agronomic measurements, in combination with milk production and economic parameters, indicated that there is ample scope for improved fallows with herbaceous legumes, especially *Lablab purpureus*. In a similar experiment, in which Guatemala grass (*Tripsacum laxum*) was compared with sorghum residues in combination with cowpea (*Vigna unguiculata*), the latter performed relatively poorly, also when compared with maize residues with Lablab (Table 58).

Table 58. Effect of use of improved crop residues (with *Vigna unguiculata*) on milk production and quality.

Treatment	**Guatemala grass**	**Sorghum + cowpea**
Milk production (l/day)	3.33[b]	2.37[a]
Fat %	5.28	4.46
Density (g/l)	1030.85	1030.68
Lactose %	4.96	4.74
Total non-fat solids %	9.00	8.68
Protein %	3.29	3.20

within rows different superscripts (ab) denote significant differences ($p<0.05$)

How drought resistant high quality grasses changed a farmer's destiny: the case of Martin Joya, La Trinidad. (hoto 6).

Martin Joya started only two years ago trying out newly the introduced drought tolerant grasses *Brachiaria brizantha* 26110 “Toledo” and the *Brachiaria* hybrid 36061 “Mulato” and his life has already completely changed

Photo 6. Martin Joya with his cattle.

Mr. Joya’s main income used to come from making bricks as member of a cooperative with 15 other people. Besides this, he had two cows that produced milk, be it only during the rainy season and for household consumption. However, he had always been interested in animal production and when he met through his sister the INTA researcher José Antonio Molina, who was involved in CIAT projects aimed at improving feed availability and quality during the dry season, he took the opportunity to obtain some seed of the new drought tolerant grasses. The seed was just enough for 0.5 *Manzana* (0.35 ha). When after some months he started cutting the grass, he decided to make some money by selling his grass to livestock owners during the dry season when demand for animal feed is high: Toledo in the form of hay and Mulato as pasture. During a period of six months he managed to sell 500 bundles of Toledo hay of 5 C$ each and rent his Mulato pasture eight times during ten days for C$ 500 per period. His total earnings that season from selling hay and renting pasture were C$ 6000, more than he earned from brick making.

Partly from the earnings from the improved grasses he enlarged his herd from 2 cows to 25 heads (at the time of the interview: 5 cows, 8 heifers, 5 steers, 1 bull, 6 calves). Nowadays he derives his main income from animal production. In the rainy season he sells around 25-30 liters of milk per day (at 5 C$/l, with a maximum production of 8 l/cow/day) and even in the dry season he still manages to sell around 7 liters (at 7 C$/ltr). By transplanting he replaced most of his Toledo plot with Mulato (according to Mr. Joya more drought resistant) and his total area of “improved grasses” is now around 5 *Manzanas*, including a plot with the cut and carry grass *Pennisetum* spp. “Camerún”. Besides this, he has around 32 *Manzanas* of natural pasture in the hills, mainly with “Gamba”(*Andropogon gayanus*) and “Jaragua” (*Hyparrhenia rufa*) and if needed he hires more land. Apart from the milk, (male) calves are another important source of income. Mr. Joya estimates that he sells yearly around five animals at C$ 4500 each.

3.3 Cratylia silage as a supplement to maintain milk production during the dry season in Nicaragua

Highlight

- A daily ration of around 5 kg of Cratylia silage can substitute 3-4 kg of concentrates without any negative effect on milk production, whereas the variable costs of the Cratylia supplement is only 5-10% of the concentrates

Contributors: R. van der Hoek, M. Mena (INTA), A. Benavidez (INTA), J.A. Molina, A. Schmidt and M. Peters (CIAT)

Rationale

Feed shortage during the 5-6 months dry season severely limits livestock production and farm income in the subhumid areas of Central America. The Forage Program of CIAT has developed and promoted improved grass and legume species suitable for grazing, cut/carry systems and silage and hay production. In addition we have been working on adapting silage technologies to smallholder systems.

Experiments in the past years showed that a daily ration of around 5 kg of Cratylia silage substituting 3-4 kg of concentrates (basal ration: sorghum + *Pennisetum* spp. + molasses) did not have any negative effect on milk production, whereas the variable costs of the Cratylia supplement were only 5-10% of the concentrates.

<u>Experiment set-up</u>

In order to validate these findings and to determine the effect of Cratylia silage as a supplement to usual farmers' practices an on-farm experiment was established in Llano Redondo, Estelí. The treatments, based on the traditional ration consisting of grazing (of natural pastures) and supplements of "vaina de carbón" (*Acacia pennatula*), sorghum bran and sugar cane, were as follows:

1. Traditional ration + sorghum stover
2. Traditional ration + sorghum stover + cowpea (*Vigna unguiculata*)
3. Traditional ration + Cratylia silage
4. Traditional ration + commercial concentrates

A cross-over design was applied in which four cows rotated simultaneously between the four treatments during a period of eight days (three days of adaptation, five days of data collection). Milk production was measured at the time of milking (in the morning), when also samples were taken to determine milk quality (fat, protein, lactose and solids non-fat) using an automated appliance "Lactoscan".

Results and conclusions

Table 59. Milk production and quality, Llano Redondo, dry season 2007.

	milk production (kg/day/cow) (n=4)	fat (%) (n=4)	protein (%) (n=4)	lactose (%) (n=4)	solids non-fat (%) (n=4)
Traditional + sorghum stover	3.80[a]	2.35[a]	3.17[a]	4.75[a]	8.65[a]
Traditional + sorg. st. + cowpea	4.15[a]	2.25[a]	3.22[a]	4.84[a]	8.80[a]
Traditional + Cratylia silage	4.81[b]	1.82[a]	3.19[a]	4.72[a]	8.69[a]
Traditional + concentrates	4.91[b]	1.81[a]	3.21[a]	4.81[a]	8.76[a]

within columns different superscripts (ab) denote significant differences ($p<0.05$)

The results are presented in Table 59 and show the following:

- Both Cratylia silage and the concentrates increase significantly milk production (with up to one liter per day), but there is no difference between these two treatments.
- There is no significant effect of treatment on milk quality.
- Fat content is unusually low for all treatments. This is probably due to a combination of the genetic characteristics of the animals and the ration. The “Lactoscan” produced correct values when tested with known samples.

When compared to traditional rations, Cratylia silage increases milk production to the same extent as commercial concentrates without affecting milk quality. As already demonstrated by earlier research, costs are however lower (see annual report 2006). Therefore, this technology is a suitable option for small and medium farmers to maintain milk production during the dry season without the need to buy expensive concentrates.

3.4 Legume trade-off analysis: The dilemma to use it as forage to increase milk production during the dry season or for soil-enhancement to improve the productivity of maize and beans

Highlight

- 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

Contributors: Ruben Dario Estrada (CIAT), Marcela Quintero (CIAT), and Federico Holmann (CIAT-ILRI).

Objective

The objective of this study was to estimate the expected benefits resulting from the adoption of the legume *Canavalia brasiliensis* either as green manure to enhance soil fertility for increased maize and bean productivity, or as forage for dry season feeding to increase the productivity of milking cows in the hillsides of Nicaragua.

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 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 60.

Table 60. 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	$ 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	$ 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

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 (ie., 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

Table 60 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 intercroped 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 (ie., 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 (ie., potential of the system, Table 61), 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 intercroped 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.

Discussion

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 by the bean plant 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, which is 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 a beef genotype than milk.

Table 61. Annual income, use of labor, and land use obtained in each of the scenarios evaluated.

	Base line	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

Use 1. *C. brasiliensis* is adopted as Green manure
Use 2. *C. brasiliensis* is adopted as Forage

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

Highlights

- Green manure experiments with *Canavalia brasiliensis* were established to compare maize yields and N budget of maize-bean with maize-Canavalia rotations.

- When planted in maize fields, *Canavalia brasiliensis* increases milk yield of cows grazing maize stover.

Contributors: S. Douxchamps[2], R. van der Hoek[1], A. Benavidez[3], F. Humbert[2], I.M. Rao[1], E.Frossard[2], A. Schmidt[1], M. Mena[3] and A. Oberson[2].
[1] CIAT, [2] ETH Zurich , [3] INTA

Rationale

Due to population growth in the rural poor areas of the Nicaraguan hillsides, land use has been intensified in a way that adversely affects soil fertility. Crop and livestock productivity have therefore declined, leading to income decrease and food insecurity. Cropping is limited to two short and successive rainy seasons, and livestock suffers forage shortage during the following five months dry season. In this research the hypothesis is tested that the introduction of the underutilized and drought tolerant cover legume, *Canavalia brasiliensis* (Canavalia) into the traditional maize-bean-livestock system can overcome soil fertility decline and produce more dry season feed of better quality.

The main objectives are (i) to evaluate the productivity of the crop-livestock system when Canavalia is used as green manure or as dry season feed, (ii) to study nitrogen (N) fluxes under those two options and (iii) to identify environmental factors affecting the biomass production of Canavalia.

The experiments

In May 2007, six green manure trials and six livestock trials were established on smallholder farms in the watershed of Rio Pire (Condega, Estelí, Nicaragua). The farms are located at different altitudes, from 600 masl near the river to 900 masl on the hillside. Soil depths vary from 30 to 180 cm. Soil texture ranges from clay to sandy loam, with a pH of 6.5 (variation of 5%), mostly unstable structure (between 7 and 15% of water stable aggregates with a diameter superior to 2 mm) and little available water (5 to 15% of mesopores).

Green manure trials

The green manure trials aim to compare maize yields and the N budget of the maize-bean rotation with the maize-Canavalia rotation. Each trial consists of four treatments with a control, with three replicates in a completely randomized block design. Maize was planted during the first rainy season and in the maize plot Canavalia was planted during the second rainy season, with 100%, 75%, 50% or 0% of Canavalia biomass being removed during the subsequent dry season to simulate grazing. The control treatment represented the traditional maize-bean system, i.e. maize

during the first rainy season and beans during the second rainy season. Each plot measures 100 m^2, except on two farms where they are 70 and 64 m^2 due to the field dimensions. At each farmer, the blocsk were established differently due to the landscape conditions.
All farmers received the same maize seed (*Catacamas*), except one who had already planted another variety (*Nutrader*), and planted at the same density. Usual fertilizer rates were applied, ranging from 30 to 75 kg N/ha, with up to 17 kg P/ha and 10 kg K/ha.

