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AGBIO4: Tropical Forages Program

CIAT
Centro Internacional de Agricultura Tropical
International Center for Tropical Agriculture
Consultative Group on International Agricultural Research

ANNUAL REPORT
2009

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AGBIO4: Tropical Forages Program

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Project Overview and Rationale

Rationale

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

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

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

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

As an activity across outcomes to target and deliver our research products, we form partnerships with different groups to define environmental and market niches, document on-farm performance of released grass and legume cultivars, and quantify the impact of selected forages on improving livelihoods and protecting the environment.

Capacity building remains an important component of our agenda, to improve: a) our research capacity through pre- and post-graduate thesis research and strengthening/benefiting from the research capacity of partners, and b) our capacity to deliver research products in different environments. Capacity building includes group and individual training and activities in the area of knowledge management.

Alignment to CGIAR Priorities

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

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

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

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

- Characterization of the genetic diversity in legume collections from the Gene Bank of CIAT, other CG Centers and research institutions to select new alternatives with superior forage quality, yield and resistance to biotic and abiotic stress factors (SP 1b, 2b, 3b);
- Development of methodologies for screening forages for quality and major abiotic and biotic constraints (SP 2b);

- Breeding to develop superior grasses (*Brachiaria*) that combine quality attributes with adaptation to major abiotic and biotic constraints (SP 2b, 2c, 2d, 3b);
- Development of a molecular map of *Brachiaria* and discovery of genes associated with adaptation to abiotic stresses (SP 2b, 2d, 3b).
- Development of methods for evaluating forages in different production systems with farmer participation (SP 5b);
- Development of Data Bases and Decision Support Tools to help target forages to different environments and production systems (SP 5a);
- Income generation from livestock through improved forages for feeding ruminants and monogastric animals and improved equity in value chains (SP 3b, also 2c and 5b, and spillover effects on 3c);
- Analysis of trade-offs between use of legumes for soil enhancement or as animal feed resource on crop-livestock productivity and environmental quality (SP 4b); and
- Capacity building consisting of short and long term training of individuals, group training and knowledge management (SP 5a)

Output Description

Changes from previous MTP Outputs

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

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

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

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

In 2008 we have consolidated our research for development activities, and our Outcomes are increasingly directed towards an outcome and market driven approach. As part of this effort we are intensifying our research on developing forages for monogastric animals, increasing on-station research and extending the field work from Southeast Asia to Latin America and Sub-Saharan Africa. In line with our mandate we are also strengthening the global reach of our work. Responding to the EPMR recommendations in 2007 we have now a Forage Expert for Central America, and a Forage Expert for East Africa has been recruited in the 1st half of 2009. We have also secured support in livestock economics for the coming years. Budget limitations have required further prioritization of forage research and related consolidation of staff.

However, funding for 2009 has further stabilized, but as stated in last year's MTP maintenance of core resources at the current level will be essential to deliver the outputs stated in this document and also to respond to new challenges. Additional resources are sought to implement in consultation with other centers and partners our strategy in Eastern and Southern Africa to strengthen our work on the contribution of forages for more healthy agroecosystems. A key component in this approach is the improved collaboration with CIAT-TSBF, and the People and Agroecosystems RDC to integrate forages into production systems and to realize their economic and environmental benefits.

Impact Pathways per Output

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

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

Output 3: Forages integrated into smallholder crop-livestock systems: realizing livelihood and environmental benefits. For its work in Sub-Saharan Africa, Southeast Asia and Latin America and the Caribbean (LAC), the CIAT Tropical Forages Program is collaborating with ILRI and CIAT-TSBF, with complementary research priorities and expertise to integrate forages in diverse crop-livestock systems, particularly in Sub-Saharan Africa and Southeast Asia. This partnership and the interaction with the private sector have allowed us to amplify networks for delivery of research outcomes. Information sharing through knowledge tools such as SoFT (www.tropicalforages.info) reaches a wide audience ranging from researchers and development practitioners to educational institutions, and complements our continued efforts of individual and group training. A particular objective for the revision of SoFT is the linkage of SoFT with forage germplasm distribution.

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

International Public Goods

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

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

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

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

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

- Selection of forages by farmers using participatory methods

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

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

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Elaboration of Partners Roles

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

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

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

3. Colombia – CORPOICA; Nicaragua – INTA: (Output 1) Desarrollo de genotipos de *Brachiaria* spp. adaptados a suelos con drenaje deficiente para aumentar producción bovina y adaptar sistemas de pastoreo al cambio climático en América Latina. Funds from FONTAGRO.

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

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

6. Germany – CIM: (Outputs 1 to 3) Forage conservation and feed systems for monogastrics; Forage experts for Central America and Eastern Africa. Funds from BMZ and CIM.

7. Germany – U of Hohenheim; Nicaragua INTA; Honduras DICTA: (Outputs 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.

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

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

10. Lao PDR – National Agriculture and Forestry Research Institute; Australia – Queensland Department of Primary Industries and Fisheries; Canada – Nutrition Prairie Swine Centre, Saskatoon: (Output2) Forage legumes for supplementing village pigs in Lao PDR. Funded by ACIAR.

11. Mexico – PAPALOTLA seed company and national partners: (Output1) Breeding and evaluation of *Brachiaria* hybrids. Funds from PAPALOTLA.

12. Switzerland – ETH; Nicaragua – INTA: (Output 3). Realizing the benefits of cover crop legumes in smallholder crop-livestock systems. Funds from ZIL-SDC.

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

14. Viet Nam – ILRI; National Institute of Animal Husbandry and Tay Nguyen University: (Output 2) Enhancing livelihoods of poor livestock keepers through increasing use of fodder. Funds from IFAD via SLP.

List of proposals funded

1. Australia. Developing improved farming and marketing systems in rainfed regions of Southern Lao PDR. Funds from ACIAR.

2. Austria – BOKU; INTA, UNA, MIS. Eco-efficient crop and livestock production for the poor farmers in the sub-humid hillside areas of Nicaragua. Funds from ADA.

3. Brazil – Embrapa. Identification of aluminum resistance genes in *Brachiaria* and phenotypic characterization of grass and legume germplasm for adaptation to and mitigation of climate change. Funds from Embrapa.

Tropical Forages Program

Goal: The goal of the Tropical Forages Program is to improve the livelihoods of poor rural crop-livestock producers while contributing to eco-efficiency of production systems.

Objective

The objective of the Tropical Forages Program is to explore the benefits of multipurpose forages for improving agricultural productivity, while reducing the ecological footprint.

	Outputs	**Intended Users**	**Outcome**	**Impact**
Output 1	**Forage germplasm developed through collection, selection and breeding**	CIAT and NARS researchers and seed companies.	New forage cultivars (*Brachiaria* and legumes) are released by partners and adopted by farmers in LAC, Asia and Africa.	Increased efficiency of livestock production through feeding high quality grasses and legumes.
Target 2009: Materials	At least 2 apomictic *Brachiaria* hybrids that combine high digestibility (>60%) and crude protein (>10%) with spittlebug resistance developed			
Target 2009: Materials	At least 5 *Brachiaria* hybrids that combine resistance to spittlebugs with adaptation to acid soils released for regional testing			
Target 2009: Materials	At least 5 *Brachiaria* hybrids with combined resistance to spittlebugs and tolerance to waterlogging developed			
Target 2010: Materials	A range of improved *Brachiaria* cultivars commercially available			
Target 2010: Materials	Two new forage options for smallholder pig and poultry systems identified			
Activity 1: Develop sexual and apomictic *Brachiaria* hybrids through breeding and evaluate for forage and seed production potential of promising hybrids **Activity 2:** Identify sexual and apomictic *Brachiaria* hybrids with resistance/tolerance to major biotic and abiotic constraints and with high forage quality attributes **Activity 3:** Evaluate forage legumes for tolerance to major abiotic constraints, forage quality attributes , and seed production potential, and identify promising germplasm accessions				

	Outputs	Intended Users	Outcome	Impact
Output 2	**Forages as high value products developed to capture differentiated traditional and emerging 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.	Improved livelihoods of smallholder farmers through increased efficiency of livestock production, return from labor and income through planting forages that are adapted to major production constraints and market opportunities.
Target 2009: Materials	A methodology developed to correlate *in vitro* and *in vivo* screening of legumes as feed for monogastric utilization			
Target 2010: Capacity	Supplementation of village pigs with the legume *Stylosanthes guianensis* is practiced by at least 1,000 small farm households through effective partnership with government and development projects in Laos			
Activity 1: Assess and improve the suitability of forage-based protein feeds for monogastric animals **Activity 2:** Co-develop partnership approaches that connect low-income farmers with new forage germplasm and associated feed management/processing, and co-examine technology effects on households and communities **Activity 3:** Evaluate the possibilities of farmers extending animal and feed sales within and beyond their communities				
Output 3	**Forages integrated into smallholder crop-livestock systems: realizing livelihood and environmental benefits**	CIAT, ARIs and NARS researchers, and seed companies.	New cultivars of grasses and legumes with adaptation to major production constraints released by partners and adopted in LAC, Asia and Africa.	Increased profitability and sustainability of livestock/crop production and improved NRM through multipurpose forages adapted to production constraints, market opportunities and climate change.
Target 2009: Materials	Released a revised version of SoFT (Selection of Forages for the Tropics) to target forages to different agro-ecological and production system niches			
Target 2010: Policy strategies	Production *vs*. environmental trade-offs determined in use of 2 cover legumes as feed supplement/for soil fertility improvement in maize-based systems in a hillside region			
Activity 1: Evaluate and disseminate superior and diverse forage grass and legume options for crop-livestock systems **Activity 2:** Quantify livelihood and environmental benefits of multipurpose forages in crop-livestock systems				

Output 1: Forage germplasm developed through collection, selection and breeding

Target region	Production constraints	Social constraints	Target traits	Research priorities	Challenges	Technical solutions	Social-economical impacts
Latin America and the Caribbean	*Brachiaria*: Insects and diseases; Soil quality; Climate change; Forage quality Legumes: Seed availability; Climate change; Forage quality	Land availability; Cash flow; Access to inputs; Land and labor availability	*Brachiaria*: Resistance to spittlebug and Rhizoctonia; Apomictic reproduction Grasses/legumes: Resistance to aluminum, waterlogging and drought; Forage quality; Seed production; Biomass	Combining biotic and abiotic stress tolerance with high forage quality attributes and with high seed production	Sustained funding from traditional and nontraditional; Maintaining interdisciplinary team; Measuring animal production using multilocational grazing trials	*Brachiaria:* Breeding using phenotypic and genotypic evaluations Grasses/legumes: Germplasm selection and evaluation	Improved livelihoods through reduced poverty and increased income generation
Southeast Asia	Lack of continuous forage supply	Land and labor availability	Drought tolerance, waterlogging tolerance, forage quality, biomass	Assess agro-ecological adaptation and productivity of diverse forage options	Sustained funding for forage position in Southeast Asia	Introducing new germplasm; Multilocational evaluations	Improved livelihoods through reduced poverty and income generation
Eastern and Southern Africa	Environmental conditions (drought, altitude, soil fertility, diseases and pests); Lack of alternatives	Land availability, Access to inputs and labor; Lack of knowledge about forages	Drought tolerance; Forage quality; Seed production; Acceptability to farmers; Productive alternatives to Napier grass	Assess agro-ecological adaptation and productivity of diverse forage options (GxE); Determine potential acceptability	Funding; Building interdisciplinary and inter-institutional partnerships; Lack of capacity; public order	Introducing new germplasm; Multilocational evaluations; Capacity building	Improved livelihoods through reduced poverty and income generation

Output 2: Forages as high value products developed to capture differentiated traditional and emerging markets for smallholders

Target region	Production constraints	Social constraints	Target traits	Research priorities	Challenges	Technical solutions	Social-economical impacts
Latin America and the Caribbean	Diverse environmental conditions (climate, altitude, soil fertility, pests)	Availability of land and labor; Access to appropriate processing technology and machinery; Market opportunities	Resistance to drought and waterlogging, and to pests and diseases; High in digestible protein, low in undigestible fiber, reduced anti-nutritive compounds, positive health effect	Defining appropriate forage species/accessions (GXE); Improve screening performance on feed quality; Addressing factors determining adoption; Functional seed systems	Adoption of technologies by (smallholder) farmers; Developing feasible small-scale processing methods; Developing value chains	Germplasm evaluation; Chemical analysis of processing effects; Digestibility evaluation (*in-vitro, in vivo*); Integration of forages in value chains	Improved livelihoods through reduced poverty and income generation
Southeast Asia	Environmental conditions (drought, waterlogging); Feed quality/quantity	Availability of land, labor; Access to inputs	Highly productive forages of high quality; Defining appropriate forage species/accessions (GXE)	Integration of forages in market driven crop-livestock systems; Functional seed systems	Maintaining forage position in SE Asia; Scaling of forages in market driven systems	Germplasm evaluation trials; Integration of forages in value chains	Improved livelihoods through reduced poverty and income generation
Eastern and Southern Africa	Environmental conditions (drought, altitude, soil fertility); Low feed quality; Instable public order	Availability of land, labor; Lack of knowledge about forages	High quality forages with drought tolerance, adapted to soils of different fertility, acceptable to farmers; Forage seed supply	Co-develop optimal partnership approaches that connect low-income farmers with new forage germplasm	Funding; Building interdisciplinary and inter-institutional partnerships; Lack of capacity	Multilocational evaluation in regional networks with farmers; Functional seed systems; Capacity building	Improved livelihoods through reduced poverty and income generation

Output 3: Forages integrated into smallholder crop-livestock systems: realizing livelihood and environmental benefits

Target region	Production constraints	Social constraints	Target traits	Research priorities	Challenges	Technical solutions	Social-economical impacts
Latin America and the Caribbean	Low fertility soils, drought, waterlogging	Land availability; Cash flow; Access to inputs; and market	Beef, pork, chicken and milk production; Improved soil fertility; Reduced global warming potential	Multilocational grazing/feeding/ soil fertility experiments in mixed systems; Strategies to enhance adoption	Fund-raising to support collaborative research on crop-livestock systems	Integration of eco-efficient tropical forages in multifunctional landscapes	Improved livelihoods through reduced poverty and income generation
Southeast Asia	Low fertility soils, drought, waterlogging	Land and labor scarcity: Market integration	Ruminant and pork production	Integration of forages in market driven crop-livestock systems	Sustained funding	Integration of tropical forages into ruminant and monogastric production systems	Improved livelihoods through reduced poverty and income generation
Eastern and Southern Africa	Land scarcity, low soil fertility, labor, instable public order	Land availability; Cash flow; Access to inputs, and market; Incentives for quality animal products	Increased meat and milk production; Improved soil fertility; Start of forage seed production	On farm multilocational feeding/soil fertility improvement in mixed systems in collaboration with other stakeholders	Funding; Building interdisciplinary and inter-institutional partnerships; Lack of capacity; Public order	Integration of tropical forages into mixed crop-livestock production systems; Capacity building	Improved livelihoods through reduced poverty and income generation

New initiatives

- Creation of a platform for forage research in LAC
- Explore/realize the potential of new forage options in crop-livestock systems in Eastern/Southern Africa
- Improving resilience to climate change of high value crop-livestock systems in LAC

Progress towards output targets 2009

- At least 5 *Brachiaria* hybrids that combine resistance to spittlebugs with adaptation to acid soils released for regional testing.

  Thirteen hybrids (BR02NO/1752, BR05NO/0334, BR06NO/1175, BR02NO/1372, BR05NO/0537, BR05NO/0563, BR05NO/0637, BR06NO/0204, BR06NO/0387, BR06NO/1348, BR06NO/1932, BR06NO/2020, and BR06NO/2058) combining tolerance to acid soils with resistance to spittlebugs have been identified to date. All of these hybrids have been delivered to our private sector seed company partner for advanced testing aimed at eventual commercial release.

- At least 5 *Brachiaria* hybrids with combined resistance to spittlebugs and tolerance to waterlogging developed

  Nine hybrids (BR02NO/1372, BR02NO/1752, BR02NO/1794, BR05NO/0563, BR05NO/0760, BR05NO/1467, BR06NO/0387, BR06NO/1000, BR06NO/1175) combining resistance to spittlebugs with tolerance to waterlogging have been identified. These hybrids have all been delivered to our private sector seed company partner for advanced testing aimed at eventual commercial release.

Research Highlights 2009

Advances in waterlogging tolerance in *Brachiaria*

A robust, reliable, large capacity methodology for screening reaction to waterlogging conditions has been developed. Given the observed phenotypic variation among genotypes of the "*decumbens/brizantha*" breeding materials, it appears feasible, by focused selection, to improve tolerance fairly rapidly. Activities aimed at developing high levels of waterlogging tolerance in sexual, hybrid-derived "*decumbens/brizantha*" germplasm have been initiated.

Five promising SX05 sexual clones were recombined in an isolated recombination block and 500 progeny clones were assessed, in two replications over time. The best (most tolerant) 20 of the 500 clones were recombined, in turn, to generate a second cycle (C_2) population. One hundred C_2 clones will be screened and recombined. It is anticipated that at least one full generation per year of selection and recombination can be achieved without any need, at least in the initial generations, for field testing.

When an adequate level of waterlogging tolerance is achieved, this tolerance will be introgressed into our "*decumbens/brizantha*" synthetic sexual breeding population.

Participatory evaluation of *Brachiaria* grass options in Rwanda

Improved *Brachiaria* grasses were tested with participation of farmers in contrasting drought and acidic soil environments in Rwanda. In both environments, farmers have adopted the new forage alternatives by increasing the size of their plots and forming cooperatives to produce planting materials of the best bet *Brachiaria* options. The five *Brachiaria* options which had been selected by farmers for multiplication are *Brachiaria* hybrid cv. Mulato II, *B. brizantha* cv. Toledo and cv. Marandu, *Brachiaria* hybrid BRO2/1485 and *B. decumbens* cv. Basilisk. These grass options were chosen by farmers under both stress conditions because of their adaptability to drought and acid soils and producing high forage biomass throughout the year. The *Brachiaria* options are now replacing the commonly used forage grass (Napier), e.g., on erosion control ridges.