For the second rainy season, bean (INTA seda rojo) and Canavalia (CIAT 17009) seeds were distributed to all farmers. No fertilization was applied.

Livestock trials

At each farmer 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 (Photo 8). Biomass and milk production and quality was measured.

Current status

Farmer participation has generally been successful. Most farmers show interest in Canavalia, especially those who have livestock.

Green manure trials

Samples of Canavalia, beans, maize and weeds were taken in November and December to be analyzed for N and ^{15}N, allowing for the calculation of the N budget for each plot and for the two raining season, using the formula:

Soil surface balance (kgN/ha) = $(N_{fertilizer} + N_{seed} + N_{fixed}) – (N_{harvested\ products})$

The inputs of the budget are the N from the fertilizer, the N from the seeds, and N_{fixed}, i.e. the amount of N derived from the symbiotic N_2 fixation by Canavalia and beans, which will be estimated using the ^{15}N natural abundance method (NA), with paired labeled weeds as references. The output is the N content in harvested products.
An essential parameter to calculate N_{fixed}, the isotopic fractionation during N_2 fixation or the ^{15}N natural abundance of a plant growing exclusively with atmospheric N, is currently determined in the greenhouse at CIAT-headquarters in Cali (Photo 7). Canavalia and beans are grown in 3-l free-draining pots filled with white sand (0.7 to 1.2 mm of diameter), and watered with N-free solution. A solution from fresh soil of Condega was used to induce the symbiosis with the naturally occurring rhizobial mixture in the trials. Plants will be harvested 40 (beans) and 90 days (Canavalia) after germination, separated into shoots and roots, and analyzed for total N content and ^{15}N natural abundance.

Internal recycling, i.e. N content in the different types of residues, will be evaluated as well. Changes in selected soil hydraulic properties (stability of aggregates, saturated hydraulic conductivity, water retention curves) will be monitored during the one year rotations.

Livestock trials

The data were analysed based on a cross-over design (with three groups of 3-5 cows (total 12) 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.

Planting of *C. brasiliensis* increased average biomass availability with almost a tonne per hectare and resulted in a significantly higher milk production ($p<0.05$). No effect was found on milk quality. Due to differences in lactation stage, differences between farmers were considerable (Table 62, Figure 67, Figure. 68).

Table 62. Biomass availability, milk production and milk quality, Santa Teresa (data based on three farmers).

	Total DM yield (t/ha)	Milk production (lt/cow/day) (n=12)	Fat (%) (n=12)	Protein (%) (n=12)	Lactose (%) (n=12)	Total non-fat solids (%) (n=12)
Maize residues and weeds (control)	3.1	2.86^{a}	5.12^{a}	3.20^{a}	4.80^{a}	8.71^{a}
Maize residues, weeds and *C. brasiliensis*	4.0	3.39^{b}	5.23^{a}	3.24^{a}	4.87^{a}	8.86^{a}

within columns different superscripts (ab) denote significant differences ($p<0.05$)

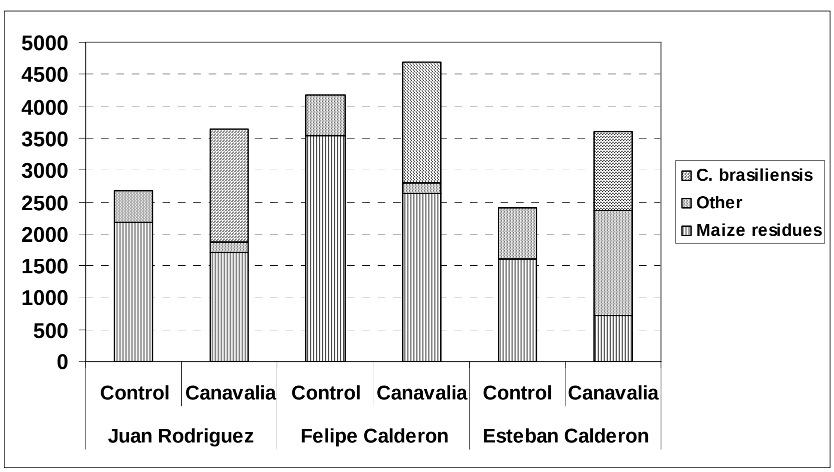


Figure 67. Biomass availability (t DM/ha) of plots without and with *Canavalia brasiliensis* in SantaTeresa (dry season)

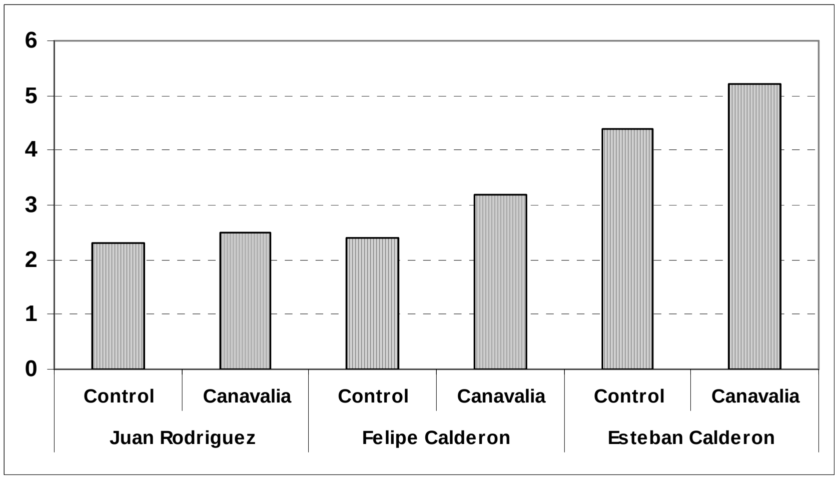


Figure 68. The effect of *Canavalia brasiliensis* on milk production (lt/cow/day), Santa Teresa (dry season)

Photo 7. *Canavalia brasiliensis* growing in sand culture with N-free solution

Photo 8. Cows grazing maize stover and *Canavalia brasiliensis* in a farmer's field

Conclusion

Canavalia increases available biomass and augments milk production in the dry season. The positive effect on milk production is recognized by the farmers and they show a clear interest in continuing with this new technology. In 2008 the first results of the green manure experiments will become available and provide more insight in the feasibility to include *Canavalia brasiliensis* in the maize-bean system of the hillsides of Central America.

3.6 Perspectives for forage work in Haiti

Contributors: R. van der Hoek, L. Eugène , A. Schmidt and M. Peters (CIAT)

Rationale

Based on former forage activities in Haiti and a request from Heifer Project International (HPI) for training and small-scale research with multipurpose forages two visits were made to Haiti in 2007.

1. Seminar on forages

From 13 to 16 November a seminar was held in Les Cayes in the Southern Province of Haiti, in close collaboration with the Haitian Ministry of Agriculture (MARNDR) in the person of Agr. Arlan Lecorps, forage expert. Themes were description of farming systems, problem ranking, establishment and management of pastures and legumes. The total number of participants was 24, representing 13 organisations. All intervention zones of HPI were represented (Sud, Nord, Petit Goave.

2. Perspectives

Some findings (based on the seminar and an earlier survey in April) are:

Technical aspects:

- Grasses: emphasis on training on management practices (e.g. grazing, cutting frequency). Another important aspect is the treatment / processing of seed (e.g. scarification). In general, local available species are suitable for the region.
- Legumes: in general, quite a wide variety of multipurpose species is available. Training of HPI project staff (including partners) and farmers is a first priority. Furthermore, the distribution of available species can be improved through local seed production. New promising multipurpose legumes like *Vigna unguiculata*, *Lablab purpureus* and *Canavalia brasiliensis* are to be tested in small demonstration plots for agronomic evaluations and participatory evaluation with project staff and farmers.

The activities would be based on a partnership between HPI, HPI's local partners and CIAT. CIAT would provide training, technical backstopping and (some) seed for the new species.

Proposed activities:

1. Inventory (diagnostic survey) of the intervention zones of HPI with different agro-ecological conditions leading to tailor-made proposals, including options for small ruminants and monogastrics.

2. Continued training on forages in the different intervention zones of HPI, integrating health, breeding (NB: inbreeding was mentioned as one of the most important constraints) and husbandry aspects.
3. Evaluation and demonstration plots (both agronomic and participatory with farmers) of forages with already proven potential. More specifically: local legumes and grasses as well as *Lablab*

purpureus, Vigna unguiculata, Canavalia brasiliensis, Cratylia argentea and *Brachiaria brizantha* “Toledo”.

4. Seed multiplication plots of legumes already present in the region: Cratylia, Mucuna, Clitoria, Siratro. At this moment, the availability of seed / vegetative material of grasses does not appear to be a limiting factor.

5. “Model” farms demonstrating improved farming practices (grazing, cut and carry, use of leguminous crops) and new options (forage species, forage conservation methodologies for periods of feed shortage). During the seminar it was proposed that SEED in Les Cayes would be a suitable organisation for this concept (staff, available area, livestock, perennial forages like Pennisetum, Brachiaria, shrubs like Gliricidia). Participants from the North mentioned other options around Cap Haïtien, Dondon.

6. Farmer seed production, to develop seed auto-sufficiency and an additional source of income.

7. Activities to improve the value chain of animal products, including pork and poultry.

3.7 Partnership in LAC to undertake evaluation and diffusion of new forage alternatives

3.7.1 On-farm evaluation of forage options in the Colombian Orinoquia (Llanos Orientales): Monitoring on-farm use of cvs. Mulato, Mulato II, *Cratylia*, and other forage options in the Colombian Llanos

3.7.1.1 Monitoring establishment and utilization of *Cratylia argentea* on Santana Farm, Puerto López (A. Durán)

Highlight

- *Cratylia argentea* seed, purchased from CIAT's Seed Unit, was sown to establish 20 ha on the Santana Ranch in the Llanos and is harvested with a cutter/chopper for inclusion into silage. This is the first case reported for mechanical harvesting of *Cratylia argentea* and one of the rare incidences known so for tropical legumes in general.

Contributors: A. Durán; D. Vergara; (CIAT) C. Plazas (UniLlanos); and J. Miles (CIAT)

Rationale

Dry-season feed deficiencies (both quantity and quality) limit livestock performance from December through March in the Colombian Llanos. The owner of the Santana Ranch has been seeking a forage plant that will allow economical production of "home-grown" protein, particularly during the dry season, to supplement grasses (Mulato, Mulato II, Maralfalfa, sugarcane). After considering several legume options, and trying several of them, including kudzu and cowpea, *Cratylia argentea* was chosen as the only option that offered the combination of strongly perennial growth, drought tolerance, reasonable feed quality, and the possibility of mechanized harvest.

Cratylia argentea may provide the basis of a viable production of high quality (crude protein content) forage either for conservation (as hay or silage) or to be fed as fresh cut forage during the dry season.

Materials and Methods

At the initiative of the Santana Farm owner (in fact, directly contrary to our recommendation to begin more modestly and expand gradually), 20 ha of C.a. were successfully established during 2007, under the direction of our Technician, D. Vergara.

Results and Discussion

Approx. 20 ha of *Cratylia argentea* were established from seed this year at the Santana Ranch. This probably represents one of the larger (if not <u>the</u> largest) planting of *Cratylia argentea* in Colombia. Following a heroic struggle with weeds in the early weeks, the planting was successfully established and harvest began in late November.

Serious weed problems in the establishment phase of the *Cratylia argentea* were encountered, owing to the enhanced fertility of the "altillanura" soils following several years of annual crop production. With technical assistance provided by our local technician (Daniel Vergara) the planting was successfully established and forage harvesting began in November.

On the Santana Farm (Puerto López) *Cratylia* is harvested with a cutter/chopper. The chopped forage is then included in silos ("bunker type") mixed with chopped napiergrass (cv. Maralfalfa) and sugarcane. This is the first case reported for mechanical harvesting of *Cratylia argentea* and one of the rare incidences known so for tropical legumes in general.

As of mid-January (2008), it seems that utilization of the entire 20-ha planting as harvested forage may not be achieved before flowering and seed production, providing the possibility of an opportunistic seed harvest from part of the 20-ha planting. This will be decided by the farm owner later in the season. I offered the services of our Seed Unit technician (A. Betancourt) for a couple of weeks in March if a decision is made to harvest seed, to organize harvest and initial seed processing.

3.7.2 On-farm evaluation of forage options in the Colombian Orinoquia: Monitoring on-farm use of cvs. Mulato, Mulato II, *Cratylia*, and other forage options in the Colombian Llanos

3.7.2.1 Monitor utilization of existing pastures of Mulato and Mulato II and the new expansion of area in Mulato II pastures with purchased seed, Santana Farm, Puerto López (A. Durán)

Highlight

- Approximately 130 ha of existing Mulato and Mulato II pastures were established in previous years by vegetative propagation. Eighty hectares of new Mulato II pastures were successfully established in 2007, for the first time from seed on the Santana Ranch.

Contributors: A. Durán; D. Vergara (CIAT); C. Plazas (UniLlanos); J.W. Miles

Rationale

High seed prices for Mulato II have inhibited adoption in the Colombian Llanos (and elsewhere in Colombia). One producer, the owner of the Santana Ranch, is a convinced believer in the merits of Mulato II (and Mulato), having several years experience with pastures established from vegetative material with very satisfactory results in terms of animal performance. He is developing intensive grazing management systems that warrant diffusion to other ranchers as use of Mulato II increases.

After analyzing costs and benefits of vegetative establishment vs. seeding, and with somewhat lower seed prices this year, a decision was made to purchase seed.

Materials and Methods

A. Durán began using cv. Mulato approx. four years ago, establishing 18 ha with vegetative material. He was impressed with animal performance on a three-paddock rotational grazing system, and continued planting Mulato. More intensive grazing management, with a larger number of pasture divisions, allowed higher stocking rates while maintaining individual animal liveweight gains. In 2005, we provided seed to establish a 4-ha area of Mulato II. A. Duran used this area as a source of vegetative propagating material. This year, for the first time, A. Duran purchased seed, was used established 80 ha of Mulato II pasture.

Four hundred kg. of Mulato II seed were purchased at something like Col$50,000 per kg. This represents an investment of Col$20 millions, or approx. US$10,000 -- about US$125 per hectare.

Results and Discussion

Establishment of the major portion of the planting was very successful. Shortage of moisture following planting caused somewhat erratic germination of the last, small area sown.

Grazing was initiated in November 2007. Using "discard cows" ("vacas de descarte"), liveweight gains on the order of 800-1,000 kg/head/day with 4 to 5 head per ha are being achieved on Mulato II pastures. Pastures are subdivided into 15 paddocks, grazed in a 3/42 day rotation. Since soils had previously been improved following several years of annual crop (maize/soy) production, existing Mulato II pastures have not needed maintenance fertilizer for the first two years of use.

The experiences on the Santana Ranch were documented in a 3-part television series produced by the Colombian network, RCN.

3.7.2.2 Monitoring of establishment and grazing of Mulato II on the Mata-Mata Farm, Puerto López (I. Soto)

Highlight

- Several areas were successfully established from seed sown in September and October 2007. Nearly 200 ha were prepared for sowing with the onset of rains, in April 2008.

Contributors: I. Soto (Ranch owner); E. Ulloa (Ranch Administrator); D. Vergara; C. Plazas (UniLlanos); J. Miles (CIAT).

Rationale

Don Isaac Soto is a very progressive rancher, being first an agriculturalist with a focus on the pasture as a crop. Following a visit to the Santana Farm (see above), he decided to establish significant areas of Mulato II and implement intensive rotational grazing as practiced at the Santana Farm.

Materials and Methods

Several areas, totaling about 40 ha, were sown in September and October 2007. Approx. 200 additional ha have been prepared for sowing during the coming rainy season, beginning in April 2008. All sowings have been with purchased seed.

Results and Discussion

The October area is still in the establishment phase, but probably could usefully be grazed (lightly) during the current dry season. The small September planting is currently (January 2008) being utilized, but without subdivisions.

We have expressed concern about apparently poor drainage conditions in parts of the plantings that might affect survival of Mulato II. I. Soto is confident that these can be dealt with by drainage within the pastures and diversion of water away from the pastures.

The idea is eventually to grow and fatten Brahman x Angus (F_1) animals on high quality, intensively grazed Mulato II pastures.

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

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

Highlight

- More than 850 kg of seed of 54 accessions of 16 forage species was produced in 2007. A total of 765 kg of seed were distributed. Seed of *Cratylia argentea* accounted for more than 60% 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.

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 852.14 kg of seed of 16 forage species was produced in 2007 (Table 63). An additional 421 kg of seed of *Vigna* spp. was produced. Just over half of the forage seed produced (433.09 kg) was seed of *Cratylia argentea*.

Table 63. Forage seed produced during 2007, by species.

Genus	Species	Accessions	Harvest
Brachiaria	*brizantha*	9	62.100
Brachiaria	*decumbens*	1	3.100
Brachiaria	*humidicola*	4	12.400
Brachiaria	*lachnantha*	1	2.300
Brachiaria	*ruziziensis*	1	8.600
Brachiaria	sp.	1	.400
Calliandra	*calothyrsus*	1	.250
Canavalia	*brasiliensis*	10	62.800
Canavalia	sp.	5	30.900
Cratylia	*argentea*	7	433.090
Desmodium	*heterocarpon*	1	35.000
Desmodium	*velutinum*	6	14.300
Lablab	*purpureus*	3	68.500
Leucaena	*diversifolia*	1	.400
Leucaena	*leucocephala*	2	83.000
Mucuna	*pruriens*	1	35.000
Total: 8	16	54	852.140

Over 765 kg of seed of 16 forage genera were distributed in 260 samples to five different countries (Tables 64 and 65). The vast majority of seed dispatched (in excess of 99%) was to destinations within Colombia.

Table 64. Distribution of forage seed during 2007, by genus.

Genus	Samples	Kg
Arachis	4	10.3000
Brachiaria	19	2.5800
Cajanus	3	1.2000
Calliandra	6	.4860
Canavalia	23	36.8800
Centrosema	15	10.4850
Clitoria	4	.1500
Cratylia	77	475.8600
Desmodium	25	56.9750
Flemingia	8	.2120
Lablab	22	50.7200
Leucaena	45	116.5630
Mucuna	1	.1000
Panicum	2	.9260
Pueraria	5	1.6000
Stylosanthes	1	.0640
Total: 16	260	765.1010

Table 65. Forage seed distribution during 2007, by recipient country.

Country	Samples	Kg
Colombia	249	762.2010
Ethiopia	2	.2000
Kenya	4	.6000
Namibia	4	.1000
Saint Lucia	1	2.0000
Total: 5	260	765.1010

3.9 Promotion of seed multiplication in Central America

Rationale

The adoption of forage technologies is intimately related to the availability of good quality seed at reasonable prices. Therefore, taking into account the current seed market in Central America, the promotion of seed supply systems with a focus on farmer-led enterprises is one of our strategies for scaling up selected forage technologies. At the same time, seed production offers a means of income for small farmers.

Forage seed production for Nicaragua

Contributors: A. Schmidt, R. van der Hoek (CIAT); M. Mena (INTA) and M. Peters (CIAT)

In San Dionisio in the Matagalpa department four farmers produced 576 kg seed of *Canavalia brasiliensis*. One of them already started in 2005 and produced 60 kg in 2006. This same farmer extended his area to 0.3 ha and produced more than 300 kg this year. The other farmers all planted 0.15 ha (Table 66).