Exploiting the biological nitrification inhibition activity in *Brachiaria* grasses

New evidence is found for the existence and active regulation of a nitrification inhibitor(s) release from *Brachiaria humidicola* root systems. Exploiting the biological nitrification inhibition (BNI) function could become a powerful strategy towards the development of low-nitrifying agronomic systems, benefitting both agriculture and the environment. A large set of hybrid-derived, *B. humidicola* clones are being progeny-tested and apomicts will be multiplied and assessed for BNI activity and forage quality. The magnitude of variation among hybrid-derived clones in BNI activity will indicate the probability of manipulating this trait in a *B. humidicola* breeding program.

Project outcome:

Expert systems for targeting forages and extension materials for promoting adoption of forages: Selection of forages for the tropics (SoFT)

Contributors: B.C. Pengelly (CSIRO), B.G. Cook (QDPI), I.J. Partridge (QDPI), D.A. Eagles (CSIRO), M. Peters (CIAT), J. Hanson (ILRI), S.D. Brown (CSIRO), J. L. Donnelly (CSIRO), B. F. Mullen (CSIRO) , R. Schultze-Kraft (University of Hohenheim), A. Franco and R. O'Brien (CIAT)

Forage research over the last 50 years has identified many tropical forages, mainly grasses and legumes, that have a role in farming systems in developed and developing countries. Information on the adaptation and use of these species has resided in peer-reviewed literature, research reports with limited distribution and, often most importantly, in the memories of forage agronomists with decades of experience of working with a wide range of forages in diverse farming systems. Selecting the right species and germplasm for particular environments and farming systems is a complex task and there is often poor access to information. This has frequently resulted in researchers not being able to learn from past experience, and there has always been a risk that repeating the mistakes of the past will result in lost opportunities and poor use of resources. Moreover, researchers and advisors in contact with communities have usually had poor access to up-to-date information on tropical forages, often resulting in suboptimal suggestions to farmers; a situation further aggravated by the decline in the overall number of forage experts over the last 20 years.

In this context the main objectives for development of SoFT were:

- To develop a knowledge system for the identification of forages suitable for specified niches within smallholder farming systems in the tropics and subtropics.
- To promote the system within the "communities" who are using tropical forages.
- To develop a strategy for maintenance and updating the knowledge system.

Capitalizing on a network of international experts SoFT provides access to the best available information on the adaptation and potential use of 180 tropical forage species and their elite cultivars or accessions in a single user-friendly database. The database, which includes a simple-to-use tool to assist in the selection of the best-bet species, is now freely available on the Internet (www.tropicalforages.info) and on CD.

The database has five main features:

(i) information in fact sheets on the adaptation, uses and management of forage species, cultivars and elite accessions

(ii) a selection tool built on LUCID™ that enables easy identification of best-bet species

(iii) a bibliography of more than 6,000 references and abstracts on forage diversity, management and use which will enable users with poor library facilities to access summaries of some of the key literature

(iv) global maps of potential climate adaptation for each species

(v) a collection of photographs and images of species to help in their identification and use

The principal outcome has been summarized information on tropical forage adaptation and use from expert knowledge, available literature and experiential sources made available in a readily accessible and consistent format. With availability on DVD and the Internet, the database allows researchers and advisors to select those forages most suitable for local conditions.

In addition to the intended uses the database has also been recognized as a valuable teaching tool for colleges and universities with feedback from many university staff from a wide range of countries attesting that the database and selection tool will have a major role in improving the way tropical forage science is taught.

Since the release in June 2005 at the XXth International Grassland Congress in Ireland in June 2005, there has been a steady utilization of the tool, with an average of more than 15,000 monthly visits to the website; in addition more than 1000 CD copies have been distributed in particular in countries or locations with poor internet access. More recently the tool is also available in a number of Asian languages.

Currently the site is most frequented by users from Australia, Brazil, Mexico, Indonesia, and Colombia in descending order. However, there are also frequent visits recorded from countries in Latin America (e.g., Paraguay, Argentina, Bolivia and Nicaragua), Asia (e.g., Malaysia and Thailand) and Sub-Saharan Africa (e.g., South Africa). Notable is that users include not only research and governmental but also a high number of Non Profit organizations and educational institutions.

Documentation

CIAT Tropical Forages Annual Reports 2002 – 2009 (though released in 2005, we monitor statistics)

Web site www.tropicalforages.info

Cook, B.G.; Pengelly, B.C.; Brown, S.D.; Donnelly, J.L.; Eagles, D.A.; Franco, M.A.; Hanson, J.; Mullen, B.F.; Partridge, I.J.; Peters, M.; Schultze-Kraft, R. (2005) Tropical Forages: an interactive selection tool. CD-ROM, CSIRO, DPI&F(Qld), CIAT and ILRI, Brisbane, Australia.

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Also published 2005 in: Tropical Grasslands 39: 241.

Output 1. Forage germplasm developed through collection, selection and breeding

1.1 *Brachiaria* breeding: Cycling synthetic sexual tetraploid "*decumbens/brizantha*" breeding population

Highlight

- One hundred seventy-five testcross families were produced, with a total of over 6,000 individual seedlings.

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

1.1.1 Establish a seedling population of 6,000-7,000 testcross progeny plants

Rationale

Repeated cycles of selection and recombination produce continuing genetic improvement in performance of our sexual breeding population. Where selection is on testcross (hybrid) performance, a cohort of novel apomictic hybrids is generated with each selection cycle. A second (3-year) cycle of selection on testcross performance commenced in 2008, with the formation of several hundred testcross families.

Given that only the apomictic individuals in the testcross are of potential interest as cultivars, identifying and culling the sexual testcross individuals will improve the efficiency of field evaluation in that all individuals will be apomictic and each a potential candidate for development to cultivar status.

A putative molecular marker of apomixis in *B. decumbens* (SCAR N14) was identified more than 10 years ago by CIAT's BRU, but it has never been used in the applied *Brachiaria* breeding program.

Materials and Methods

During 2008, sexual plants derived from our tetraploid sexual breeding population were exposed to pollen of a "tester" genotype (CIAT 606), to produce a set of hybrid testcross progenies. The seed thus obtained was germinated in early 2009 to produce a population of testcross progenies.

Results and Discussion

Nearly 6,000 individual seedlings in 175 testcross families were produced and transplanted to 4-in (10.16-cm) plastic pots.

1.1.2 Attempt to identify apomictic individuals by molecular marker. Cull plants lacking marker (putative sexuals)

Highlight

- Presence or absence of a SCAR marker of apomixis was assessed in 6,545 testcross progeny individuals.

Contributors: C. Quintero, J. Tohme, J. Miles (CIAT)

Rationale

A RAPD genetic marker was identified at CIAT more than 10 years ago, but had never been used in the ongoing *Brachiaria* breeding program. If, in fact, it can accurately distinguish between sexual and apomictic plants in a segregating hybrid population, the marker will have considerable utility in the breeding program.

Materials and Methods

Between February and April, leaf tissue samples of 6,550 testcross plants (see section 1.1) were taken and the presence/absence of SCAR N14 was assessed. Results were obtained for 6,545 of these individual plants.

Results and Discussion

N14 was absent from 3,394 of the testcross plants (52%), and these were assumed to be sexual and were culled. The remaining plants, which were overwhelmingly positive for N14, but included some with a fainter band or where there was no amplification, were vegetatively propagated and established in field nurseries at two locations in Colombia.

We will have confirmation of the utility of the SCAR N14 marker to distinguish between reproductive modes in *Brachiaria* hybrid populations during 2010, when several hundred "pre-selected" plants are progeny-tested.

One possible limitation in identifying apomictically reproducing genotypes in segregating hybrid populations using genetic markers is already anticipated: This is the inability of any genetic marker to discriminate between genotypes that are strongly apomictic and others that may be more or less facultatively apomictic.

1.1.3 Identification of superior testcross progenies and initial selection of superior maternal (sexual) clones for recombination in 2010

Highlight

- Over 3,000 testcross seedlings were vegetatively propagated and established in each of two field trials at contrasting sites in Colombia for initial visual evaluation and heavy culling.

Contributors: A. Betancourt, J. Miles (CIAT)

Rationale

Assessment of genetic merit of sexual clones by the criterion of the performance of their testcross progenies should allow accumulation over cycles of selection of those alleles in the sexual population that confer superior hybrid performance. The scheme has the additional virtue that a large cohort of apomictic genotypes is generated as an inherent product of the selection scheme. Any of these apomictic testcross hybrid genotypes is a potential candidate for development to cultivar status.

Materials and Methods

A total of 3,125 testcross genotypes were vegetatively propagated and transplanted, to two, space-planted field evaluations at contrasting sites in Colombia. Unreplicated genotypes at each location were assigned to 5-plant family plots. Plots were completely randomized at each location.

Visual assessment of plant vigor, freedom from disease or nutritional deficiency symptoms, and general agronomic merit allowed 1) identification of promising individual genotypes, and 2) identification of superior testcross families.

Results and Discussion

Currently (January 2010) 347 testcross clones are being assessed for seed set. Eighty-four superior sexual plants (of 175 sexual clones, used in forming the original testcross families) will be assessed for their own (*per se*) reaction to spittlebug nymphs and adults, Rhizoctonia leaf blight resistance, and tolerance to aluminum and waterlogging, prior to recombining a smaller sub-set by open pollination in an isolated crossing block.

1.2 Assess seed set of preselected individuals in superior testcross progenies

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

Rationale

Seed yield is a character critical to the commercial success of any released *Brachiaria* cultivar. Since flowering response at our low latitude field sites in Colombia may not be representative of flowering response in traditional *Brachiaria* seed producing regions, e.g., in Brazil, we use the proxy trait of seed set to cull genotypes that are unlikely to be high seed yielding.

Materials and Methods

Following an initial pre-selection of 347 testcross individuals, inflorescences are enclosed in mesh bags and maturing seed is collected over a period of several weeks.

"Crude seed" (i.e., as it collects in the mesh bags) is weighed. Full spikelets (i.e., containing a caryopsis) are separated from empty spikelets by density, in an adjustable vertical air flow.

A measure of seed set is obtained by expressing full seed weight as a proportion of total or crude seed weight.

Results and Discussion

Seed harvest and processing is on-going as of mid-January 2010, and the data available are too preliminary to report.

1.3 *Brachiaria* breeding: Spittlebug resistance

1.3.1 Continue to assess reaction to both spittlebug nymphs and adults of promising new hybrids (series BR02; MX02; BR04; BR05; BR06)

Highlight

- High levels of multi-species spittlebug resistance is common among advanced hybrids.

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

Rationale

A total of over 70 promising apomictic hybrids have been delivered to Semillas Papalotla over the past several years. We are compiling data on a series of entomological, pathological, and physiological attributes to help guide future decisions about commercial release.

Materials and Methods

The hybrids of interest have been propagated vegetatively for the various assays. Reaction to artificial infestation with spittlebug nymphs (plant damage and nymph survival) and adults (plant damage) is recorded.

Results and Discussion

Good resistance to spittlebug nymphs is common in the set of genotypes. However, in general, most of these selected genotypes are susceptible to spittlebug adult damage. This is, perhaps, not surprising in that these genotypes were all selected before routine assessment of reaction to spittlebug adults had been adopted and in light of the genetic independence between resistance to nymphs or adults (Cardona et al. submitted to J. Econ. Entom.).

1.3.2 Begin generating data on spittlebug reaction of tetraploid *B. humidicola* germplasm

Highlight

- A "base set" of tetraploid *B. humidicola* germplasm was shown to contain significant genetic variation in resistance to three species of spittlebug nymphs, measured either by plant damage or by nymphal survival.

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

Rationale

With the identification, in 2005, of sexual reproduction in a tetraploid accession of *B. humidicola*, plant breeding in this valuable forage species became a real possibility. Resistance to spittlebugs will be an important criterion of selection, as it is in all species of *Brachiaria*.

Materials and Methods

CIAT's collection of tetraploid *B. humidicola* totals 19 accessions. These accessions, along with a small set of hybrid genotypes (13), were propagated vegetatively and infested with either nymphs or adults of three several Colombian spittlebug species. Tests with adults are so far only preliminary, unreplicated trials, mainly to refine methodologies for handling plants of *B. humidicola*, which have a very different morphology from plants of *B. decumbens* or *B. brizantha*.

Results and Discussion

Differences among tetraploid *B. humidicola* genotypes in reaction to spittlebug nymphs, as assessed either by plant damage or nymph survival, were detected. While high levels of antibiosis resistance have not been identified in this small set of germplasm, the variability found should allow rapid development of useful resistance.

Results with adults are still too preliminary to report.

1.3.3 Assess reaction of SX08 selections to spittlebug nymphs and adults. Cull susceptible genotypes prior to final selection and recombination (in 2010)

Highlight

- Fifty-two percent of maternal sexual genotypes culled on visual assessment of testcross progenies in two field trials.

Contributors: G. Sotelo, J. Miles (CIAT)

Rationale

Based on visual assessment of testcross progeny performance in two field trials, just over 52% of 175 sexual, maternal clones have been culled. The remaining 84 sexual clones need rigorous culling on *per se* reaction to spittlebug nymphs and (especially) adults prior to recombining during second semester of 2010.

Materials and Methods

Trials with several spittlebug species have been set up.

Results and Discussion

Data are not yet available to date (12 January 2010).

1.3.4 Relation between host resistance to spittlebug nymphs and to adults

Highlight

- Resistance to spittlebug adult feeding damage is only slightly correlated with resistance to the same species of spittlebug nymphs, whether resistance to nymphs is expressed as plant damage or nymphal survival.

Contributors: C. Cardona, F. López, E. Zúñiga, G. Sotelo, J. Miles (CIAT)

Rationale

Both spittlebug nymphs and adults can cause severe economic damage on susceptible brachiariagrass pastures. Prior attention has been paid only to developing methodology to assess resistance to nymphs. Studies were conducted to assess the need to screen routinely for resistance to adults as well as to nymphs.

Materials and Methods

A preliminary study (López et al. 2009) sought to develop methodology reliably to assess host plant reaction to adult spittlebug feeding. When this methodology was applied to a small set of standard genotypes, thoroughly characterized for reaction to spittlebug nymphs, it became apparent that genotype ranking (resistant -> susceptible) for adult damage was different than for nymphs.

A subsequent study (Cardona et al., in preparation) assessed resistance to nymphs and to adults of several spittlebug species on a common set of 164 genotypes.

Results and Discussion

The correlations between resistance to spittlebug adults (plant damage score) and nymphal survival were low ($r = 0.104$ to 0.191, for three species). Where resistance to nymphs was expressed as plant damage, the estimated correlations were slightly higher, but only marginally so ($r = 0.119$ to 0.226). We conclude that resistances to the two insect life stages are essentially independent genetically, and that both will need to be assessed separately in routine screenings in the breeding program.

The correlations between different spittlebug species for adult damage ($r = 0.463$ to 0.558) were of the same order of magnitude as the correlations between different species of nymphs.

Hence, it seems that routine assessment of host plant reaction to adult feeding of several different spittlebug species will be required in the breeding program.

1.3.5 Characterization of resistance in *Brachiaria* to spittlebug adults

Highlight

- No true antibiosis to adults was detected, even when adults were forced to feed on roots of *Brachiaria* genotypes with known high levels of antibiosis resistance to nymphs. The lesser damage caused on host genotypes resistance to adult feeding (e.g., cv. Marandu) was not owing to the insects feeding less on resistant than on susceptible genotypes. Resistance to adult spittlebugs can be characterized as tolerance rather than antixenosis.

Contributors: C. Cardona; L.M. Aguirre; G. Sotelo (CIAT)

Rationale

The design of an effective and efficient strategy for developing resistance to the threat of spittlebug damage requires a characterization of resistance to adults as well as to nymphs and an understanding the genetic relation between resistance to the two different insect life stages.

Materials and Methods

1. *Antibiosis to spittlebug adults in Brachiaria roots*. *Brachiaria* genotypes that are resistant to spittlebug adults do not negatively affect the adult insect when feeding (as is normal) on leaves. Host genotypes resistant to nymphs markedly affect their survival when they feed (as is normal) on roots. Adults of three spittlebug species were forced to feed on roots to determine if the antibiotic effect in *Brachiaria* roots that affects nymphal survival also affects survival of adults.

2. *Evaluation of the possible role of antixenosis in resistance to spittlebug adults*. Spittlebug adults are xylem feeders. They ingest relatively large volumes of liquid from leaf xylem. Food ingested by adults of three spittlebug species feeding on plants of resistant or susceptible *Brachiaria* genotypes was estimated to determine whether observed resistance (less damage to resistant plants) is owing to some plant factor that results in less feeding.

Results and Discussion

1. *Antibiosis to spittlebug adults in Brachiaria roots*. No negative effect on adult longevity was detected for spittlebug adults forced to feed on roots of a *Brachiaria* genotype with strong antibiosis resistance to spittlebug nymphs.

2. *Evaluation of antixenosis in resistance to spittlebug adults*. Adults of three spittlebug species fed more on a resistant than on a susceptible host genotype.

Resistance to feeding of spittlebugs adults can be classified as tolerance, an inherent characteristic of the plant that simply reacts less than a susceptible genotype to a given level of insect infestation.

Resistance to spittlebug adult feeding appears to be the result of physiological (and genetic [see Sub-activity 2.3]) causes largely different from those that confer resistance to nymphs. We conclude that resistances to both life stages need to be assessed and weighed appropriately among the criteria of selection in the *Brachiaria* breeding program.

1.4. *Brachiaria* breeding: Rhizoctonia resistance

1.4.1 Characterize reaction to Rhizoctonia foliar blight of newly developed, promising apomictic hybrids (series BR02; MX02; BR04; BR05; BR06)

Highlight

- While significant differences were detected among hybrids, none can be classified as resistant to Rhizoctonia foliar blight.

Contributors: E. Álvarez, X. Bonilla, G. Sotelo, J. Miles (CIAT)

Rationale

Newly perfected screening methodology has allowed greater precision in assessment of host plant reaction to *Rhizoctonia solani* than had heretofore been possible. All hybrids being considered for commercial release require characterization for their reaction to Rhizoctonia foliar blight.

Materials and Methods

Seventy-one hybrid genotypes (Series BR02, MX02, BR04, BR05, and BR06) and checks were vegetatively propagated and artificially inoculated with *Rhizoctonia solani*. Damage symptoms were assessed visually.

Results and Discussion

Perhaps not surprisingly, given that essentially no attention has been given to improving host-plant resistance to Rhizoctonia foliar blight, most of the genotypes tested were found to be susceptible. Genetic differences were detected, and we believe that it will be possible in the future to improve resistance by judicious selection on reliable phenotypic data from artificially inoculated trials.