Table 66. Seed production of *Canavalia brasiliensis* in 2007.

community	farmer	area (ha)	production (kg)
Susuli Central	Matilde Zamora	0.15	58
Susuli	Juan Hernandez	0.30	311
San Ramón	Clark Davies	0.15	171
Los Limones	Migdonio Campos	0.15	37
Total		**0.85**	**576**

In the coming year (2008), seed production will dedicate more emphasis in the collaboration between CIAT and the national agricultural research institute in Nicaragua (INTA – Instituto Nicaragüense de Tecnología Agropecuaria).

In Condega, department of Estelí, farmers participating in an ETH-CIAT-INTA research project on the trade-offs of the use of *Canavalia brasiliensis* as a green manure or for improved crop residue grazing have already expressed their interest in producing seed to extend their areas and sell seed to other interested farmers. As a spin-off of this work, INTA will take the lead in validating *C. brasiliensis* on other sites leading to its release for a wider use by farmers.

Furthermore, initiatives have started to revitalize the collaboration agreement with Papalotla. In a first stage, emphasis will be put on the validation of the *Brachiara* hybrid 36087 “Mulato II” and improving its availability for especially small farmers, using efficient distribution channels guaranteeing reasonable prices.

3.10 Assessment of the potential of three tanniniferous shrub legumes to improve ruminant nutrition in the tropics compared to legumes free of tannins

Highlights

- Calliandra and Flemingia were in general superior in DM yields on the oxisol and in the dry season while *L. leucocephala* did not grow on the oxisol but performed best on the mollisol.
- There were striking differences in plant composition between soil types which might influence also their potential use.
- Cratylia met mineral requirements of ruminant livestock best.

- The yield of ruminally available N seems to be generally higher with non-CT legumes due to the negative CT effects on ruminal protein availability in Calliandra and Flemingia.

Contributors: T.T. Tiemann (ETH Zurich), L.H. Franco (CIAT), C. Plazas (CIAT), M. Peters (CIAT), C.E. Lascano (CIAT), E. Frossard (ETH Zurich), M. Kreuzer (ETH Zurich), and H.D. Hess (ALP Posieux)

Rationale

Digestibility of shrub legume leaves with potential as protein supplement might vary depending on the planting site due to type and concentration of secondary metabolites and chemical composition of the plants. Experiments carried out during 2004 and 2005 indicated that forage quality of tanniniferous shrub legumes could be improved by the selection of appropriate planting sites or by improving the growing conditions (e.g. by fertilization). The present activity concentrated on defining the actual utility of five promising shrub legumes with and without condensed tannins (CT) depending on their cultivation conditions and the extent planting site and fertilization affects differences in forage quality, and type and concentration of condensed tannins. For this purpose, experimental plots were established at two contrasting sites in Colombia. The aim of this activity was to identify if growing conditions could contribute to an improved forage quality of tanniniferous legumes and make them a viable protein supplement for ruminant nutrition.

Material and Methods

In Experiment 1, the shrub legume species *Cratylia argentea* (CIAT 18516), *Calliandra calothyrsus* (CIAT 22310), *Desmodium velutinum* (CIAT 33443), *Flemingia macrophylla* (CIAT17403) and *Leucaena leucocephala* (CIAT 17502) were raised in Jiffy™ pots and after 6-7 weeks transplanted to the plot in May 2004 at the beginning of the rainy season on a Mollisol (fine silty, mixed, isohypothermic, Aquic Hapludoll, pH: 7.5, rainfall is bimodal, average annual precipitation: 896 mm; mean annual temperature: 24.3°C) at CIAT's headquarters in Palmira and on an Oxisol in Matazul (typic isohipertermic Caolinitic Haplustox, pH 4.5, low natural fertility (in particular deficient in P, basic compounds and organic matter); rainfall is unimodal, annual total: 2251 mm (April-November); annual mean temperature: 26°C) in the Eastern Plains of Colombia, and two levels of fertilization were applied (low fertilization level [kg/ha]: 20 P, 20 K, 500 lime, 10 S; high level: 50 P, 60 K, 1000 dolomite, 40 S) in order to assess the effect of fertilization as affected by soil type.

The five legume species were transplanted in three replicates per site and fertilizer treatment, and arranged in a randomized complete block design. One year after transplanting the first standardization cut was carried out, with cutting heights of 100 cm for *Leucaena leucocephala* and of 50 cm for the remaining species. Since then the plants have been cut every 9 weeks and one sampling has been carried out. Prior to sampling, the number of surviving plants and their growth performance were assessed visually. In order to determine the feeding value, edible forage (branches up to 1cm diameter) from actively growing shoots was collected from five randomly chosen plants from every legume species per fertilizer level and replicate.

To assess dry matter production, plants were cut as described above and the harvested material was separated into leaves and stems. Samples for quality analyses were packed in plastic bags stored on ice and transported to the laboratory. Subsequently the samples were kept frozen at –20°C until freeze-drying. Dried samples were ground in a laboratory mill to pass a 1-mm screen and stored in air-tight containers at –20°C. Plant tissues were analyzed for N, P, Ca, Na, K, Mg, S, Mn, Zn, Al, B, Cu, Fe, and the concentration of condensed tannins and *in vitro* digestion dynamics of the possible supplements (by the gas transducer technique, GTT) were determined.

Results and Discussion

Contents of N and fibre (NDF and ADF) were affected ($P < 0.05$) in most of the experimental species by the planting site. In the non-CT plants (Cratylia, Desmodium), N content was higher ($P < 0.001$) on the oxisol than on the mollisol. In Calliandra and Flemingia, N contents remained unaffected by site and NDF as well as ADF contents (the latter only in Calliandra) were lower ($P < 0.05$) on the oxisol. Significant seasonal effects were only found in fibre but not in N content of the experimental plants, and season effects were larger on the mollisol than on the oxisol. Fertilisation had only a minor effect on N and fibre contents. Plants growing on the mollisol presented higher mineral concentrations as those grown on the oxisol.

The amounts of Ca, P, Mg, K and S recovered in the plant material harvested were most intensively influenced ($P < 0.001$) by site being much lower on the oxisol, which was the result of both lower biomass yields and mineral concentrations.

Biomass yield (DM and organic matter (OM) grown during the 9-week intervals between harvests) of all legume species was clearly higher ($P < 0.001$) on the mollisol than on the oxisol, and Leucaena did not even reach the cutting height on the oxisol, and plants were feeble or even died after some month. Biomass yield of Cratylia, Desmodium and Calliandra was higher ($P < 0.05$) in the rainy than in the dry season, while this was not the case for Flemingia and Leucaena. Fertilisation in general only increased DM yield of Desmodium. The maximum biomass yields (DM plant^{-1}) reached 500 g in Leucaena, while the yield in the majority of the other species ranged between 150 and 300 g on the mollisol and between 15 and 180 g on the oxisol.

Calliandra had the highest contents of extractable and total CT among the three CT species. The amount of total and extractable CT was higher ($P < 0.01$) in Flemingia grown on the oxisol than on the mollisol. In Calliandra, site effects approached ($P < 0.1$) significance for both extractable and bound CT, but changes were partially compensatory, leaving total CT quite similar on both soils ($P > 0.1$). Fertilisation did not affect ($P < 0.05$) the CT contents of most species. There were no interactions between site and fertilisation.

The GTT incubations showed that the planting site affected most variables resulting in a lower gas production, a larger time at point of inflection and a lower dry matter degradability for plants grown on the oxisol. In Desmodium and Calliandra, the proportion of dietary N remaining undegraded after 144 h of incubation was higher ($P < 0.05$) on the oxisol, while this was not the case in Cratylia and Flemingia. The addition of the CT-inactivating substance PEG increased ($P < 0.05$) gas production and degradation of dry matter and N-containing compounds in the CT species, while it had no or a much smaller effect on the fermentation characteristics of Cratylia and Desmodium. Consequently, there were various interactions of PEG and site in the tanniniferous species as PEG addition reduced the site effects suggesting that the site effects were at least partially mediated through differences in CT-related properties. The site × fertilisation interaction demonstrated that total gas production was decreased in Cratylia, Desmodium and Calliandra cultivated on the mollisol and increased on the oxisol with the high level of fertilisation. Again, PEG addition reduced fertilisation effects within site in the CT species (visible also from several significant three-way interactions).

Concerning the plants' yields of ruminally degradable N sources, at the mollisol Leucaena was clearly superior to all other species. The other non-CT species were yielding about one third to half of that and Flemingia and especially Calliandra, where CT largely inhibited ruminal N degradation, provided very low to zero degradable N. On the oxisol, Cratylia and Desmodium were still superior to Calliandra and Flemingia in degradable N yield.

In summary, the results indicate that in the majority of the cases, the CT-related limitations were facilitated by unfavourable environmental conditions, but sometimes also by fertilisation. One exception is Leucaena, but its use is limited to low-acidic soils. In conclusion, the CT species evaluated appear to be less suitable even on oxisol than the non-CT species, despite generally higher yields. Still, at certain unfavourable soil and climatic conditions CT-legumes might represent a feasible option.

3.11 Research and development of multipurpose forage legumes for smallholder crop-livestock systems in the hillsides of Latin America

Highlights

- Successful participatory procedure for evaluating green manure legumes has been developed
- Capacity building that links on-station and participatory research has been established
- Seed multiplication plots have been established in smallholder farms
- Green manure technology to improve traditional maize systems is economically viable

Contributors: Luis Alfredo Hernández R. (CIAT), María Consuelo Tabares Cuartas (CORPOICA), Belisario Hincapié, Luis Horacio Franco, Michael Peters (CIAT), Jairo Ramírez Rojas, Gustavo Acosta Herrera (CORPOICA), Rainer Schultze-Kraft (University of Hohenheim)

Rationale

An effective strategy of forage technology improvement addresses the production constraints in the target areas, incorporating participatory research to generate desired technology characteristics and to offer new technologies to the intended users for further adaptation and innovation. A technology with forage legumes as green manure, when generated by conventional means, is likely not going to solve farmer and livestock problems unless combined with other approaches like farmer participation. Thus, in this study we integrate soil fertility management and (multipurpose) forage legumes with participatory tools. The role of a participatory support consists mainly in developing methods for participatory techniques and in capacity building.

It is hypothesized that farmers and researchers working together will be able to identify forage germplasm options for hillsides in Colombia, in particular legumes, to enhance sustainability of agricultural production systems in such areas, primarily through the improvement of animal production (milk and meat) and resource conservation such as erosion control and improvement of soil fertility. Their versatility allows forages to be used in different ways in the complex production systems of the tropics. Thus, most forages, in particular legumes, have direct effects on crop production including weed suppression, pest and disease reduction; indirect effects include their use as green manures, improved fallows, cover crops, and live barriers.

3.11.1 Participatory evaluation of green manure

Methodology

A participatory evaluation was conducted on 20 January 2007 at the finca El Rosal, municipality of Caldono, Cauca, to assess the effect of green manure species on a subsequent maize crop. Using preference ranking and open evaluation methods, a total of 9 farmers from the village of Pescador were interviewed (6 male and 3 female farmers). The information was gathered via participatory discussions in three groups, composed of 3-4 farmers and 1 facilitator (technician).

Spontaneous responses regarding farmers' criteria in evaluating maize were recorded. Multivariate analysis was then employed to identify criteria of high importance in relation to the maize crop.

Results

Results indicate that according to farmers' assessment of the maize crop, grain yield, plant height, stem diameter and leaf color (from high to less importance respectively) are the criteria more important for farmers to evaluate the effect of legumes as green manure. Thus, plots where cowpea (*Vigna unguiculata* 9611) and canavalia (*Canavalia brasiliensis* CIAT 17009) were established, showed evident and positive effects on a subsequent maize crop (based on the criteria aforementioned).

Regression analysis revealed diverse ranges of acceptance and rejection in relation to the green manure effect on the maize crop (Figure 69). It seems that fallow ("rastrojo") did not have a green manure effect on the subsequent maize. So, it was consistently rated as having low acceptance (last in the ranking,); canavalia had the highest acceptance followed by cowpea. Lablab had intermediate acceptance. The high level of canavalia acceptance probably is due to the biomass volume reached by this species .

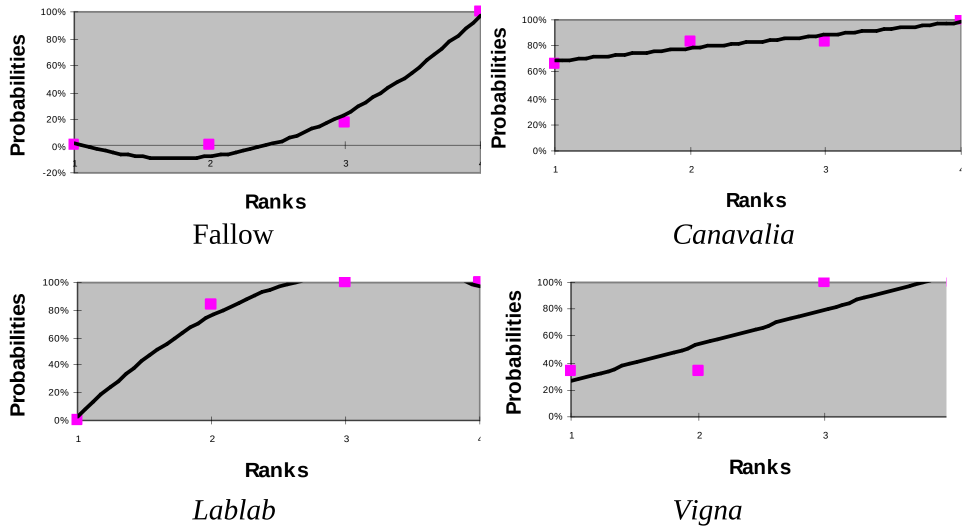


Figure 69. Acceptance tendency of three green manure legumes and fallow

3.11.2 Strategic seed production of farmer selected legumes

Methodology

Three forage legumes, *Vigna unguiculata* 9611, *Lablab purpureus* CIAT 22759 and *Canavalia brasiliensis* CIAT 17009 had been selected by farmers. They were sown for seed multiplication in five different locations at different altitudes in the Cauca department: two sites in Cajibío, one in Morales and two in Piendamó (Table 67). Planting distance was 0.5 x 0.25 m, 2 seeds were planted per site, and fertilization was 320 kg/ha triple superphosphate.

Table 67. Sites for forage legume seed production.

	Site (municipality and vereda)				
Farm	Cajibío (La Venta) Luna	Cajibío (Cenegueta) Rosalinda	Morales (Las Mercedes) La Grandezza	Piendamó (El Mango) San Isidro	Piendamó (El Mango) La Hacienda
Owner	Julieta Guerrero	Juan P. Morales	Narriman Leyva	Marco Tombé	Nelson Vivas
Location	N 02° 35’ W 76° 33’	N 02° 36’ W 76° 36’	N 02° 40’ W 76° 33’ ’	N 02° 45’ W 76° 32’	N 02° 45’ W 76° 34’
m.a.s.l.	1.880	1.795	1.782	1.632	1.627

In Table 68 seed production so far obtained is presented. Many plots are still in process of flowering or seed formation; in some cases drought affected establishment and/or seed production.

Table 68. Seed production at sites selected with farmers.

	Farm				
	Luna	Rosalinda	La Grandezza	San Isidro	La Hacienda
Vigna unguiculata					
Area planted m^2	1.000	1.000	1.000	800	500
Seed yield kg/ha	488	n.a.	905	1.281,250	n.a.
Lablab purpureus					
Area planted m^2	1.000	1.000	1.000	600	500
Seed yield kg/ha	272	n.a.	678	n.a.	n.a.
Canavalia brasiliensis					
Area planted m^2	1.000	1.000	1.000	1.000	500
Seed yield kg/ha	No seed production	n.a.	No seed production	n.a.	n.a.

n.a. – not available

3.11.3 Economic and environmental effect of green manures in smallholder farms in the hillsides of Cauca, Colombia

Methodology

The economic and environmental effect of green manures was analyzed comparing results with and without intervention. The effects of technology adoption on production costs, crop yields, and the environment are estimated, with the anticipation that positive effects on livelihoods of smallholder farmers are achieved.

Results

In Table 69, costs for maize production comparing the traditional system with a system including legume green manures are presented (values in 1,000 COP (Colombian pesos), 1 US $ = approx. $ 2,000 COP).

Table 69. Costs and benefits of inclusion of green manures in maize production.

Parameter	Without green manure	With green manure	Difference
Labour	615,000	720,000	+105,000
Supplies incl. fertilizers	352,700	209,800	-142,900
Subtotal	967,700	929,800	-37,900
Cost for green manure production	0	931,068	
Total costs	967,700	1.860,868	+893,168
Maize yield (kg/ha)	1,500	3,100	1,600
Income from maize production	1.200,000	2.480,000	+1.280,000
Benefit	223,300	611,132	+386,832

With the inclusion of green manures, production costs per ha were higher, due to additional costs for the production of green manures and their incorporation into the soil. A biological nitrogen fixation through the green manures of 70 kg/ha per crop cycle is assumed, reducing the need for fertilization and weeding. The utilization of the legumes for human nutrition is not included in this analysis but could provide additional benefits. On the other hand, maize yield increased from 1,500 to 3,100 kg/ha, providing higher income.

4. *Ex ante* analysis of green manure adoption

To estimate the social and economic impact of green manure technology adoption, an initial adoption of 5% of farmers is assumed for 2008 (end of the current project), reaching a maximum of 30% in 2017. The net benefit for the inclusion of the green manures compared to traditional maize production is calculated at COP 386,832/ha (see Table 69). The net benefit is now multiplied with the increase in area based on the above estimation of the adoption estimates. Over the 20 years projected, the net benefit of green manure adoption is thus estimated at COP 3.973,700,000 or US $ 1,986,850. , which is equivalent to the benefits of adopting farmers for 25 years (based on 2008 peso values). The internal rate of return is estimated at 61.9%, which means that for every COP 100 invested in research, there is a gain of COP 62 annually for maize producers.
Based on the above estimations, it is expected that by 2017, 4,844 farmers will have adopted the technology, assuming that each farmer cultivates 1 ha of maize annually. In addition, there is a positive effect on employment generation due to the labor costs for the green manure cultivation, increasing from 47 to 666 between 2008 a 2017, assuming the need of 33 man days per ha and 240 yearly working days.

3.12 On-farm evaluation of forage options in Norte del Valle del Cauca, Colombia

Contributors: C.V. Durán (Universidad Nacional de Palmira), L. M. Ocampo, M. Carvajal (Secretaría de Agricultura y Pesca del Valle), M. Valderrama (Instituto Técnico de Roldanillo, INTEP), farmers group, J.I. Roa, L.H. Franco and M. Peters (CIAT)

Rationale

The Norte del Valle of Colombia is an important livestock area. However forage options available to livestock holders are limited and hence restrict productivity of livestock operations. Through a participatory approach we aim to define and adapt forage technologies suitable to smallholder production systems to improve livelihoods of farmers.

Material and Methods

Forage technologies developed with farmers include germplasm options and forage conservation technologies. A participatory process is followed facilitating adaptation, innovation and adoption by farmers. The main collaborators in the process are the farmer group, the Universidad Nacional de Palmira, the Instituto Técnico de Roldanillo (INTEP), the Secretaría de Agricultura y Pesca del Valle del Cauca, the cooperative of farmers COGANCEVALLE y SENA.