A cautionary note regarding the repeatability of our screening methodology is raised by comparing the results of two trials of the same set of 30 genotypes (28 BR06 clones, plus two checks), the first of these two trials having ten replications, the second five replications. Differences among genotypes means were declared highly significant (by ANOV). However, the correlation of mean damage scores over genotypes did not differ from zero, whether the two checks were included or not ($r = 0.014$, or $r = -0.050$, respectively).

1.4.2 Assess resistance to Rhizoctonia of SX08 selections and cull

Contributors: E. Álvarez, X. Bonilla, G. Sotelo, J. Miles (CIAT)

Rationale

Based on visual assessment of testcross progeny performance in two field trials, just over 52% of 175 sexual, maternal clones have been culled. The remaining 84 sexual clones need rigorous culling on *per se* reaction to Rhizoctonia foliar blight prior to recombining during second semester of 2010.

Materials and Methods

Standard screening methodology will be employed on vegetative replicates of the SX08 clones of interest.

Results and Discussion

It is anticipated that results of these screenings will be available by 01 July 2010.

1.4.3 Assess reaction to Rhizoctonia foliar blight in a set of 77 clones derived from crosses with CIAT 16320

Highlight

- Genetic variation for reaction to Rhizoctonia foliar blight detected in a set of 77 clones derived from crosses with Rhizoctonia-resistant *B. brizantha* accession CIAT 16320.

Contributors: E. Álvarez, X. Bonilla, G. Sotelo, J. Miles (CIAT)

Rationale

Crosses of Rhizoctonia-resistant *B. brizantha* accession CIAT 16320 with sexual clones from our tetraploid sexual "*decumbens/brizantha*" breeding population were made several years ago, with the goal of introgressing the high level of Rhizoctonia resistance found in the *B. brizantha* accession into the sexual population. This project was not pursued at the time owing to methodological deficiencies for reliably screening large populations for reaction to Rhizoctonia foliar blight. With recent methodological developments, attention to this project has been renewed.

Materials and Methods

Seventy-seven putatively sexual clones deriving from crosses with Rhizoctonia-resistant CIAT 16320 were replicated vegetatively 10 times and artificially inoculated. Disease development was assessed visually.

Results and Discussion

Accession CIAT 16320 consistently shows its high level of disease resistance. Mean disease damage score ranged from 2.6 to 4.2 (on a 5-point scale) among the 77 hybrid-derived clones. None of the 77 clones was as resistant as CIAT 16320 (mean of 1.7 on the visual damage scale).

Twelve clones showing least disease damage were propagated and recombined in an isolated crossing block to form a tetraploid sexual "Rhizoctonia population". Assessment of the progeny of these selected clones will determine the potential for the development of high levels of Rhizoctonia resistance by selection.

1.5 *Brachiaria* breeding: Waterlogging tolerance

1.5.1 Continue screening a "waterlogging tolerance synthetic sexual population"; select most tolerant genotypes and recombine

Highlight

- A large sexual population (500 unique genotypes) was screened for tolerance to waterlogging and 20 clones selected to recombine.

Contributors: I. Rao, J. Rincón, A. Betancourt, J. Miles (CIAT)

Rationale

A decision was made to form a "Waterlogging tolerance" sexual population, applying intense selection strictly on this one character in order to develop high levels of resistance that could subsequently be introgressed into our main tetraploid sexual synthetic breeding population.

Materials and Methods

A routine screening of a set of 31 SX05 clones identified five clones apparently less sensitive to waterlogging damage. These five clones were recombined in an isolated crossing block and 500 progeny plants generated. These 500 clones were assessed for waterlogging tolerance and 20 clones selected to again recombine. The 20 clones were propagated five times each and the resulting 100 plants completely randomized in an isolated crossing block. Open pollinated seed was hand harvested on individual plants in 2009.

Results and Discussion

Seed has been harvested and is awaiting germination and subsequent evaluation for tolerance to waterlogging of the resulting progenies.

1.5.2. Assess tolerance to waterlogging of SX08 selections and cull

Contributors: I. Rao, J. Rincón, A. Betancourt, J. Miles (CIAT)

Rationale

Based on visual assessment of testcross progeny performance in two field trials, just over 52% of 175 sexual, maternal clones have been culled. The remaining 84 sexual clones need rigorous culling on *per se* reaction to waterlogging stress prior to recombining during second semester of 2010.

Materials and Methods

This activity will be pursued during first semester, 2010.

Results and Discussion

None to date (12 January 2010).

1.5.3 *Brachiaria* breeding: Forage nutritional quality

1.5.3.1. Assess crude protein content and dry matter digestibility of 28 BR06 selections

Highlight

- Differences among 28 selected hybrids were detected for both *in-vitro* digestibility as well as crude protein content.

Contributors: S. Martens, P. Ávila, J. Miles (CIAT)

Rationale

Forage nutritional quality is an important character in any forage breeding program, as it impacts directly on animal performance.

Materials and Methods

A set of 28 selected BR06 apomictic hybrids and three checks (cvv. Basilisk, Marandu, and Mulato II) were established in a small-plot, replicated trial at Quilichao in June 2008. Two samplings were taken (29 April, and 24 September 2009) for determinations of digestibility and crude protein by NIRS. Data from the two dates were submitted to a combined analysis of variance.

Results and Discussion

<u>IVDMD</u>: Differences among genotypes and between sampling dates were highly significant, though not large (particularly between sampling dates) (Range: 56.7 - 62.4% among genotypes; 58.5 - 59.2% between sampling dates). No interaction between genotype and sampling date was detected, suggesting that reliable genotype ranking for this trait may not require extensive sampling.

<u>CP</u>: Highly significant differences were detected for genotype and for sampling date, though, as for digestibility, differences, particularly between sampling dates, were not large (Range: 14.7 - 18.2% among genotypes; 16.1 - 17.1% between sampling dates). The genotype-sampling date interaction, while "significant" (at the $\alpha = 0.05$, but not at the $\alpha = 0.01$ probability level), was a relatively unimportant effect as compared with genotype.

A considerable degree of heterogeneity of variance among genotypes was detected. This suggests that there may be room for improvement in sampling procedures and processing of samples for NIRS or introduction of blockwise physical and statistical treatment.

1.5.4 *Brachiaria* breeding: Developing a broad-based, synthetic sexual *B. humidicola* breeding population

1.5.4.1 Continue (and complete) harvest of open-pollinated seed from individual plants in segregating progenies in our 2008 progeny trial

Highlight

- Open-pollinated seed hand harvested from over 400 individual plants in segregating families.

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

Rationale

Sustained genetic advance in *B. humidicola* breeding requires a sexual germplasm as broadly based genetically as it is possible. We are attempting to incorporate genes from the entire tetraploid *B. humidicola* collection into sexual germplasm.

Materials and Methods

Nineteen tetraploid *B. humidicola* germplasm accessions and 13 hybrids were established in a space-planted crossing block at CIAT-Popayán in 2007. Open-pollinated progenies of each genotype were transplanted to a field trial at CIAT-Quilichao in 2008, with two objectives: 1) to identify sexual and apomictic genotypes among the 13 hybrids and 19 germplasm accessions, and 2) to harvest seeds resulting from open-pollinated from individual plants in segregating progenies (progenies of sexual maternal genotypes) for subsequent progeny-testing.

The individual plants in segregating progenies are assumed to be the open-pollinated progenies of sexual plants in the 2007 CIAT-Popayán crossing block. Hence, these individual plants in segregating progenies should, as a group, contain more or less the entire genetic diversity of the CIAT tetraploid *B. humidicola* germplasm collection, since their (sexual) mothers were exposed to pollen from plants of this collection. These individual plants in segregating progenies, being the result predominantly of sexual-by-apomictic crosses, are expected to segregate for reproductive mode.

Results and Discussion

Segregating progenies were identified. Approximately one-half of the small set of hybrids produced segregating progenies (see 2008 Ann. Rep.). This result is consistent with genetic control of apomixis by a single, dominant Mendelian factor, as has been reported by C.B. do Valle and colleagues of Embrapa.

Only one of the 19 germplasm accession (CIAT 26146) proved to be sexually reproducing, i.e., produced a segregating progeny. Three additional tetraploid *B. humidicola* accessions labelled in the CIAT GRU data bases as sexually reproducing (CIAT 16871, CIAT 26155, and CIAT 26181), produced uniform progenies, indicating apomictic, rather than sexual reproduction.

Over all, the segregating progenies contained 413 individual progeny plants. As these plants flowered and set seed, they were hand harvested from individual plants over a period of 11 months (October 2008, to September 2009).

1.5.4.2 Progeny-test the plants harvested in 1.5.4.1(above). Identify fully sexual plants to recombine in isolated crossing block (in 2010)

Highlight

- One hundred forty-six (of over 400) families established in a field progeny trial.

Contributors: A. Betancourt, J. Miles (CIAT)

Rationale

Sustained genetic advance in *B. humidicola* breeding requires a sexual germplasm as broadly based genetically as it is possible. We are attempting to incorporate genes from the entire tetraploid *B. humidicola* collection into sexual germplasm.

Materials and Methods

Seed of the early harvests (October 2008, to May 2009) was hand scarified and sown in the greenhouse in September 2009. Progenies of individual plants (2,155 individuals) were transplanted to a space-planted field trial during January 2010 in 5-plant family plots, with 1 to 5 replications (5 to 25 individuals per family).

More recently harvested seeds (June to September 2009) will be germinated in early 2010 for families with few or no progenies already established in the first planting.

Results and Discussion

Progenies of 146 of the 413 maternal plants were transplanted to the field trial.

Assessment of the plant-to-plant uniformity within these progenies will allow the identification of the progenies of sexual plants. The sexual mothers, which are expected to contain the diversity of tetraploid *B. humidicola* germplasm available, will then be recombined to form a broad-based synthetic sexual breeding population.

The merit of apomictic progenies identified in the progeny trial will be assessed for commercial potential.

1.6 Genotypes of *Brachiaria* with adaptation to abiotic constraints

Highlights

- Eleven *Brachiaria* genotypes including parents and promising hybrids were evaluated for root development under individual and combined stress factors of low soil fertility and drought. Two apomictic hybrids (BR02/1752 and BR02/1372) and one sexual hybrid (SX03/2367) were found to be outstanding in their total root length production across soil depth under combined stress factors of low soil fertility and drought.
- A total of 79 *Brachiaria* genotypes including 71 promising *Brachiaria* hybrids were evaluated for their resistance to drought when grown in pots with high fertilizer application. One *Brachiaria* hybrid, BR06/1932, was found to be outstanding in its drought adaptation as determined by green leaf biomass production and green leaf biomass proportion. But its water use for growth was also greater than the other hybrids. Another hybrid, BR06/1922, was identified to be capable of producing greater green leaf biomass proportion with moderate use of soil water.
- Evaluation of 500 *Brachiaria* hybrids from the IN08 population resulted in identification of one hybrid, IN08/313, as outstanding in terms of waterlogging tolerance based on green leaf biomass production. Green leaf biomass proportion to total shoot biomass was identified as a useful selection index to evaluate waterlogging tolerance.
- Phenotypic differences in the anatomy of roots of six *Brachiari*a genotypes with contrasting levels of tolerance to waterlogging were determined. Results indicated that the higher percentage of aerenchyma formation and its supposedly constitutive nature in two highly waterlogging tolerant accessions of *B. humidicola* (CIAT 6133 and CIAT 679) should be of adaptive advantage at the onset of and during waterlogging.

1.6.1 Phenotypic differences in root development and distribution of eleven *Brachiaria* genotypes exposed to individual and combined stress of aluminum toxic acid soil and drought

Contributors: J. Polanía, G. Borrero, J. Miles and I. M. Rao (CIAT)

Rationale

Aluminum (Al) toxicity affects root development which in turn affects the acquisition of nutrients and water. There is very limited knowledge on the physiological and biochemical bases of *Brachiaria* grass' adaptation to either individual or combined stress factors of drought and Al toxicity. Seasonal drought affects both quantity and quality of forage in tropical savanna environments. *Brachiaria* grasses differ in their level of drought resistance. *B. brizantha* CIAT 6780 and *B. decumbens* CIAT 606 were found to be relatively more adapted to drought stress. Our objective was to determine phenotypic differences in root development and distribution of eleven *Brachiaria* genotypes that were exposed to individual and combined stress of aluminum toxic acid soil and drought stress conditions. This knowledge is needed to develop effective screening method(s) to evaluate *Brachiaria* hybrids generated by the *Brachiaria* breeding program at CIAT for their level of resistance to combined stress of drought and Al toxicity.

Materials and methods

A greenhouse study was conducted at CIAT-Palmira in 2009 using a soil from Matazul farm in the Llanos of Colombia. Plants were grown for 49 days in plastic cylinders (80 cm long with 7.5 cm diameter) that were inserted in PVC tubes. The trial included 11 *Brachiaria* genotypes: two apomictic *Brachiaria* parents (*Brachiaria decumbens* cv. Basilisk CIAT 606, *Brachiaria brizantha* cv. Marandú CIAT 6294), one sexual *Brachiaria* parent (*B. ruziziensis* 44-02), two commercial *Brachiaria* hybrids (*Brachiaria* hybrid cv. Mulato CIAT 36061, *Brachiaria* hybrid cv. Mulato 2 CIAT 36087), three apomictic hybrids from BR02 population (BR02/1752, BR02/0465, BR02/1372), and three sexual hybrids from SX03 population (SX03/0846, SX03/0881 and SX03/2367) to determine genotypic differences in root development and distribution under individual and combined stress of Al-toxic acid soil and drought. The trial was planted as a randomized complete block arrangement with two levels of water supply: 100% field capacity (well-watered) and withholding of watering (to simulate terminal drought stress conditions) and two levels of fertilizer application to soil: high fertilizer application in which the soil was fertilized with adequate level of nutrients (kg/ha of 80 N, 50 P, 100 K, 101 Ca, 29.4 Mg, 20 S, 2 Zn, 2 Cu, 0.1 B and 0.1 Mo) and low fertilizer application in which the soil was fertilized with kg/ha of 20 P, 20 K, 47 Ca, 14 Mg and 10 S; as main plots and genotypes as sub-plots with three replications. Table 1 shows the details on soil characteristics. Treatments of water stress were imposed after 10 days of initial growth of plants that were established with stem cuttings. The initial soil moisture for all the treatments was of 100% field capacity. Plants with well-watered treatment were maintained by weighing each cylinder every two days and applying water to the soil at the top of the cylinder. Plants with terminal drought were monitored for water stress by weighing each cylinder every two days for determination of decrease in soil moisture. Plants were harvested at 49 days after establishment, i.e., 39 days of withholding of water application.

Table 1. Soil characteristics with high and low fertilizer application

Fertilizer application	pH	AL	Ca	Mg	K	P ($mg\ kg^{-1}$)	Al saturation (%)	Bulk density ($g\ cm^{-3}$)
			($cmol\ kg^{-1}$)					
Low	4.7	2.65	0.12	0.05	0.08	4.2	91	1.5
High	4.5	2.45	0.18	0.05	0.13	7.8	87	1.5

A number of shoot traits were measured during the experiment, including total chlorophyll content (SPAD), photosynthetic efficiency, leaf conductance and rooting depth. At harvest time (49 days after planting; 39 days with water stress treatment), leaf area, shoot biomass distribution, and root traits were determined. The soil from the tube was removed and sliced into 6 layers (0-5, 5-10, 10-20, 20-40, 40-60 and 60-75). Roots in each soil layer were washed free of soil and root length, mean root diameter, specific root length, and root dry weight, fine root proportion (root length with 0 and 0.5 mm of diameter/total root length x 100) were determined. Root length and mean root diameter were measured with an image analysis system (WinRHIZO, Regent Instruments Inc). Root weight was determined after roots were dried in an oven at 60 ^{o}C for 48 h.

Results and discussion

During the plant growth and development the maximum and minimum air temperatures were 34 and 20 ^{o}C (Figure 1). The final soil moisture with terminal drought stress was at 56% of the field capacity. Significant genotypic differences were observed in leaf biomass under drought stress. Under irrigated and high fertilizer application conditions the genotypes CIAT 6294 and

BR02/1752 were outstanding in their leaf biomass production, while under individual drought stress (drought with high fertilizer) the apomictic hybrids BR02/1372 and BR02/1752 were superior to other genotypes in leaf biomass production (Figure 2). The low fertilizer application significantly reduced the leaf biomass production. Under individual low fertilizer + irrigated conditions the genotypes SX03/2367, CIAT 36087 and BR02/1752 showed the highest leaf biomass. Under combined low fertilization and drought stress BR02/1752 and SX03/2367 were outstanding in leaf biomass production (Figure 3). The apomictic hybrid BR02/1752 was particularly outstanding in leaf production among genotypes tested under both fertilizer and water regimes.

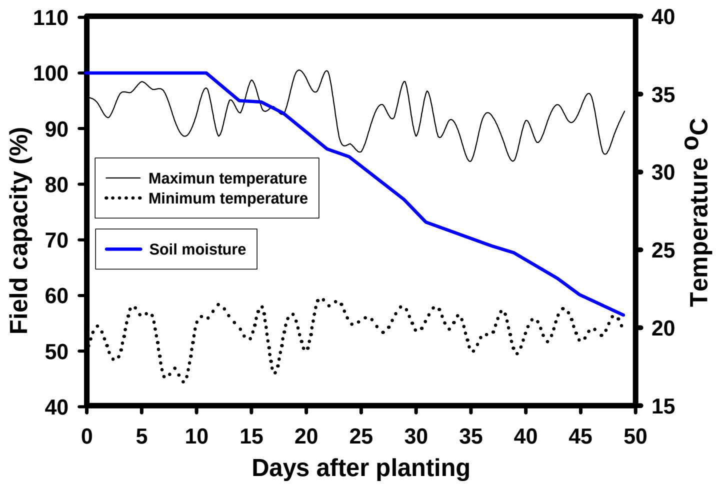

Figure 1. Soil moisture (field capacity), maximum and minimum temperature during soil drying and root development in soil tubes under greenhouse conditions of CIAT, Palmira.