Initially, in 2004, the main beneficiaries of this work were a group of farmers (30) from the municipality of Roldanillo; currently the work has been expanded to 5 groups in 5 municipalities in the Norte del Valle del Cauca (Roldanillo, Bolívar, El Dovio, Versalles and Sevilla) (Photo 9). In 2006 has been expanded to municipally of Buga Tulúa, Zarzal and Dagua reaching directly 300 farmers, and indirectly others 300 farmers. Altitudes in the 8 municipalities range from 1000 to 2000 m.a.s.l., representative of the variable environments in the region.

Participatory approach and process

From the onset, a participatory approach was employed, in order to understand farmers demands and livestock systems, with the aim to select and co-develop different forage alternatives suitable to the prevalent farming systems**.**

Participatory diagnosis

In each of the 9 municipalities a participatory diagnosis was carried out to identify opportunities and constraints of livestock holders. The methodology employed used a group brainstorming approach, with farmers further stratifying and prioritizing opportunities and constraints through an individual votation process.

Farmer cross visits and visits to on-station trials further supported the process through exposure to new technologies and sharing of experiences with technicians and farmers.

Experiments

Eight experiments were established in five municipalities, representing different climatic (altitudes between 1000 and 2000 m) and edaphic niches. At each site, 18 multipurpose forages were sown. These experiments were used for the participatory selection of forage technologies and lead to further on-farm testing. The innovation and adoption process is accompanied by training in pasture establishment and management, artesanal production of seed as well as on the utilization of hay and silages. The training is supported by extension type publications.

Photo 9. Farmer training in utilization and management of pastures and forage conservation

Results and discusión

During the time of the on-farm evaluation more than 50 technical field vists with farmers to follow up advances in the participatory evaluation in both rainy and wet seasons were done in the nine participating municpios. Grasses were most widely adapted, with largest differences in locations for *Panicum* and B. d*ictyoneura*. Amomng the herbaceous legumes across environments *Canavalia* was the most widely adapted, followed by *Centrosema*, *Arachis*, *Desmodium* and *Clitoria;* among the shrub legumes all species including *Cratylia*, *Leucaena* and the local check *Tithonia diversifolia* (Botón de Oro) were adapted.

For the selection of forages, farmers identified the following criteria as most important, in this order: Palatability, colour, forage on offer, low soil fertility adaptation, drought tolerance, pest and disease tolerance, organic matter production, cover (aggresivity)m rooting capacity, persistence and adaptation to a wide range of altitude and soil fertility

In addition, field days an training events were held, to further disseminate the information obtained, with a total of more than 500 farmers participating

Based on farmer selection of forages, larger plots of 1 ha to 10 ha were established, with cost for establishment being shared with farmers, i.e., half of the seed were paid by farmers. (photo 10) The materials selected by farmers include: *Brachiaria* híbrido cv. Mulato, Mulato 2, *B. brizantha* cv.*Toledo, B.* d*ictyoneura*, *Cratylia*, *Leucaena*, *Vigna* and *Lablab*). So far more than 10 ha of improved forages were established, with *Centrosema molle* and *Canavalia brasiliensis* now being added to the list of preferred forages. Furthermore seed banks of the selected forages were established in each municipio and by now another 200 ha were planted by farmers using their own resources.

Photo 10. Farmer field visits to semi comercial forage plots in Roldanillo, Norte del Valle del Cauca.

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

Contributors: Mupenzi Mutimura (ISAR, Rwanda)

1. Conduct exploratory diagnosis/assessment of current forage use patterns in target area: Rwanda

This is a brief report on progress on participatory evaluation of forage options in Rwanda from the BMZ-GTZ funded 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*".

Photo 11. Farmer Joseph in his Napier grass plot and his cows

Farmer selection: The selection of farmers was done in conjunction with local extension personnel, by targeting farmers that are seeking for new forage options for an intensive management system. Two areas were selected, the Bugasera and the Gikongora districts, differentiated by intensity of drought and altitude. The most common forages encountered were Napier grass (*Pennisetum purpureum)* and the fodder tree *Calliandra spp.* Most farmers possess only 1 to 5 cows, supported by government policy and different NGOs providing improved livestock and artificial insemination to improve the genetic base of the animals (photo 11,12,13).

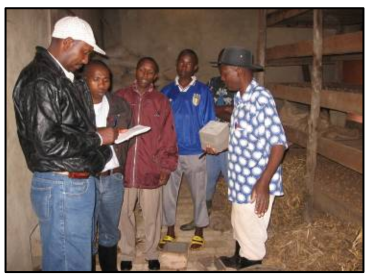


Photo 12. Joseph makes himself feed supplement

Photo 13. Farmer Bigirumunsi Emile at Nzega cell with his cow and Napier grass plot

2. Feeding calendar Development

During wokshops with farners, the availability and utilisation of feeds throughout the year was defined using feed calendars. Table 70 shows results on ranking of feed resources in Bugesera according to farmer criteria.

Table 70. Animal feeds and farmers' reasons/criteria for selection of the feed resources in Bugesera.

Criteria Feeding system	availability	Palatability	Stomach fill	Easy to cut	Increase milk yield	Soil fertility and drought adaptation	Easy to store	coppice	Score	Rank
Napier	19	19	19	19	4	19	6	19	124	1
Sweet potato vines	7	18	4	17	9	6	0	4	65	2
Natural grass	11	11	11	10	9	1	0	9	62	3
Maize stover	3	18	13	13	12	0	0	0	59	4
Tripsacum	6	9	8	10	3	3	1	8	48	5
Banana stems	8	8	6	10	0	14	0	0	46	6
Setaria	7	11	0	16	0	1	1	3	39	7
Bean residue	20	11	0	0	2	0	6	0	39	8
Sweet potatoes	3	14	0	0	5	5	0	0	27	9
Fucus	8	6	0	0	4	6	0	2	26	10
Mucuna utilis	0	5	1	5	5	3	0	1	20	11
Albizia amygdalina	4	7	0	0	3	0	0	0	14	12
Cabedge leaves	0	3	0	1	0	1	0	1	6	13

Napier grass was the most preferred feed, followed by sweet potato vines, native or naturalized grass and maize stover. The ranking confirms the perception that Napier grass is a major fodder crop used throughout Rwanda. The criteria for farmers to choose Napier include its forage availability throughout the year, palatability, low soil fertility and drought adaptation, stomach fill, easy handling for cutting and good regrowth. Many farmers were not sure which forage option may result in higher milk yields.

Preferences of farmers for different forages are differentiated according to season (Table 71). In the wet season Napier, native grass, sweet potato and bean peelings are the feed resources mostly used, while in the dry seaoson mostly banana stems, napier and native grass are used.

Table 71. Typical Matrix Scoring of Feed resources by Farmers in Bugesera

Feeding system	Wet season (%)	Dry season (%)
Napier	100	70
Sweet potato vines	85	40
Nativel grass	100	60
Setaria	35	5
Tripsacum	30	10
Fucus	5	45
Albizia amygdalina	0	35
Maize stover	35	0
Bean peelings	70	0
Cabedge leaves	5	5
Sweet potatoes	20	15
Mucuna utilis	15	15
Banana stems	0	80

In Nyamamagabe, *Comelina bengalensis* is the feed resource receiving the highest rank by the farmers, indicating the shortage of feed resources in the area. Napier, maize stover , Panicum, Albizia and sweeet potatao are the other feed resources used by farmers. However due to lower availability of feed, a wider range of feed resources with equal importance is employed (Table 73)

Table 72. Animal feeds and farmers' reasons/criteria for selection of the feed resources in Nyamagabe.

Criteria / Feeding system	Availability	Palatability	Stomach fill	Easy to cut	Increase milk yield	Soil fertili ty and drough	Easy to store	Coppice	Score	Rank
Napier	10	10	10	0	1	10	0	10	51	2
Tripsacum	1	6	6	7	0	0	0	0	20	17
Panicum	10	7	7	7	6	0	0	10	47	4
Cooking banana peelings	4	7	0	5	0	6	0	0	22	15
Rice bran	3	3	3	0	3	3	3	0	18	18
Rice straw	3	3	3	3	0	3	3	3	21	16
Maize stover	10	10	10	10	10	0	0	0	50	3
Sweet potato vines	5	7	3	10	4	10	5	0	44	6
Mucuna utilis	2	2	2	2	2	0	0	0	10	20
Natural grass	7	7	5	6	7	0	0	10	42	7

Continues…

Table 72. Animal feeds and farmers' reasons/criteria for selection of the feed resources in Nyamagabe.

Criteria **Feeding system**	**Availability**	**Palatability**	**Stomach fill**	**Easy to cut**	**Increase milk yield**	**Soil fertility and drought tolerance**	**Easy to store**	**Coppice**	**Score**	**Rank**
Banana stems	7	7	6	3	0	10	0	0	33	11
Fucus	6	1	0	10	0	10	0	10	37	8
Albizia amygdalina	10	6	0	10	0	10	0	10	46	5
Commelina bengalensis	7	8	10	10	8	10	8	0	61	1
Suckers of Sorghum	1	10	1	10	6	3	0	3	34	10
Bean peelings	0	10	6	7	6	0	0	0	29	13
Leacena sp	6	4	0	6	6	7	0	6	35	9
Calliandra sp	2	4	0	7	4	10	0	5	32	12
Banana peelings	3	7	4	7	7	0	0	0	28	14
Beer sorghum residues	3	3	3	3	3	0	0	0	15	19
Banana beer residues	2	4	0	0	0	0	0	0	6	21

In contrast to Bugesera, in Nyamagabe bean peelings are used mostly in the dry season. In this drier environment Napier and other grasses are mostly used in the wet season while crop residues and fodder trees are used throughout ther year (Table 73).

Table 73. Typical Matrix Scoring of Feed Sources by Farmer in Nyamagabe

Feeding system	Wet season (%)	Dry season (%)
Napier	50	25
Tripsacum	50	0
Panicum	50	15
Cooking banana peelings	50	50
Rice bran	15	15
Rice straw	15	15
Maize stover	15	25
Sweet potato vines	20	35
Mucuna utilis	10	0
Natural grass	50	0
Banana stems	50	50
Fucus	50	50

Continues…

Table 73. Typical Matrix Scoring of Feed Sources by Farmer in Nyamagabe

Albizia amygdalina	50	45
Commelina bengalensis	50	50
suckers of Sorghum	0	25
Bean peelings	0	50
Leucaena sp	35	35
Calliandra sp	50	50
Banana peelings	25	25
Beer sorghum residues	20	20
Banana beer residues	15	15

3. On – farm evaluation of Brachairia spp.

A total of 8 *Brachiaria* grass options with 3 local checks were established at Karama research station, and were used as vegetative material for on-farm participatory trials: 18 in Bugesera region (drought) and 12 in Nyamagabe (Gikongoro) region (Al-toxic acid soil) (Photo 14)Most Brachiaria species established very well across sites, however to extended drought some replanting was needed (Figure 70).

Mulato 2	Mulato	BR02NO /04565	B d Basilisk	B d local
B b Toledo	BR02NO /1485	B b Marandu	BR02NO /1452	*Cenchrus ciliaris*

Figure 70. Establishment of *Brachiaria* spp in Gikongoro.

Photo 14. Farmers in Gikongoro observe *Brachiaria* in one farm of their neighbor.

Annex

List of publications 2007

Articles in Refereed Journal

Abello, J. F.; Kelemu, S.; Garcia, C. 2007. *Agrobacterium*-mediated transformation of the endophytic fungus *Acremonium implicatum* associated with *Brachiaria* grasses. Mycological Research (in press)

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Holmann, F. and Tiemann, T. Costs and benefits of supplementing milking cows with legumes during the dry season in the hillsides of Nicaragua. Journal of Livestock Research for Rural Development (submitted).

Kelemu, S.; Fory, P. 2007. *Brachiaria* plant growth enhanced by endophytic bacteria containing *nif*H gene sequences. Phytopathology 97: S55.

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Franco, L. H.; Calero, D.; Ávila, P. (2007). Alternativas para la conservación de Forrajes. Proyecto: Evaluación de tecnologías por métodos participativos para la implementación de sistemas ganaderos sostenibles en el norte del departamento del Valle del Cauca. CIAT, Universidad Nacional de Colombia- Gobernación del Valle del Cauca – Secretaría de Agricultura y Pesca.

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Franco, L.H.; and Peters, M. (2007) *Canavalia brasiliensis*. Una leguminosa multipropósito. Leaflet, CIAT.

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Capacity Building (Training)

BS Thesis

Name	Status	University	Title
Carabalí Jenny	Completed	Universidad Nacional de Colombia, Palmira, Colombia	Efectos de la suplementación con *Cannavalia brasiliensis* en la utilización por ovinos de un heno de gramínea de baja calidad
Hoyos Valerio	Completed	Universidad de Caldas, Colombia	Physiological screening of *Brachiaria* spp. genotypes for their tolerance to drought stress and aluminum toxicity in greenhouse conditions.
Vallejo Camila	Completed	Universidad de Caldas, Colombia	Efecto de tiempo de cosecha y secado en la calidad, presentación y ocurrencia de pérdidas del heno de tres accesiones de caupí (*Vigna unguiculata*)
Zúñiga Edier	On-going	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
Atzmanstorfer Karl	On-going	University of Salzburg, Austria	GIS-Based Analyses of Cowpea Adaptation to Colombian Hillside Environments
Bernal Laila	Completed	Universidad Nacional, Colombia	Efecto de taninos en las leguminosas Vigna unguiculata y Calliandra callotyrsus evaluados a nivel in vitro e in vivo en bovinos de leche
López Machado Francisco	Completed	Universidad del Valle, Colombia	Caracterización de la tolerancia al daño causado por adultos como componente de resistencia a *Aeneolamia varia* (F.) en genotipos de *Brachiaria* spp
Monsalve Castro Lina Maria	Completed	Universidad Nacional de Colombia, Palmira, Colombia	Efectos sobre la fermentación ruminal, el flujo de proteína duodenal y la absorción de nitrógeno en ovinos alimentados con leguminosas con y sin taninos
Pabón Alejandro	Completed	Universidad de Viçosa, Brazil	Mechanisms of resistance to *Deois incompleta* and *Notozulia entreriana* en *Brachiaria* spp.
Sanabria Adriana	Completed	Universidad Nacional, Bogotá, Colombia	Genetic diversity among casual agents of anthracnosis in tropical fruits

PhD Thesis

Name	Status	University	Title
Sanchez Elsa	On-going	University of Hohenheim, Germany	From subsistence to market oriented livestock smallholder development in Nicaragua and Honduras
Hernández Luis Alfredo	Completed	University of Hohenheim, Germany	Selection of Tropical Forages: Development and implementation of a participatory procedure and main results from Honduras, Nicaragua and Costa Rica.
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
Louw-Gaume Annabé	On-going	ETH, Zurich, Switzerland	Adaptation of *Brachiaria* grasses to low P soils
Mejia Kerguelen Sergio	Completed	Universidad Nacional de Colombia, Palmira, Colombia	Identification of candidate genes responsible for adaptation of tropical forage grass, *Brachiaria* to low phosphorus soils
Reiber Christoph	On going	University of Hohenheim, Germany	Encouraging adoption of research-based offerings with contrasting extension approaches
Tiemann Tassilo	Completed	Swiss Federal Institute of Technology (ETH), Zurich, Switzerland	The forage potential of tanniniferous legumes: Search for sustainable ways to cope with nutritional limitations in smallholder livestock

List of Donors

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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

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 – 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.

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. Proposal submitted to IFAD by the SLP led by ILRI. Funds for CIAT to operate in Vietnam.

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. 2008

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

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

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)

Philippines, ADB

Capacity Building for Smallholder Livestock Systems Project

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)

United States - North Carolina State University

Adoption of the Nutrient Management Support System (NuMass)Software Troughout Latin America.

List of Collaborators

Austria

Albert R., University of Vienna
Bernhard. Freyer, BOKU Vienna
E. Heberle-Bors, University of Vienna
Gabriele Pietsch, BOKU Vienna
Thomas Blaschke, University of Salzburg

Australia

Bruce Cook, Ian Partridge, QDPI
Bruce Pengelly, Stuart Brown, David Eagles CSIRO
Max Shelton, University of Queensland
P. Wenzl, DarT P/L, Canberra
Rob Corner, Curtin University
Sukumar Chakraborty, CSIRO

Brazil

Cacilda Borges do Valle, EMBRAPA/ CNPGC, Campo Grande, MS

Cambodia

Sorn San, NAHPIC

China

Huang Dongyi, South China University
Yi Kexian, CATAS

Colombia

Alexander Gómez Salazar, Universidad Nacional de Colombia, Sede Palmira, Valle del Cauca
Andrés Sandoval, COGANCEVALLE
Angela María Quintero Varela, Universidad Nacional de Colombia, Sede Palmira, Valle del Cauca
Antonio Pérez, Universidad de Sucre
Beatriz Elena Quiceno, Universidad Nacional de Colombia, Sede Palmira, Valle del Cauca
Carlos González, Universidad del Cauca, Popayán
Carlos Montoya, Universidad Nacional de Colombia, Sede Palmira, Valle del Cauca
Carlos Lascano, Corpoica, Bogotá
Carlos Vicente Durán, Universidad Nacional de Colombia, Palmira, Valle del Cauca
Carmen B. de Muñoz, Universidad de la Amazonía, Florencia, Caquetá
Corpoica Macagual, Caquetá
Daniel Villada, FIDAR
Edgar A. Cárdenas, Universidad Nacional de Colombia, Bogotá
Euclides Garavito, SENA-Buga
Fabio Prado, Universidad del Cauca, Popayán
Gerardo Gallego, CIAT
Gustavo Guerra, Universidad del Valle, Cali, Valle del Cauca
Harold Suarez, Universidad del Quindio,
Henry Mateus, CORPOICA, Barrancabermeja, Santander
Jaime Andres Acosta, Universidad del Cauca, Popayán
Jairo Osorio, CORPOICA, Colombia
Jairo Ramírez Rojas, Corpoica, Popayán, Cauca
Jorge Medrano, Corpoica, Villavicencio
José Restrepo, FIDAR, Valle del Cauca
Iván Hugo Vélez, SENA-Tulúa
Luz Mery Ocampo, Secretaria de Agricultura y Pesca del Valle SAP
Luz Stella Muñoz, Universidad Nacional de Colombia, sede Palmira, Valle del Cauca
Manuel Arboleda, Fondo Ganadero del Cauca
María Consuelo Tabares Cuartas, Corpoica, Popayán, Cauca
Maribel Osorio, Universidad Nacional de Colombia, Sede Palmira, Valle del Cauca
Mario Carvajal, Secretaria de Agricultura y Pesca del Valle SAP
Marino Valderrama, Farmer group Ondina
Martha Almanza, Universidad del Cauca, Popayán, Cauca

Nelson Vivas, Universidad del Cauca, Popayán, Popayán, Cauca
Noe Albán, Universidad del Cauca, Popayán, Popayán, Cauca
Patricia Sarria, Universidad Nacional de Colombia, Sede Palmira, Valle del Cauca
Pedro Argel, Corpoica,
Rafael Mora, Universidad de los Llanos, Villavicencio
Robinson Ortega, Universidad del Cauca, Popayán, Popayán, Cauca
Rolando Barahona, Corpoica, Bogotá
Rolando Barahona, Universidad Nacional de Colombia, Bogotá
Sandra Morales, Universidad del Cauca, Popayán
Tito Díaz, CORPOICA-Tibaitatá

Congo

Dieudonné Katunga, CIALCA

Costa Rica

Corporación de Fomento Ganadero, CORFOGA
Diego Obando, Cámara de Ganaderos del Sur
Francisco Romero, ECAG
Guillermo Pérez, CORFOGA
Jobny Chávez, Cámara de Ganaderos de Cañas