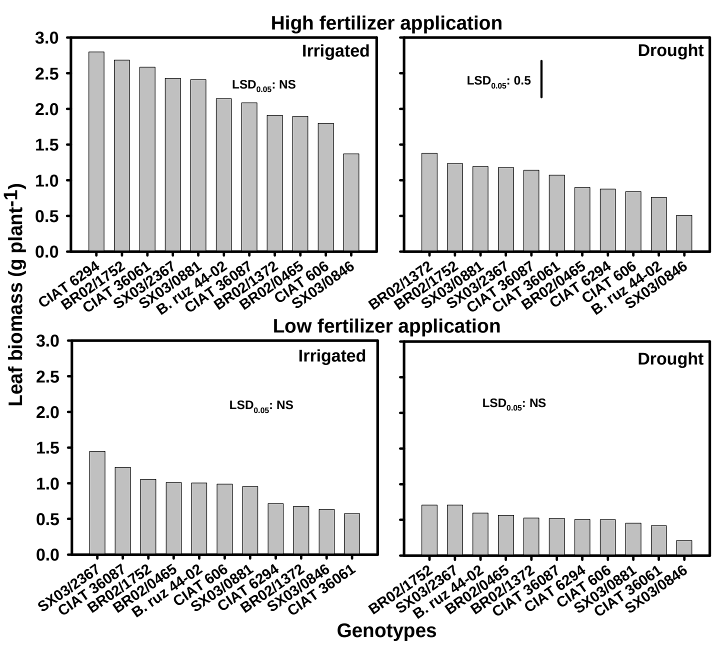

Figure 2. Influence of individual and combined stress of low soil fertility and drought on leaf biomass of 11 *Brachiaria* genotypes under greenhouse conditions of CIAT, Palmira.

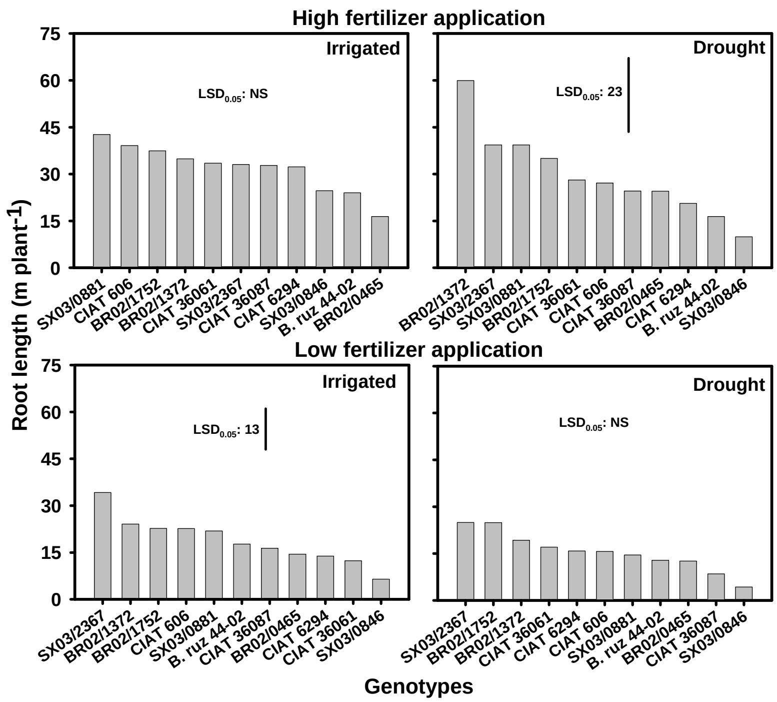

Figure 3. Influence of individual and combined stress of low soil fertility and drought on total root length of 11 *Brachiaria* genotypes that were grown under greenhouse conditions of CIAT, Palmira.

Genotypic differences were observed in photosynthetic efficiency and leaf conductance at 44 days after planting under individual low fertilization and combined low fertilization and drought stress. Under individual drought stress conditions (high fertilizer + terminal drought) two genotypes BR02/1372 and BR02/1752 showed the lower values of leaf conductance than the others genotypes tested, indicating stomata control (Table 2). Under combined low fertility and drought stress conditions the genotypes that showed the regulation of stomatal conductance were SX03/0881, SX03/2367 and CIAT 6294.

Differences were observed in deep rooting among treatments. Under irrigated and high fertilizer application the genotypes CIAT 36061 and SX03/0881 showed greater ability for deep rooting at 43 days after planting than the other genotypes while the genotypes CIAT 606 and CIAT 6294 had lesser ability for deep rooting (Table 3). Three genotypes (CIAT 36061, SX03/0881 and BR02/1752) were outstanding in deep rooting ability under individual drought stress. Three genotypes (CIAT 36061, SX03/0881 and B. ruz 44-02) showed greater deep rooting ability than the other genotypes when grown under individual low soil fertility stress. The hybrids BR02/1752 and CIAT 36061 were outstanding in their deep rooting ability at 43 days after planting under combined low soil fertility and drought stress while SX03/0846, CIAT 6294 and CIAT 36087 showed lesser ability for deep rooting under combined stress conditions (Table 3).

Table 2. Influence of individual and combined stress factors of low soil fertility and drought on photosynthetic efficiency, leaf chlorophyll and leaf conductance of 11 *Brachiaria* genotypes that were grown under greenhouse conditions of CIAT, Palmira (I, irrigated and TD, terminal drought).

Genotype	Photosynthetic efficiency (fv'/fm')				Leaf chlorophyll content (SPAD)				Leaf conductance (mmol m^{-2} s^{-1})			
	High fertilizer		Low fertilizer		High fertilizer		Low fertilizer		High fertilizer		Low fertilizer	
	I	TD	I	TD	I	TD	I	TD	I	TD	I	TD
B. ruz 44-02	0.60	0.58	0.47	0.51	52.5	48.9	53.6	47.5	48.8	55.7	59.6	45.2
BR02/0465	0.56	0.58	0.59	0.59	50.6	45.2	43.6	46.6	76.4	35.7	58.7	54.5
BR02/1372	0.64	0.63	0.64	0.58	45.5	47.1	42.2	42.8	44.1	16.4	43.7	39.7
BR02/1752	0.58	0.54	0.59	0.59	46.4	49.8	43.5	46.8	28.7	16.2	39.0	36.4
CIAT 36061	0.56	0.56	0.58	0.54	51.0	54.4	49.6	54.6	62.9	34.7	47.1	59.8
CIAT 36087	0.49	0.55	0.63	0.54	48.3	46.9	46.5	45.9	65.6	46.4	36.3	34.9
CIAT 606	0.59	0.63	0.60	0.55	41.3	38.7	43.2	41.1	47.4	34.9	44.1	32.8
CIAT 6294	0.63	0.60	0.56	0.37	48.2	41.0	45.9	44.2	55.8	66.4	57.1	28.9
SX03/0846	0.61	0.61	0.63	0.57	43.0	44.2	46.5	41.0	71.4	43.2	39.6	35.4
SX03/0881	0.59	0.62	0.58	0.53	43.8	42.0	39.7	42.1	60.0	31.3	77.7	32.6
SX03/2367	0.62	0.58	0.61	0.53	52.6	47.5	47.0	52.9	58.6	24.5	67.7	30.2
Mean	**0.59**	**0.59**	**0.59**	**0.54**	**47.6**	**46.0**	**45.6**	**45.9**	**56.3**	**36.9**	**51.9**	**39.1**
$LSD_{0.05}$	**NS**	**NS**	**0.07**	**0.12**	**NS**	**NS**	**NS**	**5.5**	**NS**	**NS**	**28.9**	**25.4**

Significant genotypic differences were observed in total root length under individual terminal drought stress conditions and individual low fertility conditions. The apomictic hybrid BR02/1372 and the sexual hybrid SX03/2367 showed greater values of root length production under individual terminal drought stress conditions (Figure 4). The hybrids SX03/2367, BR02/1372 and BR02/1752 showed the best performance in root length development under low soil fertility conditions.

Table 3. Influence of individual and combined stress factors of low soil fertility and drought on deep rooting at 31 and 43 days after planting of 11 *Brachiaria* genotypes that were grown under greenhouse conditions of CIAT, Palmira (I, irrigated and TD, terminal drought)

Genotype	Deep rooting at 31 days after planting (cm)				Deep rooting at 43 days after planting (cm)			
	High fertilizer		Low fertilizer		High fertilizer		Low fertilizer	
	I	TD	I	TD	I	TD	I	TD
B. ruz 44-02	37	40	48	55	50	70	62	67
BR02/0465	35	35	41	31	41	67	44	53
BR02/1372	37	53	54	29	51	75	59	55
BR02/1752	**55**	**56**	**39**	**54**	**58**	**75**	**54**	**75**
CIAT 36061	55	56	61	52	66	75	75	74
CIAT 36087	32	38	29	25	48	70	53	38
CIAT 606	31	31	39	46	41	64	50	64
CIAT 6294	24	23	19	27	40	48	30	42
SX03/0846	33	32	31	32	47	50	38	48
SX03/0881	42	66	41	41	63	75	68	66
SX03/2367	31	61	34	39	52	74	60	63
Mean	**37**	**44**	**40**	**39**	**51**	**68**	**54**	**59**
$LSD_{0.05}$	**NS**	**23**	**NS**	**NS**	**NS**	**12**	**23**	**NS**

Two apomictic hybrids (BR02/1752 and BR02/1372) and one sexual hybrid (SX03/2367) were found to be outstanding in their total root length production across soil depth under combined stress of low fertility and drought. The sexual hybrid, SX03/0846, showed the lowest value of total root length production among genotypes and among soil fertility and water regimes tested (Figure 5). *B. decumbens* CIAT 606 and *B. brizantha* CIAT 6294 were outstanding in thin root development with the highest values of fine root proportion than the other genotypes tested under control (high fertilizer + irrigated) and individual and combined stress factors of low fertility and drought (Photo 1).

Drought stress increased the root length development in deep soil layers than under irrigated conditions. The sexual hybrid, SX03/0881 and the apomictic hybrid, BR02/1372 showed greater values of root length at soil depth of 60-75 cm under individual drought stress (Figure 5). The cv. Mulato (CIAT 36061) was the best in deep root development in terms of root length under low soil fertility conditions. The apomictic hybrid, BR02/1752 and cv. Mulato (CIAT 36061) were found to be outstanding in root length at soil depth of 60-75 cm under combined low soil fertility and drought stress indicating their superior adaptation to combined stress conditions (Figures 5 and Photo1). Two genotypes (CIAT 6294 and SX03/0846) showed poor development at soil depth of 60-75 cm than the other genotypes under individual and combined low soil fertility and drought stress conditions (Figure5).

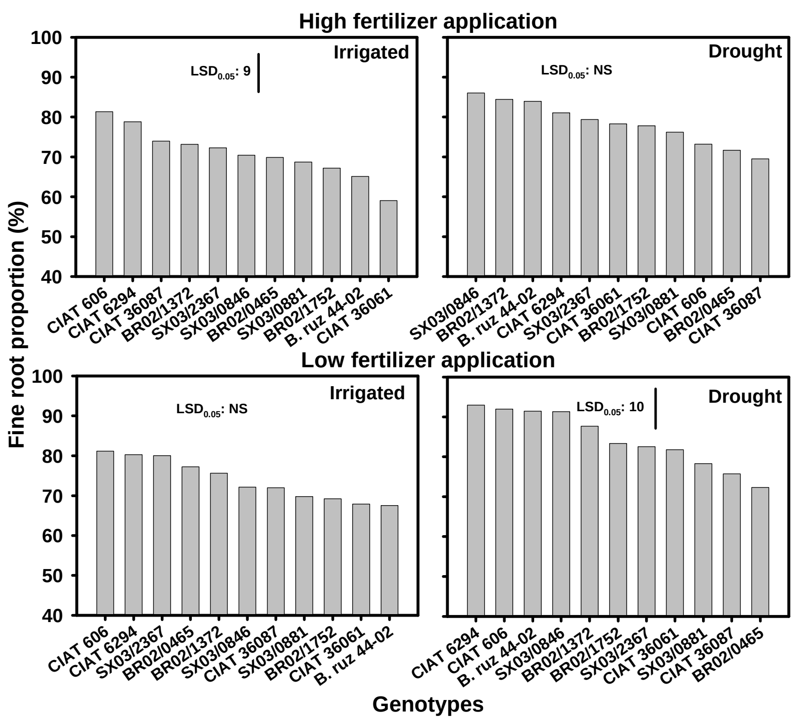

Figure 4. Influence of individual and combined stress of low soil fertility and drought on fine root proportion of 11 *Brachiaria* genotypes under greenhouse conditions at CIAT, Palmira.

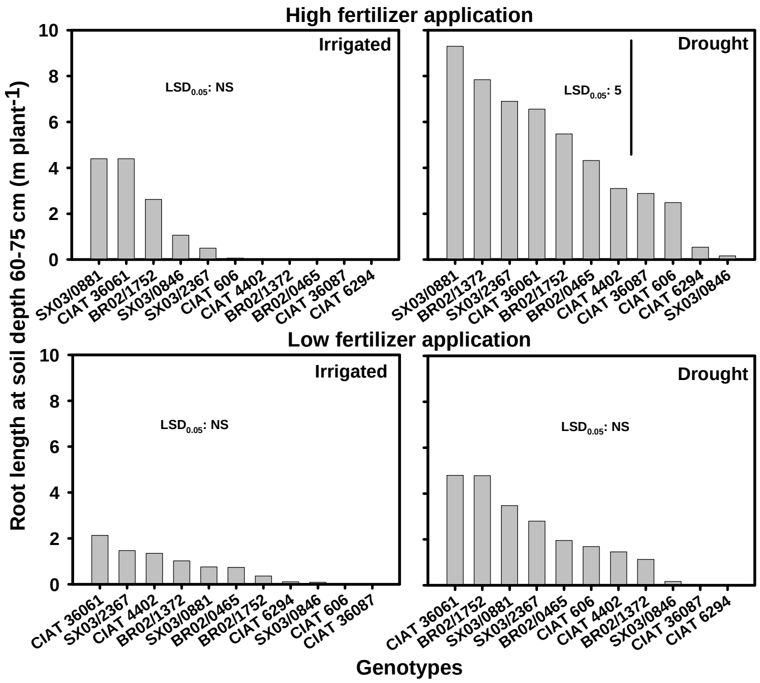

Figure 5. Influence of individual and combined stress factors of low soil fertility and drought on root length (at soil depth of 60-75 cm) of 11 *Brachiaria* genotypes grown under greenhouse conditions at CIAT, Palmira.

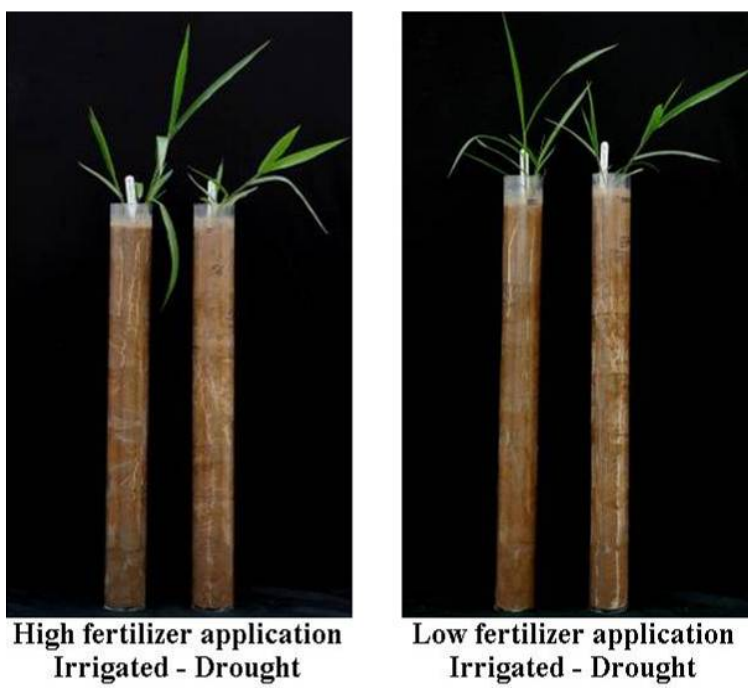

Photo 1. Influence of individual and combined stress factors of low soil fertility and drought on shoot and root development of an apomictic hybrid, BR02/1752, grown under greenhouse conditions of CIAT, Palmira (Photo by Neil Palmer).

Conclusions

Results from this greenhouse study indicated that two apomictic hybrids (BR02/1752 and BR02/1372) and one sexual hybrid (SX03/2367) were outstanding in their total root length production across soil depth under combined stress factors of low soil fertility and drought.

1.6.2 Phenotypic differences in drought resistance of 79 *Brachiaria* genotypes

Contributors: J. Polanía, G. Borrero, J. Miles and I. M. Rao (CIAT)

Rationale

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

Material and Methods

A greenhouse experiment using pots was conducted at CIAT Palmira to determine differences in resistance to drought among 79 *Brachiaria* genotypes (5 hybrids from BR02 series; 8 hybrids from BR04 series; 20 hybrids from BR05 series; 28 hybrids from BR06 series; 10 hybrids from MX02 series; and 8 checks). The trial was planted as a randomized complete block arrangement with 3 replications. Each pot was filled with 3.5 kg of fertilized top soil (0-20 cm) from Santander de Quilichao and sown with two stem cuttings. An adequate fertilizer was supplied (kg ha^{-1}: 80N, 50P, 100K, 66Ca, 28Mg, 20S, 2Zn, 2Cu, 0.1B and 0.1Mo) to soil at the time of planting. Plants were grown for 50 days at field capacity conditions. Terminal drought treatment was imposed by withholding water supply. At the time to induce terminal drought stress, all the pots were weighed and adequate amount of water was applied to reach to field capacity. During the drought stress treatment leaf chlorophyll content (SPAD) was measured. After 10 days under terminal drought stress, green leaf biomass (g $plant^{-1}$), dead leaf biomass (g $plant^{-1}$) and stem biomass (g $plant^{-1}$) were determined.

Results and discussion

During the plant growth and development the maximum and minimum air temperatures were 32 and 20 ^{o}C. Significant genotypic differences were observed in green leaf biomass production under terminal drought stress conditions. Five genotypes (BR06/1932, CIAT 26110, CIAT 6294, CIAT 36087 and BR06/0387) were found to be outstanding in their green leaf biomass production. Four genotypes (BR04/02405, BR04/02774, BR05/00744 and BR02/1752) were found to be inferior in their green leaf biomass production (Figure 6).

The inferior performance of BR02/1752 needs further confirmation since this genotype was outstanding in its level of drought adaptation under low soil fertility and drought stress conditions when evaluated with soil tubes. Significant genotypic differences were observed in green leaf biomass proportion (green leaf biomass/total leaf biomass x 100). Six genotypes (*B. ruziziensis* 44-02, CIAT 6133, BR06/1922, BR06/1278, MX02/02552 and MX02/03626) showed higher green leaf biomass proportion than the other genotypes tested. Six hybrids (BR06/1932, MX02/02531, BR06/1132, BR06/1433, BR06/2204 and BR02/1372) showed greater values of water loss by evapotranspiration among the genotypes tested while five genotypes (CIAT 6133, BR05/00563, B. ruz 44-02, BR02/1718 and BR06/1000) showed lower values of evapotranspiration (Figure 7).

The genotype BR06/1932 was outstanding in its green leaf biomass production and also showed higher value of green leaf biomass proportion. This same genotype also presented a higher value of evapotranspiration, indicating a high water use for its growth. However the apomictic hybrid BR06/1922 (Photo 2) combined a high green leaf biomass proportion with a moderate value of evapotranspiration.

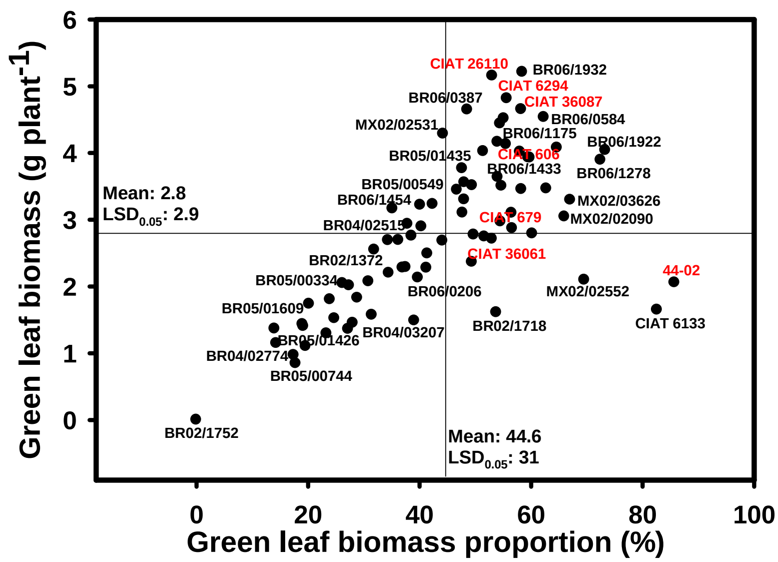

Figure 6. Identification of genotypes with higher green leaf production with higher green leaf biomass proportion (green leaf biomass/total leaf biomass) when grown under terminal drought stress at CIAT, Palmira. Genotypes with greater values of green leaf biomass and green leaf biomass proportion were identified in the upper, right hand quadrant.

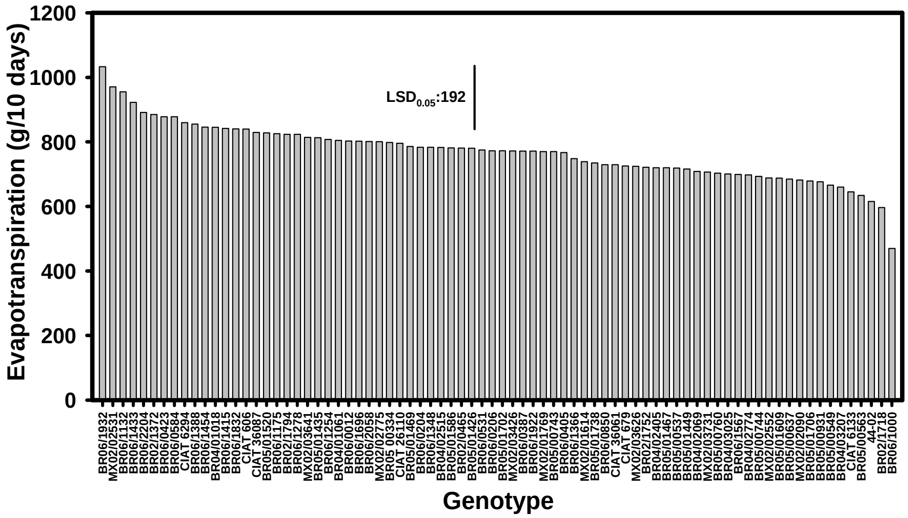

Figure 7. Differences in the amount of water lost through evapotranspiration of 79 *Brachiaria* genotypes when grown under terminal drought stress conditions for 10 days in pots at CIAT, Palmira.

Photo 2. Influence of 10 days of terminal drought stress on the appearance of an apomictic hybrid (BR02/1922) when grown in a pot under greenhouse conditions at CIAT, Palmira.

Conclusions

Results from this greenhouse study indicated that the *Brachiaria* hybrid, BR06/1932, was outstanding in its drought adaptation as determined by green leaf biomass production and green leaf biomass proportion. But its water use for growth was also greater than the other hybrids. Another hybrid, BR06/1922, was identified to be capable of producing greater green leaf biomass proportion with moderate use of soil water.

1.6.3 Genotypic variation in waterlogging tolerance of 508 *Brachiaria* genotypes

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

Rationale

In the tropics, *Brachiaria* pastures during the rainy season occasionally face waterlogging conditions that severely limit pasture productivity and animal performance. Waterlogging or flooding reduces the availability of soil oxygen to the plant. Since 2005 we have been using a screening method to identify *Brachiaria* genotypes that are tolerant to waterlogging. The main objective of this work was to screen a large population of *Brachiaria* hybrids that were specifically developed in 2008 to improve waterlogging tolerance.

Material and methods

One trial was conducted outside in the Forages patio area of CIAT Palmira during 2009 to determine differences in tolerance to waterlogging among 508 *Brachiaria* genotypes (500 hybrids from IN08NO series; 3 parents - *B. decumbens* CIAT 606; *B. ruziziensis* 44-02; *B. brizantha* CIAT 6294 and 5 checks – *B. brizantha* CIAT 26110; *Brachiaria* hybrid cv. Mulato CIAT 36061; *Brachiaria* hybrid cv. Mulato 2 CIAT 36087; *B. humidicola* CIAT 679; *B. humidicola* CIAT 6133). The trial was replicated twice over time.

Mean values of two replications with statistical analysis are reported. Each experimental unit within each replication consisted of one pot filled with 1.25 kg of top soil (0-20 cm) from Santander de Quilichao (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 60 days under field capacity conditions before applying waterlogging treatment. Waterlogging treatment was imposed by an excessive water supply (5 cm over soil surface) for 10 days.

Leaf chlorophyll content (in SPAD units) was measured at weekly intervals on a full expanded young leaf marked at the initiation of waterlogging treatment. At the end of the 10 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 as % of total leaf biomass.

Results and discussion

Weather conditions during the two replications were similar (Table 4). Most of the genotypes showed above 50% of dead leaves. A high variability in waterlogging tolerance was observed within IN08 population (Table 5). Relationships between total chlorophyll content, leaf area, green leaf biomass and dead leaf biomass vs green leaf biomass proportion to total leaf biomass are shown in Figures 8 to 11.

Table 4. Weather conditions during the trial with 2 replications over time to evaluate 508 *Brachiaria* genotypes

Trial conditions	Replication 1	Replication 2
Date of establishment	27 January 2009	16 February 2009
Temperature	Maximum 27.5 - 32.3 Minimum 17.4 - 20.4	Maximum 30.3 - 32.6 Minimum 18 - 20
Solar radiation	12 to 20 MJ m^{-2} d^{-1}	14.1 to 22 MJ m^{-2} d^{-1}
Effective sunshine hours per day	4.54	4.64
Date of harvest	6 February 2009	26 February 2009

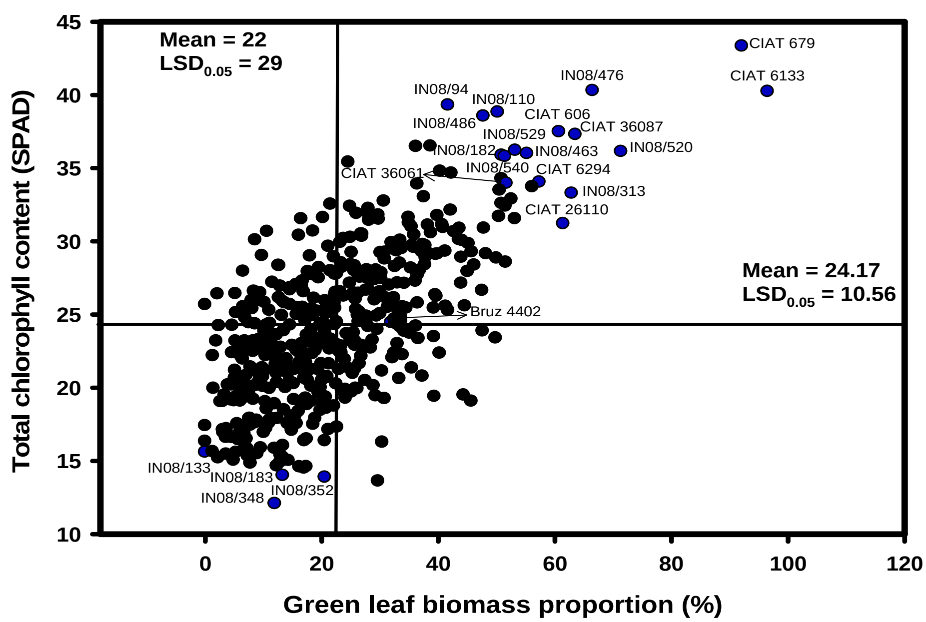

Figure 8. Relationship between total chlorophyll content (SPAD) and green leaf biomass proportion to total leaf biomass of 508 *Brachiaria* genotypes after 10 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia.

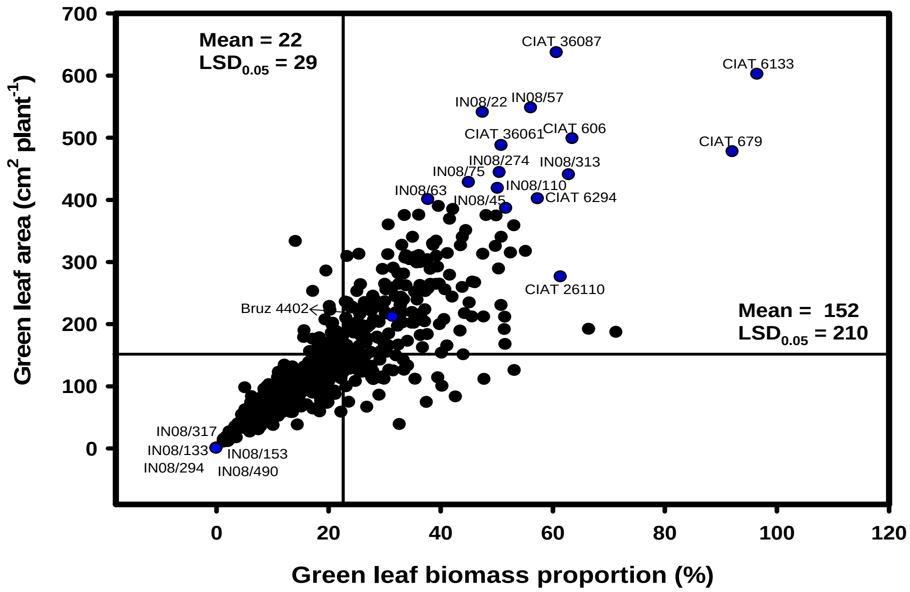

Figure 9. Relationship between green leaf area and green leaf biomass proportion to total leaf biomass of 508 *Brachiaria* genotypes after 10 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia.

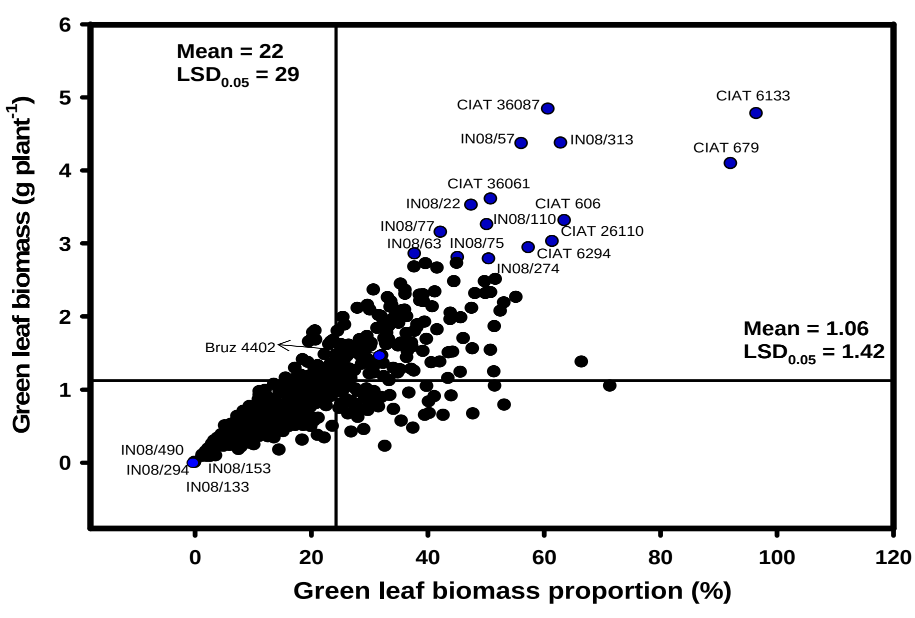

Figure 10. Relationship between green leaf biomass and green leaf biomass proportion to total leaf biomass of 508 *Brachiaria* genotypes after 10 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia.

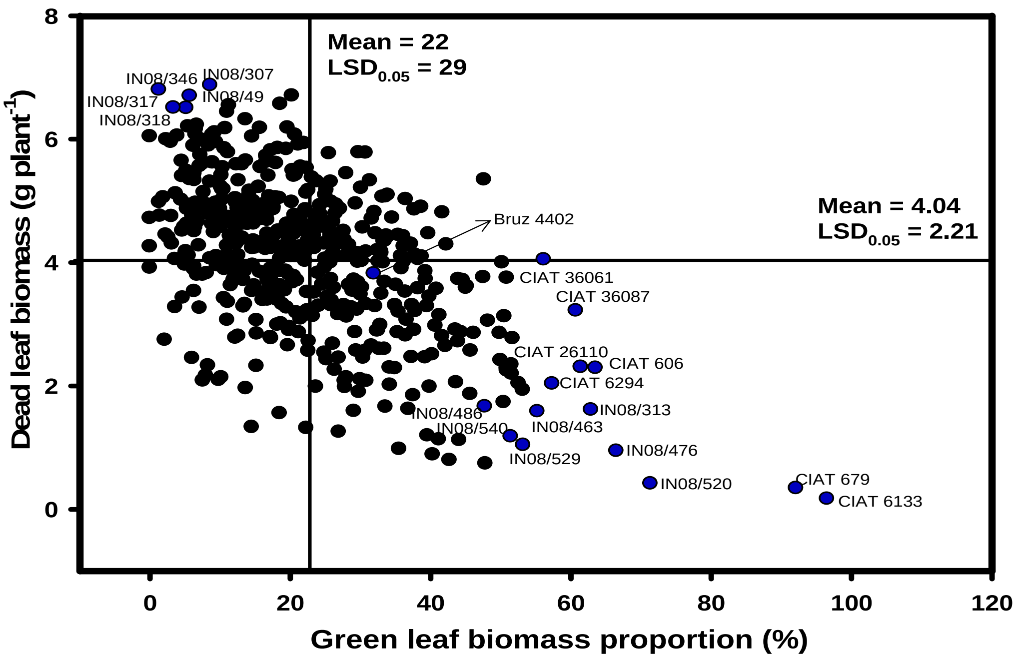

Figure 11. Relationship between dead leaf biomass and green leaf biomass proportion to total leaf biomass of 508 *Brachiaria* genotypes after 10 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia.

The checks CIAT 6133 and CIAT 679 showed higher leaf chlorophyll content than the other genotypes under waterlogging conditions (Figure 8). These genotypes were also found to be outstanding in their leaf area and green leaf biomass values, combined with lower dead leaf biomass among the genotypes tested under waterlogging conditions (Figures 8 to 11). The greater level of waterlogging tolerance of these genotypes was associated with greater values of green leaf biomass and leaf area, and lower values of dead leaf biomass.

One of the parents, *B. ruziziensis* 44-02 had lower values of leaf chlorophyll content, green leaf biomass, leaf area, green leaf biomass proportion to total leaf biomass than the other parents and checks tested. This genotype also showed a higher value of dead leaf biomass. These observations are consistent with previous studies conducted at CIAT.

Four *Brachiaria* hybrids (IN08/313, IN08/57, IN08/22 and IN08/110) were found to be outstanding in their level of waterlogging tolerance based on green leaf biomass production and leaf area among the 500 hybrids tested. Among these four hybrids, the hybrid IN08/313 showed the highest value of green leaf biomass proportion to total leaf biomass (Table 5).

Four *Brachiaria* hybrids (IN08/153, IN08/133, IN08/490 and IN08/294) were found to be very sensitive to waterlogging conditions based on the values of green leaf biomass and leaf area (Figures 9 and 10; Table 5).