Denmark

José Adalberto Fernández KVL, Denmark
Niels Kyvsgaard, KVL, Denmark

Ethiopia

Areka Agricultural Research Institute, Ethiopia
Ethiopia Agricultural Research Organization (EARO), Ethiopia
FARM Africa, Ethiopia
International Livestock Research Institute (ILRI), Ethiopia
Jean Hanson, ILRI
Melkassa Agricultural Research Center, Ethiopia
Mr. Endale Gebre, EARO, Ethiopia
Mr. Muluneh Minta, EARO, Etiopía
S.A. Tarawali, ILRI
Salvador Fernandez, ILRI

Germany

Andreas Berk, FLI, Braunschweig
Christoph Tebbe, Von-Thünen-Institut, Braunschweig
Brigitte Maass, University of Goettingen
Günter Pahlow, Julius-Kühn-Institut, Braunschweig
Norbert Claassen, University of Goettingen, Goettingen
Rainer Schultze-Kraft, University of Hohenheim
Volker Hoffmann, University of Hohenheim
Walter Horst, University of Hannover, Hannover

Guatemala

Asocación de Criaderos de Ganado Brahman, ASOBRAHMAN
Ramiro Pérez, (MAGA)

Haiti

Jean Camille Bissereth, Heifer Project International
Paul dit Justin Alcé, Heifer Project International

Honduras

Ernesto Ehrler, DICTA
Gustavo Agurcia, FENAGH
J. Jimenez, IPCA
Marlen Iveth Posas Ponce, SERTEDESO

India

Michael Blummel, ILRI

Indonesia

Dinas Peternakan Samarinda

Italy

Caterina Batello, FAO

Japan

G. V. Subbarao, JIRCAS, Tsukuba, Japan
O. Ito, JIRCAS, Tsukuba
K. Okada, JIRCAS, Tsukuba, Japan
M. Osaki, Hokkaido University, Sapporo
T. Shinano, Hokkaido University, Sapporo
T. Ishikawa, JIRCAS, Tsukuba, Japan
T. Wagatsuma, Yamagata University, Yamagata
Tadano, Hokkaido University, Sapporo
Y. Saito, National Grassland Research Institute, Kitasaku, Nagano
Sumio Miyawaki- Coordinador, JICA

Kenya

Bernard Vanlauwe, CIAT-TSBF
D. Friesen, IFDC-CIMMYT
Pieter Pypers, CIAT-TSBF
Steve Franzel, ICRAF
William Thorpe, SLP

Lao, PDR

Bounthavong Kounnavongsa, NAFRI
Viengsavanh Phimphachanhvongsod, NAFRI
Viengxay Photakoun NAFE

Malawi

Department of Agricultural Research Service (DARS), Malawi

México

Andrei Nicolayevsky, Semillas Papalotla, Mexico, DF
Armando Peralta M., Agroproductos de Iguala, S.A., Iguala, Guerrero
Eduardo Daniel Bolaños Aguilar, INIFAP, Huimanguillo, Tabasco
Eduardo Stern, Semillas Papalotla, Mexico, DF
Francisco Javier Henríquez, INIFAP, Isla, Veracruz
Jorge David Guiot, Semillas Papalotla, Villahermosa, Tabasco

Nicaragua

Alejandro Blandón, INTA
Alexander Benavides, INTA
Carlos Ruiz, Universidad Nacional Agraria
Emilio Pérez, Universidad Nacional Agraria
Glenda Bonilla, Universidad Nacional Agraria
Instituto de Desarrollo Rural, IDR
Martin A. Mena, INTA

Philippines

Eduedo Magboo, PCARRD
Elsie Gabonada, Impasugong
Francisco Gabunada, ViSCA
Judith Saguinhon, MAO, Malitbog
Leonardo Moneva, Mag-Uugmad Fdn.
Perla Asis, City Veterinary Office, Cagayan de Oro

Rwanda

Mupenzi Mutimura, ISAR

Switzerland

A.Gaume, ETH, Zurich
A. Oberson, ETH, Zurich
Andrea Machmüller, Methanogenesis, ETH Zurich
Dieter Hess, ETH, Zurich
E. Frossard, ETH, Zurich

Michael Kreuzer, ETH, Zurich

Thailand

Chaisang Phaikaew, DLD

Ganda Nakamanee, PCANRC

United States

C. Schardl, University of Kentucky

Peter Andersen (University of Florida)

James White, Rutgers University

Uganda

Africa 2000 Network

African Highland Initiative, Kampala

National Agricultural Research Organisation (NARO), Uganda

Vietnam

Le Hoa Binh, NIAH

Truong Tan Khanh, Tay Nguyen

University Vu Thi Yen, DARD

Project Staff List 2007

Principal Staff
Peters Michael, Forage Germplasm Specialist and Outcome Line Leader 100%
Elizabeth Alvarez, Plant Pathologist (MIP) 30%
Holmann Federico, Animal Production Systems/Economics (joint position with ILRI)100%
Kelemu Segenet, Plant Pathologist (until August 2007)
Lascano Carlos, Animal Nutrionist and Forage Project Leader (until March 2007)
Miles John, Plant Breeder 100%
Rao Idupulapati, Plant Nutritionist/Physiologist 50%
Rein van der Hoek, Forage Expert, Nicaragua (Associate Researcher, CIM)100%
Stur Werner, Forage and Livestock Systems, Southeast Asia 100%

Consultants/Advisors
Cardona Cesar, (August 2007-August 2008)
Schultze-Kraft Rainer, Specialist Germoplasm
Wenzl Peter, CAMBIA, Canberra, Australia

PostDoc
Lentes Peter, Socio-Economics and GIS, Honduras (until November 2007)
Martens Siriwan, Animal Nutritionist and Microbiologist (Associate Researcher, CIM)

Regional Research Fellow
Phengsavanh , Phonepaseuth - Animal Science, Asia

Visiting Scientists
Pabón Alejandro, Universidad Federal de Vicosa, Vicosa, Brasil
Alexander Benavides, INTA
Subbarao Guntur, JIRCAS, Tsukuba, Japan

Biometrics Specialist
Ramirez Gerardo (until March 2007)

Research Associates and Assistants
Abello Javier Francisco, Plant Pathology
Avila Patricia, Forage Quality
Borrero Gonzalo, Plant Nutrition/Physiology
Fory Paola, Plant Pathology (until December 2007)
Franco Luis Horacio, Germplasm
Franco Manuel Arturo, Data Base
Gabunada Francisco, Animal Science, Asia
Galvis Jesus, Plant Nutrition/Physiology
Hernandez Luis Alfredo, (Participatory research from SN)
Hurtado Maria del Pilar, Plant Nutrition/Physiology
Polanía Jose Arnulfo, Plant Nutrition
Quintero Marcela, Plant Nutrition/Physiology
Rincón Lozano Joisse Dayana, Drought
Samson Jindra, Asia Regional Evaluation
Sotelo Guillermo, Entomology
Garcia Ramiro, Experto 2

Specialists
Betancourt Aristipo, Genetics
García Ramiro, Plant Nutrition/Physiology
Hincapié Belisario, Germplasm
Segura Gustavo, Plant Pathology

Technicians
Alvarez Arvey, Plant Nutrition/Physiology
Bonilla Ximena Patricia, Plant Pathology
Córdoba Gilberto, Entomology
López Luis Alberto, Plant Nutrition/Physiology
Mera William, Caqueta, Entomology
Mezu Hernan, Plant Nutrition/Physiology
Ospinal Gustavo, Forage Quality
Pareja José Reinaldo, Entomology
Pizarro Fabián, Genetics
Rojas Castillo Claudia Ximena, Plant Nutrition
Vergara Daniel, Genetics (Villavicencio)
Viveros Darío H., Pathology

Workers
Amaya José Nelson, Genetics
Aragón José Ever, Forage Evaluation (Quilichao)
Hernández Gutiérrez Isled Yomar, Plant Nutrition
García Benilda, Forage Quality
Gutiérrez Pedro José, Genetics (Popayán)
Lasso Jesús, Forage Germplasm, (Quilichao)
López Luis Alberto, Plant Nutrition
Mona Alvarez Héctor Fabio, Genetics
Recio Maria Eugenia, Plant Nutrition
Zúñiga Harold Orlando, Forage Evaluation (Quilichao)

Ph.D. Students
Castro, Aracely, Universidad Nacional de Colombia, Sede Palmira, Colombia
Douxchamps, Sabine, Swiss Federal Institute f Technology (ETH), Zurich, Switzerland
Hernández, Luis Alfredo, University of Hohenheim, Germany (Completed)
Louw-Gaume, Annabé, Swiss Federal Institute f Technology (ETH), Zurich, Switzerland
Mejia Kerguelen, Sergio Luis, Universidad Nacional de Colombia, Sede Palmira (Completed)
Reiber, Christoph, University Hohenheim, Germany
Sanchez, Elsa, University of Hohenheim
Tiemann Tassilo, Swiss Federal Institute Technology (ETH), Zurich, Switzerland (Completed)

MSc. Students
Bernal Laila, Universidad Nacional de Colombia, Sede Palmira (Completed)
López Machado Francisco, Universidad del Valle, Colombia
Monsalve Castro Lina Maria, Universidad Nacional de Colombia, Sede Palmira (Complete)
Pabón Alejandro, University of Vicosa, Brazil
Phengsavanh Phonepaseuth, SLU, Uppsala, Sweeden
Ricaurte Jaumer, Universidad Nacional de Colombia, Sede Palmira, Colombia
Sanabria Adriana, Universidad Nacional de Colombia, Bogota, Colombia

Pre-Graduate Students
Carabalí Jenny, Universidad Nacional de Colombia, Sede Palmira, Colombia
Hoyos Valerio, University of Caldas, Colombia
Suarez Harold, Universidad del Quindío, Colombia
Vallejo Camila, Universidad de Caldas, Colombia
Zúñiga Edier, Universidad Nacional de Colombia, Sede Palmira, Colombia

Secretaries
Arenas Salazar Beatriz (until August 2007)
Burbano Jenny Milena
Gómez Quintero Julia