Table 5. Green leaf biomass, green leaf area, total chlorophyll content, dead leaf biomass and green leaf biomass proportion to total leaf biomass of a few selected hybrids of *Brachiaria* along with 3 parents and 5 checks after 10 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia. The maximum and minimum values from the 500 hybrids tested were also included for comparison

Genotype	Green leaf biomass (g plant^{-1})	Green leaf area (cm^2 plant^{-1})	Total chlorophyll content (SPAD)	Dead leaf biomass (g plant^{-1})	Green leaf biomass proportion (%)
Parents					
Bruz 4402	1.43	213	24.45	3.82	32
CIAT 606	3.31	498	37.29	2.29	64
CIAT 6294	2.94	401	34.04	2.04	57
Checks					
CIAT 679	4.09	477	43.33	0.34	92
CIAT 6133	4.78	602	40.23	0.17	97
CIAT 26110	3.03	276	31.20	2.31	61
CIAT 36061	3.61	487	34.26	3.75	51
CIAT 36087	4.84	637	37.48	3.22	61
Hybrids					
Tolerant					
IN08/313	4.37	440	33.28	1.62	63
IN08/57	4.37	548	33.71	4.05	56
IN08/110	3.26	418	38.81	4.00	50
IN08/22	3.52	540	26.64	3.76	48
Sensitive					
IN08/133	0	0	15.59	4.26	0
IN08/153	0	0	16.33	6.05	0
IN08/294	0	0	17.40	3.92	0
IN08/490	0	0	25.66	4.72	0
Maximum	4.84	637	43.33	6.88	97
Minimum	0	0	12.07	0.17	0
Mean	**1.06**	**152**	**24.17**	**4.04**	**22**
LSD $_{0.05}$	1.42	210	10.56	2.21	29

Brachiaria humidicola **CIAT 26110**

Mulato 2 CIAT 36087 **IN08/313**

Photo 3. Influence of waterlogging on shoot growth at harvest time (10 days of waterlogging treatment). *B. humidicola* (high level of tolerance with no dead leaves); *B. brizantha* CIAT 26110 (intermediate level of tolerance); Mulato 2 CIAT 36087 (moderately sensitive with chlorotic leaves); IN08/313 (tolerant hybrid).

Results on correlation coefficients among the shoot traits are shown in Table 6. Highly significant correlations were observed among the shoot traits measured. Green leaf biomass proportion to total shoot biomass under waterlogging stress was found to be positively associated with green leaf area, chlorophyll content, green leaf biomass and negatively associated with dead leaf biomass (Table 6). Green leaf biomass proportion to total leaf biomass was found to be an important shoot trait to identify genotypes with tolerance to waterlogging.

Table 6. Correlation coefficients (r) among shoot traits of 508 *Brachiaria* genotypes after 10 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia

	Green Leaf Biomass	Leaf area	Chlorophyll content	Dead leaf biomass	Green leaf biomass proportion
Green leaf biomass	1.00				
Leaf area	0.95***	1.00			
Chlorophyll content	0.49***	0.50***	1.00		
Dead leaf biomass	-0.14***	-0.22***	-0.43***	1.00	
Green leaf biomass proportion	0.78***	0.81***	0.65***	-0.59***	1.00

Conclusions

Results from this greenhouse study indicated that out of the total 500 hybrids from the IN08 population tested, the hybrid IN08/313 was outstanding in terms of waterlogging tolerance based on green leaf biomass production. This study also showed that green leaf biomass proportion to total shoot biomass could serve as a selection index to evaluate waterlogging tolerance.

1.6.4 Phenotypic differences in formation of aerenchyma in roots of *Brachiaria* genotypes under waterlogging conditions

Contributors: J.A. Cardoso, J. Rincón and I.M. Rao (CIAT)

Rationale

The roots of plant species that are adapted to waterlogging usually display changes in root anatomical characteristics that enable them to withstand the adverse conditions in water-saturated soils. The efficacy of internal aeration within a root is partially determined by traits including features such as formation of aerenchyma in the cortex. Aerenchyma are cortical airspaces that provide a low resistance internal pathway for the movement of O_2 from the shoots to the roots, where it is consumed in respiration and could also partially oxidize the rhizosphere. The present work explores the extent to which aerenchyma formation occurs under well drained and waterlogged conditions in *Brachiaria* genotypes with contrasting levels of tolerance to poorly drained soils.

Material and methods

A pot experiment was conducted in the Forages patio area of CIAT-Palmira from January 16 to March, 2009 to determine phenotypic differences in the anatomy of roots of *Brachiari*a genotypes with contrasting tolerance to waterlogging. Genotypes tested included two highly waterlogging tolerant *B. humidicola* CIAT 6133 and *B. humidicola* CIAT 679; one moderately tolerant *B. brizantha* CIAT 26110; and three intolerant *B. ruziziensis* (Bruz 44-02), *B. brizantha* CIAT 6294 and the *Brachiaria* hybrid cv. Mulato 2 (CIAT 3607). The classification of the genotypes is based on previous experiments (see above Activity 1.5.3)

The trial was designed as a randomized complete block with four replications. Each experimental unit consisted of one pot filled with 3.5 kg of fertilized top soil (0-20 cm) from Santander de Quilichao (Oxisol) and sown with two vegetative propagules (stem cuttings). An adequate 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 the soil at the time of planting. Plants grew for 50 days under 100% field capacity of soil moisture. Waterlogging treatment was imposed by applying excessive water to the pots (5 cm over soil surface) for 21 days. Plants without waterlogged soils and maintained at field capacity were used as a control.

Root Anatomy: The anatomical structure of healthy adventitious roots (belowground) was studied. Sections of roots were cut every 50 mm and infiltrated with water to remove air bubbles for 5 min under near vacuum (5 kPa) in a vacuum desiccator. Subsequently, hand cross sections were taken and photographed with a digital camera connected to a Leitz Ortholux II Microscope. The area of the root cross section and aerenchyma within each capture were measured using ImageJ software.

Results

For all genotypes tested, a 21 day waterlogging treatment, increased the area of aerenchymatous root tissue when compared to the control treatment (Table 7; Photo 4). As expected, the two highly waterlogging tolerant accessions (*B. humidicola* CIAT 6133 and CIAT 679) showed more area in aerenchyma than the rest of the examined genotypes. Both accessions of *B. humidicola* also showed greater area of aerenchymatous tissue in the control treatment, suggesting that this could be a constitutive trait with benefits under optimum as well as waterlogged conditions.

Table 7. Percentage of aerenchyma of roots grown in an oxisoil maintained at field capacity or waterlogged for 21 days. Values given are the means of the four replicates. For each genotype, * denotes a statistically significant difference between means within rows at 95% confidence level

Genotype	% Aerenchyma	
	Field capacity	Waterlogged
CIAT 6133	30.5	35.1
CIAT 679	27.8	33.0
CIAT 26110	1.5	10.4*
Bruz 44-02	2.7	7.8*
CIAT 6294	3.1	9.3*
CIAT 36087	1.2	9.4*

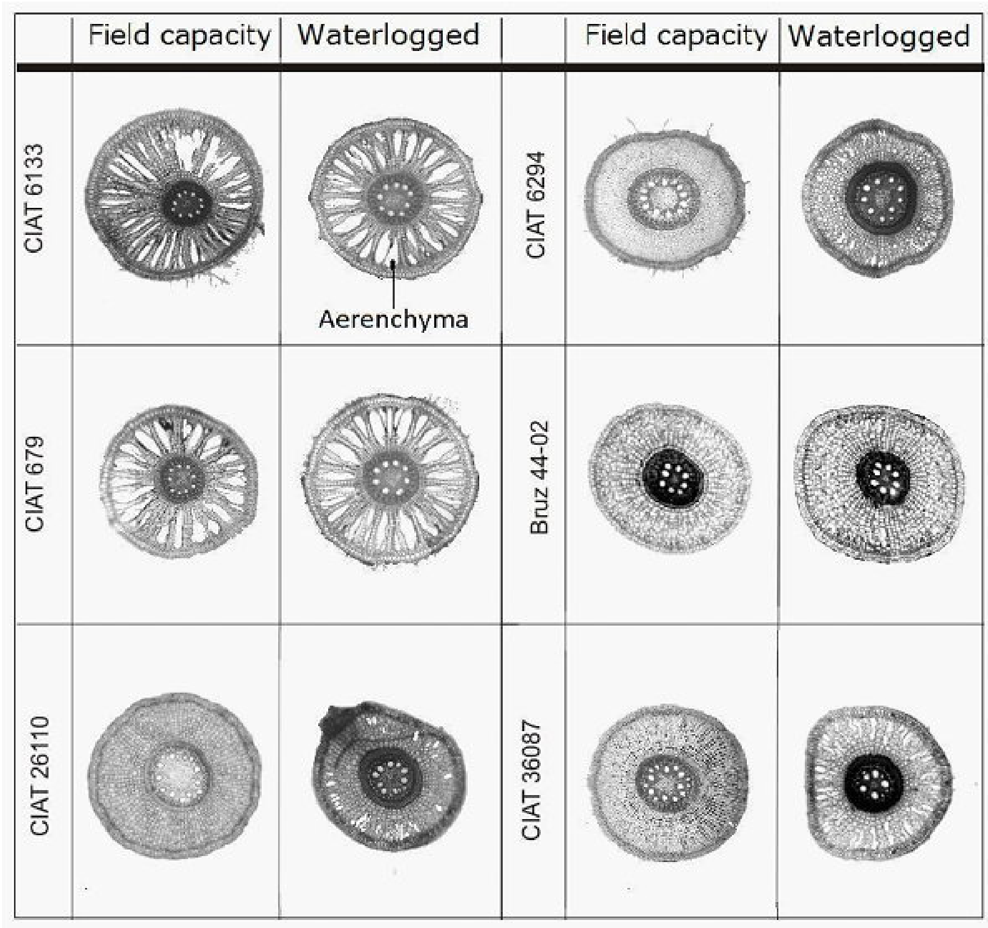

Photo 4. Root anatomy of *Brachiaria* genotypes under field capacity and waterlogging conditions. Sections were taken at the distance of 150 mm from the root tip.

Although the rest of the genotypes had significant increase of aerenchyma formation under waterlogged conditions, it was not possible to establish the role of aerenchyma in their lower level of tolerance to waterlogging (Data not shown). The difference between one moderately tolerant (CIAT 26110) and three intolerant (B. ruz 44-02, CIAT 6294 and CIAT 36087) genotypes in aerenchyma formation was not significant and therefore the moderate level of waterlogging tolerance observed for CIAT 26110 may not be related to aerenchyma formation.

Conclusions

All genotypes responded to soil waterlogging by increasing the formation of root aerenchyma. Results indicated that the higher percentage of aerenchyma formation and its supposedly constitutive nature in two highly waterlogging tolerant accessions of *B. humidicola* (CIAT 6133 and CIAT 679) should be of adaptive advantage at the onset of and during waterlogging. It is not surprising that tolerance to waterlogging is not correlated with only one trait, namely aerenchyma formation. It is speculated that waterlogging tolerance in *Brachiaria* species may involve the synergistic effects of both morphological and physiological traits.

1.7 Pathogenic and morphological characterization of *Rhizoctonia* isolates causing leaf blight in *Brachiaria* spp.

Highlight

- We obtained 78 *Rhizoctonia* isolates from *Brachiaria* cv. Mulato in three departments of Colombia: Cauca, Meta, and Casanare. They were morphologically characterized in monothallic cultures, and their pathogenicity was evaluated under greenhouse conditions. Statistically significant differences were detected among the isolates for both morphology and pathogenicity. Isolates from Meta and Casanare were more pathogenic than those from Cauca. They also differed in color, growth rate, and sclerotia production.

Contributors: E. Álvarez and M. Latorre (CIAT)

Rationale

Of the available sources of feed for beef cattle, forages are the most economical. Among these, the *Brachiaria* genus has significant economic importance at world level, where cattle-raising is a key sector in the economy of the tropics. This grass has been established not only in various parts of tropical Latin America, but also in Sub-Saharan Africa and tropical Asia. In Colombia, in particular, large extensions of land are planted to commercial cultivars. Leaf blight is an invasive and destructive disease, caused by the cosmopolitan pathogen *Rhizoctonia* spp. These fungi have a broad range of hosts, and attack most *Brachiaria* cultivars. This disease is widespread in Colombia, causing significant losses and reductions in forage quality in areas such as Caquetá, Córdoba, and the Eastern Plains. This study aimed to characterize *Rhizoctonia* isolates causing leaf blight in *Brachiaria* cultivars in Cauca, Meta, and Casanare. Pathogenicity, culture morphology, and nuclear condition of isolates collected in the field were therefore studied. This study will serve as a basis for improving the resistance of *Brachiaria* spp. to *Rhizoctonia* spp.

Materials and methods

Collecting Rhizoctonia isolates
We collected 154 tissue samples with symptoms of leaf blight caused by *Rhizoctonia* spp. from different *Brachiaria* accessions in the Departments of Cauca, Meta, and Casanare. They were kept at a temperature of 4 °C until isolations of the fungus could begin.

Isolating, purifying, and storing the pathogen
Isolates were obtained in petri dishes containing potato dextrose agar (PDA) culture medium. The samples were cut into fragments of healthy and diseased tissues, washed in 70% alcohol for 1 min, 1% sodium hypochlorite for 1 min, and two baths of sterilized distilled water for 1 min each. They were then dried with sterilized paper towels and affixed to the dish cover with a small piece of tape to ensure that they did not come into direct contact with the culture medium. They were then incubated for 24 h at 30°C.

The mycelium that grew over the sample was transferred to petri dishes containing PDA medium and incubated for 48 to 72 h at 30°C. Isolates belonging to the *Rhizoctonia* genus were identified through macroscopic and microscopic observations, taking into account the color of the culture medium, hyphal branches that formed right angles, constriction at the beginning of the branching, and septa in both branches of the angle. Identified organisms were transferred to new culture media for growth. Those isolates that, by their morphology, belonged to the *Rhizoctonia* genus were purified and kept on filter paper, according to the methodology described by Aricapa and Correa (1994).

Obtaining monothallic cultures

Pure isolates were cultured on simple agar, and observed under a stereoscope, using the fungus's apical cells. Hyphal apices were transferred to petri dishes containing PDA medium and an antibiotic (amoxicillin at 300 mg/L) and left to incubate at 30ºC in darkness for 48 to 96 h. Finally, any monothallic cultures obtained were stored on filter paper.

Morphological characterization of Rhizoctonia isolates

Morphological characterization of the isolates was carried out on PDA medium. The cultures were incubated at 30°C in darkness and evaluated every 24 h over 10 days. The parameters evaluated were color of the colony, growth rate, and distribution of sclerotia. They were analyzed in a randomized complete block design with three replications.

The number of nuclei per cell was determined in cultures, 48 h old, that had grown in 2% water agar. From these, micropreparations were made with 3% KOH plus 0.5% safranine O, and then observed under an optical microscope with a 400X magnification.

Pathogenicity tests

For pathogenicity tests, 40-day-old plants of the susceptible cv. Mulato were grown in pots, each pot measuring 10 cm in diameter and containing 500 g of sterilized substrate.

We evaluated the pathogenicity of 78 *Rhizoctonia* isolates obtained from different *Brachiaria* genotypes, particularly of cv. Mulato II (Meta and Casanare) and *B. brizantha* (Cauca). The fungus was grown for 8 days on PDA medium (i.e., 39 g of PDA per liter of distilled water), supplemented with amoxicillin (300 mg/L). For inoculation, the fungus in PDA medium was taken and, from each isolate, disks (7 mm in diameter) were extracted and placed at the base of the leaf blade of each of the first two leaves, that is, between the leaf blade and the stem. The inoculated plants were incubated under greenhouse conditions (~28°C), using plastic bottles as micro-chambers to create conditions of high relative humidity (80%–100%) and to isolate individual plants so as to avoid physical contact between adjacent plants.

Plant response to the disease was evaluated, using the Horsfall–Barratt severity scale to estimate the percentage of affected area. The evaluation was carried out every 3 days after inoculation for 18 days.

A randomized complete block design was used with five replications. A single plant was the experimental unit. Data on severity were used to calculate the area under the disease progress curve (AUDPC). These AUDPC values were submitted to an ANOVA to determine statistically significant differences between isolates. The Duncan's multiple range test was then used to separate groups of isolates that differed in pathogenicity.

Results and discussion

Isolate collection

From monothallic cultures, we obtained 78 isolates of *Rhizoctonia* spp., which showed variability in morphology (zonation, texture, and sclerotia production) and growth rate. These isolates were shown to be associated with the symptoms of leaf blight in commercial cultivars of *Brachiaria* spp. With these isolates, symptoms were obtained at a much higher frequency than with isolates of other fungal species such as *Helminthosporium* spp., *Sclerotium* spp., and *Fusarium* spp., which were isolated in minimal quantities.

Morphological characterization

Morphological differences among the isolates were observed, based on characteristics such as color of the colony, distribution and grouping of sclerotia, and number of nuclei per cell.

Isolates from Cauca produced white colonies, with few sclerotia; while those of Meta and Casanare produced colonies of a pale to dark brown color, with abundant sclerotia (Photo **5**). Differences in growth rate were also detected, with the isolates from Cauca having a sluggish growth rate (needing 7 days to develop well), while those of Meta and Casanare grew faster (needing 3 or 4 days). These results are significant, as growth rate may be related directly to pathogenicity level.

The color of sclerotia ranged from white to pale brown in young colonies, becoming dark-coffee colored as they age. In some isolates, the sclerotia formed aggregates of 3 to 8 mm in diameter, with their color being brown to dark brown.

With respect to the nuclear condition, most isolates were multinucleate, which may indicate that they belong to *Rhizoctonia solani*, which is pathogenic to many plant groups, including the *Brachiaria* genus. To a lesser degree, binucleate isolates that were pathogenic to plants of *Brachiaria* cv. Mulato were also obtained (Photo 6).

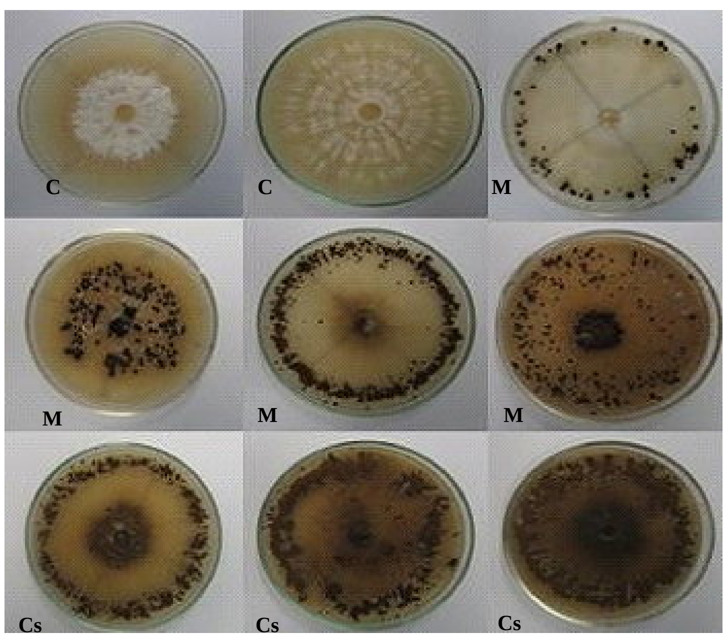

Photo 5. Morphological differences between 8-day-old *Rhizoctonia* isolates in PDA medium. C refers to isolates from the Department of Cauca; Cs to isolates from the Department of Casanare; M to isolates from the Department of Meta.

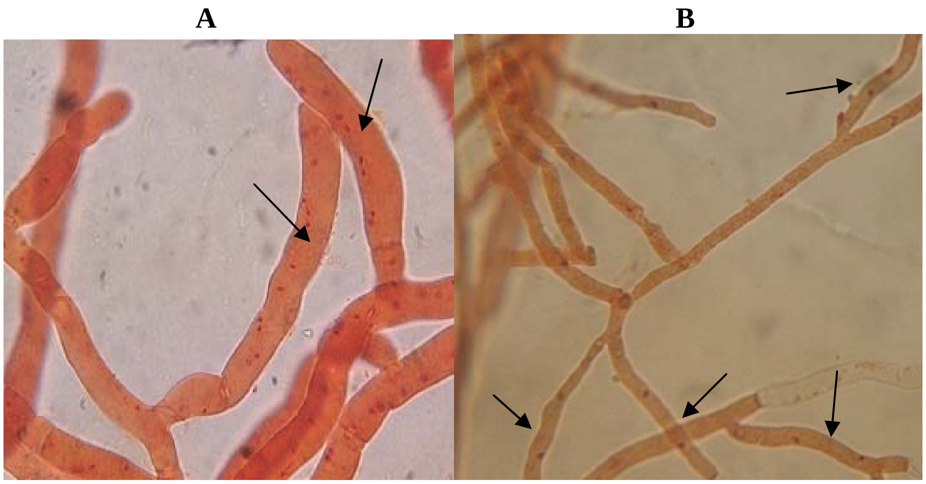

Photo 6. Nuclear condition of *Rhizoctonia* isolates. (A) Multinucleate isolates; (B) binucleate isolates.

Evaluation of the isolates' pathogenicity

The 78 *Rhizoctonia* isolates were collected from different areas in the Departments of Cauca, Meta, and Casanare in 2008 and 2009, and from different commercial cultivars in the field. The isolates mostly came from *B. brizantha* in Cauca and cv. Mulato II in Meta and Casanare (Table 8).

In the pathogenicity tests, the isolates caused typical symptoms of the disease in cv. Mulato, which is susceptible to leaf blight caused by *Rhizoctonia* spp. Results were consistent, showing uniformity between replications of any given isolate.

The AUDPC showed differences in pathogenicity between isolates, separating them into two major groups: one of high pathogenicity and the other of low pathogenicity (Table 9; Figure 12).

Analysis of variation (ANOVA) gave statistically significant differences among isolates ($P < 0.05$). Isolates from Meta and Casanare were highly pathogenic, whereas those from Cauca had low pathogenicity (Table 9).

Table 8. Origin and pathogenicity of *Rhizoctonia* isolates used in the study

No.	Isolate	*Brachiaria* material	Origin[a]	AUDPC[b]
1	8-114 (1)	*B. brizantha*	CES	2.08335
2	8-114 (2)	*B. brizantha*	CES	2.21835
3	8-114 (3)	*B. brizantha*	CES	1.67235
4	8-115 (1)	*B. decumbens*	CES	2.35035
5	8-115 (2)	*B. decumbens*	CES	2.08635
6	8-116 (1)	*B. decumbens*	CES	1.60035
7	8-116 (2)	*B. decumbens*	CES	1.90635
8	8-121 (1)	*B. brizantha*	CES	1.96935
9	8-121 (2)	*B. brizantha*	CES	2.11935
10	8-123 (1)	*B. jubata*	CES	2.40135
11	8-123 (3)	*B. jubata*	CES	2.04435
12	8-123 (4)	*B. jubata*	CES	1.73235
13	8-124 (1)	*B. brizantha*	CES	1.82235
14	8-124 (2)	*B. brizantha*	CES	2.11935
15	8-125 (1)	*B. brizantha*	CES	1.82835
16	8-125 (2)	*B. brizantha*	CES	1.97835
17	8-127 (1)	*B. brizantha*	CES	2.25435
18	8-128 (1)	*B. brizantha*	CES	3.05535
19	8-128 (2)	*B. brizantha*	CES	2.40735
20	8-128 (3)	*B. brizantha*	CES	2.08035
21	8-129 (1)	*B. brizantha*	CES	1.63335
22	8-129 (2)	*B. brizantha*	CES	2.14035
23	8-129 (3)	*B. brizantha*	CES	1.83135
24	8-129 (4)	*B. brizantha*	CES	2.02335
25	8-130 (2)	*B. brizantha*	CES	2.31435
26	8-131 (2)	*B. brizantha*	CES	1.67835
27	8-131 (3)	*B. brizantha*	CES	2.53635
28	8-131 (4)	*B. brizantha*	CES	2.29635
29	8-131 (5)	*B. brizantha*	CES	2.14335
30	8-132 (1)	*B. brizantha*	CES	2.23335
31	8-132 (2)	*B. brizantha*	CES	2.42535
32	8-132 (3)	*B. brizantha*	CES	2.65935
34	8-132 (5)	*B. brizantha*	CES	2.64435
35	8-132 (6)	*B. brizantha*	CES	2.23635
36	8-132 (7)	*B. brizantha*	CES	2.33535
37	8-132 (8)	*B. brizantha*	CES	2.38035
38	8-133 (1)	*B. jubata*	CES	2.27535
39	8-133 (2)	*B. jubata*	CES	2.55435
40	8-135 (3)	*B. jubata*	CES	1.79535
41	8-135 (1)	*B.jubata*	CES	1.60635
42	8-135 (2)	*B. jubata*	CES	1.88535
43	8-135 (3)	*B. jubata*	CES	3.22335
44	8-140 (1)	*B. platynota*	CES	2.43135
45	8-140 (2)	*B. platynota*	CES	1.92735
46	8-140 (3)	*B. platynota*	CES	2.14035
47	8-153 (1)	cv. Mulato II	DF	2.39235
48	8-156 (1)	cv. Mulato II	DF	7.83735
49	8-157 (1)	cv. Mulato II	DF	8.11635
50	8-157 (2)	cv. Mulato II	DF	9.79635
51	8-157 (3)	cv. Mulato II	DF	8.79135
52	8-158 (1)	cv. Mulato II	DF	9.46935
53	8-158 (2)	cv. Mulato II	DF	9.86535
54	8-159 (1)	cv. Mulato II	DF	8.19135
55	8-160 (1)	cv. Mulato II	DF	7.29135

Continue….

Table 8. Origin and pathogenicity of *Rhizoctonia* isolates used in the study

No.	Isolate	*Brachiaria* material	Origin[a]	AUDPC[b]
56	8-160 (2)	cv. Mulato II	DF	9.40935
57	8-161 (1)	cv. Mulato II	DF	8.94735
58	8-167 (1)	cv. Mulato II	MF	9.02535
59	8-167 (2)	cv. Mulato II	MF	8.03835
60	8-168 (1)	cv. Mulato II	MF	6.28635
61	8-169 (1)	cv. Mulato II	MF	4.16235
62	8-171 (1)	cv. Mulato II	MF	5.58735
63	8-178 (1)	cv. Mulato II	SCF	3.85035
64	8-178 (2)	cv. Mulato II	SCF	8.17635
65	8-180 (1)	cv. Mulato II	SCF	9.74235
66	8-187 (1)	cv. Mulato II	SCF	9.99435
67	8-187 (2)	cv. Mulato II	SCF	8.63535
68	8-191 (1)	cv. Mulato II	LIF	9.46035
69	8-191 (2)	cv. Mulato II	LIF	6.91335
70	8-197 (1)	cv. Mulato II	LIF	7.73535
71	8-197 (2)	cv. Mulato II	LIF	9.02835
72	8-202 (1)	cv. Mulato II	LIF	8.31135
73	8-202 (2)	cv. Mulato II	LIF	9.91335
74	8-202 (3)	cv. Mulato II	LIF	6.91335
75	8-202 (4)	cv. Mulato II	LIF	6.92835
76	8-206 (1)	cv. Mulato II	LIF	9.02235
77	8-206 (2)	cv. Mulato II	LIF	7.10835
78	8-218 (1)	cv. Mulato II	LIF	8.92035

a. CES = CIAT Experiment Station–Popayán; DF = The Dacha Farm, Port López, Meta; MF = Montana Farm, Port López, Meta; SCF = Santa Clara Farm, Remolino, Port López, Meta; LIF = "La Ilusión" Farm, Morichal Village District, Yopal, Casanare.

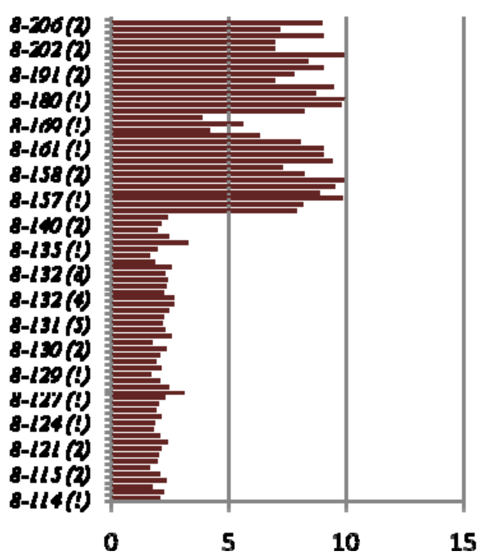

Figure 12. Pathogenicity of *Rhizoctonia* isolates expressed as the area under the disease progress curve (AUDPC).

Table 9. Analysis of variation (ANOVA) for 78 *Rhizoctonia* isolates

Source	df	Sum of squares	Mean squares	*F* value	*P* > *F*
Rep	4	30.203012	7.550753	4.35	0.0019
Isolate	78	3936.697592	50.470482	29.10	**<0.0001**
Error	312	541.102768	1.734304		
Corrected total	394	4508.003372			

Duncan's multiple range test grouped the isolates into three clusters: isolates from Cauca had low pathogenicity and an AUDPC value between 1.6 and 2.7; isolates from Meta and Casanare had high pathogenicity and an AUDPC value between 6.3 and 9.9; and three isolates from Puerto López, Meta, formed the third cluster, which had intermediate values of 3.85, 4.16, and 5.58 (Table 10; Photo 7).

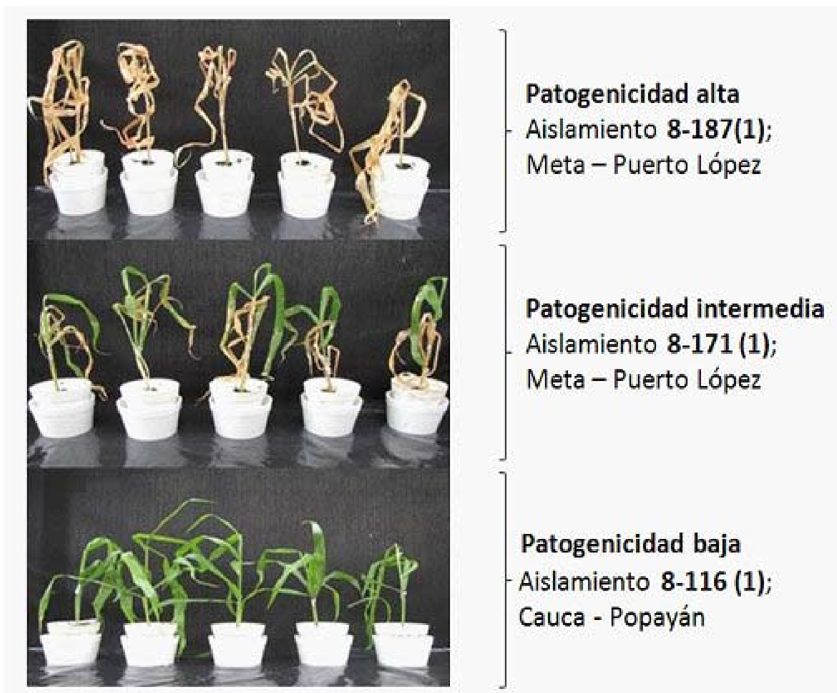

Photo 7. Reaction of cv. Mulato to *Rhizoctonia* isolates with high, intermediate, or low pathogenicity.

The most pathogenic isolates were from Meta: 8-187(1), 8-180(1), 8-158(2), and 8-157(2), with values between 9.4 and 9.9; and from Casanare: 8-202(1) and 8-218(1), with values between 9.0 and 9.92 (Table 9). These isolates may be most useful for selecting host plant resistance and thus be highly relevant in improvement programs.

The pathogenic variation observed among *Rhizoctonia* isolates (Photo 8) constitutes an essential basis for acquiring stable and lasting genetic resistance in *Brachiaria*, provided a representative group of *Rhizoctonia* isolates is obtained from different areas and hosts. Furthermore, the establishment of the nuclear condition and differences in pathogenicity of the evaluated isolates may be useful for understanding leaf blight and for developing control strategies such as genetic improvement.

Photo 8. Pathogenic variation between *Rhizoctonia* isolates in *Brachiaria* spp. under greenhouse conditions.

Outlook

This study is part of a wider project that includes the establishment of pathogenicity, morphological characterization, resistance trials, and molecular characterization of *Rhizoctonia* isolates from Cauca, Meta, Casanare, Córdoba, and Caquetá. The results of this study will help identify and characterize isolates that can be used in improvement programs; identify possible sources of resistance, and evaluate improved germplasm.

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

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

Rationale

Continuing the search for high quality and productive forage legumes adapted to acid soils a collection of *Cratylia* and *Dioclea* is being evaluated at CIAT`s research station in Santander de Quilichao. In addition to agronomic characterization, this study aims to identify morphological differences between and within species. The evaluation is being finalized in 2009/10.

Materials and Methods

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

Four months after sowing (October 2007) plants were transferred to the field station in Santander de Quilichao. A Randomized Block design with three replications was used for the agronomic evaluation. Five plants per accessions were sown with 1 m in the row and 1.5 m between rows. Plants were fertilized with P40, K50, Mg20, and S20 (kg/ha); during the first eight weeks irrigation was applied to ensure establishment, and pests were controlled. After a standardization cut – when plants were fully established – cuts were carried out in 8-week intervals. DM yield was recorded each year once in the dry and once in the wet season.

Results and Discussion

Plants developed well in the field and no replanting was necessary; no significant diseases and pests were observed (Photo 9).

Photo 9. Collection of *Cratylia* spp. and *Dioclea* spp. in Quilichao

In Table 10 results from six cuts (three each in the dry and wet season) are presented for the four groups of species and accessions, according to their origins: A) six accessions of *Cratylia argentea* from Brazil and Bolivia (CIAT 18516, 18668, 18674, 22406, BOL-01 and -02); B) six accessions of *Dioclea* spp. (CIAT 7799, 8193, 9311, 8008, 8196 and 828); C) eleven accessions of twining *Cratylia* sp. from Bolivia (CIAT 22397, Bol-03, -04, -05, -06, -07, -08, -09, -10, -11 and -12); and D) two accessions of *C. mollis* (CIAT 7940 and 8034). DM yields/plant showed highly significant ($P<0.01$) differences between groups in both seasons, with the Brazilian and Bolivian *C. argentea* accessions having the highest yields with 284 and 246 g/plant in the dry and wet season, respectively. *C. mollis* had the lowest yields in both seasons. In average, dry season yields were similar to wet season yields, as was the number of regrowing branches (Table 10).

Table 10. Agronomic evaluation of a collection of *Cratylia* spp. and *Dioclea* spp. in Quilichao, comparison of groups. Data of six evaluation cuts (three in the wet season and three in the dry season).

Species	Plant height	Plant diameter	Regrowing points	Mean DM yield	Plant height	Plant diameter	Regrowing points	Mean DM yield
	Dry				Wet			
	(cm)		(No.)	(g/pl)	(cm)		(No.)	(g/pl)
C. *argentea* – Brazil, Bolivia	116	112	27	284	107	106	23	246
Dioclea spp.	42	73	29	83	44	59	21	86
Cratylia sp.	38	76	26	75	41	70	23	99
C. mollis	77	50	18	27	81	45	12	33
Mean	61	82	26	124	61	74	22	126
LSD (P<0.05)				50.9				39.8

Table 11 shows data for the 11 accessions of the twining *Cratylia* species: plant height, plant diameter, number of regrowing points and DM yields for the two seasons in Quilichao. Significant (P<0.05) differences were found for DM yields although average yields were low compared with other forage legumes evaluated under the conditions of Quilichao, with only *Cratylia* sp. CIAT 22397 reaching DM yields above 100 g/plant in the dry season, and CIAT 22397, BOL-05, BOL-10, BOL-07, BOL-03 and BOL-11 in the wet season. Numbers of regrowing points were higher in the dry than in the wet season but this was not reflected in higher DM yields.

Table 11. Agronomic evaluation of a collection of *Cratylia* sp. in Quilichao. Data of six evaluation cuts (three in the wet season and three in the dry season).

Accession	Plant height	Plant diameter	Regrowing points	Mean DM yield	Plant height	Plant diameter	Regrowing points	Mean DM yield
	Dry				Wet			
	(cm)		(No.)	(g/pl)	(cm)		(No.)	(g/pl)
CIAT 22397	60	89	28	146	60	80	24	135
BOL-05	33	81	32	95	32	76	27	119
BOL-10	39	79	28	83	41	73	24	111
BOL-07	48	77	34	83	58	74	33	134
BOL-03	37	77	26	78	40	72	23	110
BOL-11	34	80	29	76	36	72	23	112
BOL-04	33	79	23	67	35	69	21	82
BOL-08	38	73	26	60	41	69	23	84
BOL-09	33	70	22	55	37	68	20	75
BOL-06	30	64	20	40	27	53	17	49
BOL-12	29	62	17	32	38	58	16	60
Mean	38	76	26	75	41	70	23	99
LSD (P<0.05)				46.9				55.8

For the Brazilian and Bolivian *C. argentea* group (CIAT 18674, 22406, 18516, 18668, BOL-01 and BOL-02) no significant (P<0.05) differences between accessions were found for DM yields in both seasons (Table 12).

Table 12. Agronomic evaluation of a collection of *Cratylia argentea* from Brazil and Bolivia in Quilichao. Data of six evaluation cuts (three in the wet season and three in the dry season).

Accession	Plant height	Plant diameter	Regrowing points	Mean DM yield	Plant hPlant dight	Diameter	Regrowing points	Mean DM yield
	Dry				Wet			
	(cm)		(No.)	(g/pl)	(cm)		(No.)	(g/pl)
BOL-01	110	115	28	339	104	109	24	281
CIAT 18674	119	111	29	309	113	114	27	342
CIAT 22406	123	118	27	293	108	103	21	193
CIAT 18668*	122	108	23	267	105	101	21	207
CIAT 18516*	112	111	25	264	102	105	24	264
BOL-02	110	105	27	231	107	103	21	190
Mean	119	112	26	284	107	106	23	246
LSD (P<0.05)				265.5				161.4

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

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

Average yields of accession BOL-01 were 339 and 281 g DM/plant in the dry and wet season, respectively while accession BOL-02 had low yields in both seasons.

Results for *Dioclea virgata* and *D. guianensis* are shown in Table 13. DM yields were slightly higher in the wet season than the dry season, with CIAT 828 having the highest yields with more than 114 g DM/plant. Both species were similar in respect to agronomic performance.

Table 13. Agronomic evaluation of a collection of *Dioclea* spp. in Quilichao. Data of six evaluation cuts (three in the wet season and three in the dry season).

Species and accession (No. CIAT)	Plant height	Plant diameter	Regrowing points	Mean DM yield	Plant height	Plant diameter	Regrowing points	Mean DM yield
	Dry				Wet			
	(cm)		(No.)	(g/pl)	(cm)		(No.)	(g/pl)
D. virgata 828	41	79	34	114	44	64	28	120
D. guianensis 7799	42	79	30	96	41	63	21	90
D. guianensis 9311	42	75	29	83	42	60	21	83
D. virgata 8196	49	74	34	80	53	58	18	76
D. guianensis 8193	37	68	24	66	41	59	16	75
D. virgata 8008	42	61	24	61	44	53	21	70
Mean	42	73	29	83	44	59	21	86
LSD (P<0.05)				66.0				72.7

The *C. mollis* accessions CIAT 7940 and 8034 had low yields, below 35 g DM/plant (Table 14).

Table 14. Agronomic evaluation of a collection of *Cratylia mollis* in Quilichao. Data of six evaluation cuts (three in the wet season and three in the dry season).

Accession	Plant height	Plant diameter	Regrowing points	Mean DM yield	Plant height	Plant diameter	Regrowing points	Mean DM yield
	Dry				Wet			
	(cm)		(No.)	(g/pl)	(cm)		(No.)	(g/pl)
CIAT 7940	75	54	19	31	78	42	13	30
CIAT 8034	80	47	17	23	83	47	10	37
Mean	77	50	18	27	81	45	12	33
LSD (P<0.05)				65.2				32.5

Using 8-week regrowth samples collected in the wet and dry season, *in vitro* dry matter digestibility (IVDMD) and crude protein (CP) content differed highly significantly (P<0.01) among accessions (Table 15). In the wet season, *Cratylia argentea* accessions CIAT 18674, 22406, 18668, BOL-01 and -02 as well as *Dioclea virgata* CIAT 8008 (Photo 10)showed a digestibility above 65% . High CP concentrations, all above 25%, were measured in *C. argentea* CIAT 18674, 22406, and 18516, and *Cratylia* sp. CIAT 22397, BOL-05, -08 and -04. Digestibility of *Dioclea* spp. accessions CIAT 8196, 828, 9311, 8193 and 7799 was below 45%; CP content was also below the average of the collection.

For most accessions, IVDMD and CP were higher in the dry than in the wet period. Highest nutritive values were obtained for *Cratylia* sp. BOL-08, -10, -05, -06, -12, -11 y -04; *Cratylia argentea* CIAT 22406, 18516, 18674, 18668, BOL-02 and -01, with digestibilities above 67% and CP contents above 25%. For the *Dioclea* spp. accessions, CP content in the dry period was lower than in the wet season. Digestibilities were low, with exception of accession CIAT 8008 with a digestibility of 67% (Table 15).

Photo 10. Regrowth of twining *Cratylia* spp. and young shoots of *Dioclea virgata* in Quilichao.

Table 15. Forage quality of accessions of *Cratylia* spp. and *Dioclea* spp. in the wet and dry season in Quilichao

Species* and accession	IVDMD	CP	IVDMD	CP
	%			
	Wet		Dry	
Csp BOL-08	60	25.4	71	30.8
Csp BOL-10	55	24.2	70	28.6
Ca CIAT 22406	70	27.2	70	25.3
Csp BOL-05	61	27.9	70	28.1
Csp CIAT 22397	63	25.3	70	29.3
Ca CIAT 18516**	63	26.9	68	27.1
Csp BOL-06	56	23.7	68	28.3
Csp BOL-12	56	23.7	67	28.1
Ca BOL-02	65	24.2	67	25.1
Csp BOL-11	56	23.2	67	27.7
Dv CIAT 8008	65	22.2	67	18.5
Csp BOL-04	59	25.7	67	26.9
Ca CIAT 18674	71	28.6	67	27.2
Ca BOL-01	67	22.5	67	24.7
Ca CIAT 18668**	66	24.8	67	26.3
Csp BOL-09	59	24.3	66	27.6
Csp BOL-03	56	24.6	65	28.4
Csp BOL-07	55	24.6	65	28.6
Cm CIAT 7940	61	23.4	59	20.6
Cm CIAT 8034	64	22.8	59	19.6
Dv CIAT 828	43	22.6	44	17.1
Dv CIAT 8196	44	21.2	39	15.6
Dg CIAT 7799	36	20.7	37	16.0
Dg CIAT 9311	40	20.5	35	14.7
Dg CIAT 8193	37	20.2	31	15.3
Mean	57	23.9	61	24.2
LSD (P<0.05)	13.5	3.9	9.8	4.4

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

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

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Rationale

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

Materials and Methods

The available collection of *Tadehagi triquetrum*, consisting of 114 accessions, was sown in plastic bags in the greenhouse and after eight weeks, in June 2008, transplanted to the field in Santander de Quilichao (Photo 11).

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

Photo 11. *Tadehagi triquetrum* collection established in Quilichao

Three growth habit of plants was determined by measuring plant height and diameter and subsequently calculating a height/diameter quotient as growth habit indicator, with values from 0.1 to 0.38; 0.39 to 0.69; and >0.69 corresponding respectively to prostrate, ascendent and erect habits.

Results

Five months after transplanting, the plants were considered fully established and considerable morphological differences were observed in terms of branching, leaf color, flowering and seed production. Most plants did not reach 1 m in height, with the average height and diameter being 0.44 m and 0.77 m, respectively. Three growth habits were distinguished: erect (15 accessions), ascendent (31) and prostrate (38) (Photo 12). Large differences were found in initial development and 50% of the accessions needed replanting; leaf eaters and leaf suckers were observed, in addition to fungal infection, in some cases resulting in death of plants.

Photo 12. *Tadehagi triquetrum* growth habits.

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

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

In Tables 16, 17 and 18, the performance of plants in the establishment phase, separated according to growth habit, is shown.

Among the erect accessions, a large variation in plant height was found, partly due to the replanting of a number of accessions. Accessions that reached more than 0.7 m in height were CIAT 761, 880, 899, 422, 23112, 21912 and 21913. In contrast, accessions CIAT 21911 and 21916 were the least vigorous.

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

Table 16. Vigor, plant height and diameter at the end of the establishment phase (5 months in the field) of erect *Tadehagi triquetrum* accessions in Quilichao

Accession	Vigor	Height	Diameter
	Scale 1-5	cm	
CIAT 422	4	73	93
CIAT 23751	3	62	91
CIAT 23111	4	72	88
CIAT 899	4	74	73
CIAT 880	4	80	72
CIAT 761	4	81	71
CIAT 33110	3	68	65
CIAT 23953	3	48	59
CIAT 13996	3	50	56
CIAT 23750	3	63	56
CIAT 21913	3	70	52
CIAT 21916	3	40	44
CIAT 21912	3	70	43
CIAT 918	3	51	42
CIAT 21911	2	37	36
Mean	3.3	63	64
Range	1-5	1-140	2-145

Table 17. Vigor, plant height and diameter at the end of the establishment phase (5 months in the field) of ascendent *Tadehagi triquetrum* accessions in Quilichao

Accession	Vigor	Height	Diameter	Accession	Vigor	Height	Diameter
	1-5	cm			1-5	cm	
CIAT 21921	4	50	112	CIAT 21928	4	51	83
CIAT 23428	4	79	109	CIAT 13540	3	35	81
CIAT 13277	4	91	103	CIAT 21914	3	42	81
CIAT 23950	4	68	98	CIAT 33393	3	57	78
CIAT 13726	4	55	98	CIAT 13728	3	35	77
CIAT 23113	4	53	97	CIAT 23227	3	38	76
CIAT 23749	4	63	97	CIAT 33418	3	54	67
CIAT 23943	4	64	92	CIAT 13542	3	31	67
CIAT 13270	3	56	90	CIAT 13273	3	62	66
CIAT 23424	4	60	89	CIAT 23939	3	64	64
CIAT 23427	4	49	89	CIAT 23941	3	31	55
CIAT 23753	4	51	86	CIAT 13269	3	39	48
CIAT 21929	3	53	85	CIAT 13730	2	40	48
CIAT 13727	4	57	84	CIAT 465	2	21	40
CIAT 33456	4	49	84	CIAT 13274	2	32	38
CIAT 23426	3	40	84				
Mean					3.4	51	80
Range					1-5	2-145	1-200

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

Table 18 Vigor, plant height and diameter at the end of the establishment phase (5 months in the field) of prostrate *Tadehagi triquetrum* accessions in Quilichao

Accession	Vigor	Height	Diameter	Accession	Vigor	Height	Diameter
	1-5	cm			1-5	cm	
CIAT 21923	5	39	136	CIAT 21979	3	24	78
CIAT 21925	4	25	129	CIAT 21915	3	25	77
CIAT 13268	4	33	118	CIAT 13544	2	42	76
CIAT 21918	4	32	117	CIAT 21927	4	31	75
CIAT 23945	4	50	116	CIAT 33397	3	27	73
CIAT 33423	4	55	114	CIAT 23957	3	27	67
CIAT 21919	3	26	104	CIAT 21920	3	17	64
CIAT 23852	4	67	103	CIAT 21917	3	25	62
CIAT 23236	4	64	102	CIAT 23114	2	23	57
CIAT 13724	4	33	101	CIAT 21940	2	16	57
CIAT 23947	4	50	100	CIAT 23756	3	50	53
CIAT 33438	3	47	100	CIAT 13723	2	11	53
CIAT 23956	4	53	88	CIAT 21958	3	10	53
CIAT 23228	3	32	88	CIAT 21924	2	10	48
CIAT 23955	3	32	87	CIAT 23755	2	12	44
CIAT 33384	3	28	85	CIAT 21922	2	12	40
CIAT 33424	4	48	85	CIAT 13275	2	13	37
CIAT 21939	3	18	85	CIAT 21930	2	6	30
CIAT 23954	3	26	83	CIAT 21926	1	5	19
Mean					3.1	31	80
Range					1-5	1-120	1-229

During the time of the experiment, a few accessions were lost, some were not well adapted to the conditions at Quilichao and some were affected by frequent cutting. Results of evaluations during the production phase during dry and wet seasons are shown in Tables 19, 20 and 21.

DM yields differed significantly ($P<0.05$) among growth habits and accessions. In general, yields were lower in the dry than in the wet season, with on average 40 and 70 g/plant, respectively. Highest yields were recorded in both seasons for the ascendent types, as well as average plant height, diameter and number of regrowing points.

For the prostrate growth habit, CIAT 13268, 21923, 33424, 33423, 23956 and 21958 were the accessions with wet season yields above 140 g/plant, while in the dry season only accessions CIAT 23956, 13724, 13275 and 33423 yielded more than 50 g /plant (Table 20).

Table 19. Agronomic evaluation of a collection of *Tadehagi triquetrum* in Quilichao. Data of four evaluation cuts (two each in the wet and dry season).

Growth habit	Plant height	Plant diameter	Regrowing points	Mean DM yield	Plant height	Plant diameter	Regrowing points	Mean DM yield
	Dry				Wet			
	(cm)		(No.)	(g/pl)	(cm)		(No.)	(g/pl)
Ascendent	36	73	44	35	51	92	61	104
Erect	48	62	30	29	70	74	36	74
Prostrate	23	69	38	27	30	83	58	76
Mean	32	69	39	30	45	85	55	86
LSD (P<0.05)				4.1				11.9

Table 20. Agronomic evaluation of a collection of prostrate *Tadehagi triquetrum* accessions in Quilichao. Data of four evaluation cuts (two each in the wet and dry season).

Accession	Plant height	Plant diameter	Regrowing points	Mean DM yield	Plant height	Plant diameter	Regrowing points	Mean DM yield
	Dry				Wet			
	(cm)		(No.)	(g/pl)	(cm)		(No.)	(g/pl)
CIAT 23956	30	86	65	69	37	103	92	144
CIAT 13724	27	80	70	60	38	107	101	127
CIAT 13275	21	74	44	59	30	79	55	74
CIAT 33423	26	88	58	51	33	107	75	145
CIAT 13268	20	85	79	44	36	106	125	191
CIAT 21958	25	80	52	44	20	106	99	143
CIAT 23114	31	83	44	39	44	104	63	131
CIAT 23947	26	72	38	37	32	83	56	54
CIAT 21918	25	84	48	36	32	105	64	93
CIAT 21926	24	67	40	35	28	77	42	49
CIAT 33424	26	81	51	34	32	109	64	148
CIAT 23236	38	78	38	33	48	101	64	132
CIAT 21930	12	61	36	31	14	64	68	60
CIAT 21924	17	74	44	31	17	98	71	122
CIAT 23945	26	76	42	30	35	94	51	74
CIAT 23952	32	73	33	28	30	88	72	112
CIAT 21925	26	74	41	26	29	102	108	114
CIAT 33438	19	65	42	24	28	79	54	60
CIAT 13723	19	60	33	20	32	60	47	53
CIAT 23954	26	73	38	20	27	71	50	48
CIAT 13544	25	72	43	19	39	92	53	72
CIAT 21923	23	79	49	18	35	111	111	157
CIAT 23755	17	56	25	18	24	73	40	64
CIAT 23228	25	64	23	18	29	84	46	43
CIAT 33384	21	62	33	18	32	66	44	39
CIAT 23756	25	63	31	17	43	83	40	67
CIAT 21920	19	63	34	17	25	65	41	36
CIAT 21940	22	64	26	17	22	61	30	27
CIAT 21939	20	65	26	17	25	74	49	50
CIAT 23957	21	58	32	16	27	60	45	33
CIAT 21917	25	53	29	15	33	73	35	28
CIAT 21927	19	56	28	14	30	66	36	30
CIAT 33397	21	58	30	14	23	67	45	37
CIAT 21919	20	61	24	13	21	77	38	41
CIAT 21979	25	59	18	11	24	59	29	16
CIAT 21915	19	46	21	9	29	71	34	38
CIAT 23955	19	61	23	9	26	64	34	23
CIAT 21922	16	52	20	9	17	58	32	18
Mean	23	69	38	27	30	83	58	76
LSD (P<0.05)				32.4				95.8

Among the ascendent accessions, CIAT 23427, 23428, 13270, 23943, 21929 and 13269 yielded more than 150 g/plant in the wet season, while in the dry season only accessions CIAT 23427, 23943, 23424, 13269 and 23426 had yields above 50 g/plant (Table 21).

Table 21. Agronomic evaluation of a collection of ascendent *Tadehagi triquetrum* accessions in Quilichao. Data of four evaluation cuts (two each in the wet and dry season).

Accession	Plant height	Plant diameter	Regrowing points	Mean DM yield	Plant height	Plant diameter	Regrowing points	Mean DM yield
	Dry				Wet			
	(cm)		(No.)	(g/pl)	(cm)		(No.)	(g/pl)
CIAT 23427	43	91	69	66	61	127	82	242
CIAT 23943	41	87	55	63	57	107	97	157
CIAT 23424	38	77	52	58	55	102	61	146
CIAT 13269	34	80	51	53	49	108	67	150
CIAT 23426	41	77	53	53	56	100	66	139
CIAT 13726	31	78	57	46	45	108	81	142
CIAT 23941	30	73	32	43	41	84	52	107
CIAT 13270	36	75	54	41	51	105	91	164
CIAT 23428	47	85	58	40	64	115	76	166
CIAT 13727	35	73	50	40	51	95	67	114
CIAT 21929	37	75	52	40	55	101	77	151
CIAT 13728	31	80	63	38	57	97	88	144
CIAT 21921	33	84	50	36	43	105	96	134
CIAT 33393	34	69	39	36	47	85	49	68
CIAT 21928	33	80	41	35	41	88	73	100
CIAT 23113	28	84	42	35	33	102	60	89
CIAT 13273	43	70	38	34	58	95	61	110
CIAT 465	35	64	29	32	42	74	43	58
CIAT 23950	31	78	48	32	47	93	60	88
CIAT 13274	40	65	46	31	70	89	64	124
CIAT 33418	25	71	34	29	43	76	46	53
CIAT 23749	53	73	35	27	59	85	41	57
CIAT 13730	40	64	40	26	64	94	57	94
CIAT 23939	45	64	29	25	100	83	36	65
CIAT 23227	28	68	51	24	43	84	72	75
CIAT 23753	35	70	47	23	55	99	58	87
CIAT 13277	35	71	31	22	62	84	34	60
CIAT 13540	35	60	25	17	38	69	36	35
CIAT 21914	38	62	31	17	33	68	28	32
CIAT 33456	33	67	35	17	32	68	38	34
CIAT 13542	29	50	20	10	33	54	33	35
Mean	36	73	44	35	51	92	61	104
LSD (P<0.05)				29.0				95.1

Among the erect types, highest dry season yields were measured for accessions CIAT 899, 33110, 13996 and 21913, while in the wet season accessions CIAT 13996, 21912 and 21913 performed best with more than 100g/plant for the 8-week regrowth (Table 22).

Table 22. Agronomic evaluation of a collection of erect *Tadehagi triquetrum* accessions in Quilichao. Data of four evaluation cuts (two each in the wet and dry season).

Accession	Plant height	Plant diameter	Regrowing points	Mean DM yield	Plant height	Plant diameter	Regrowing points	Mean DM yield
	Dry				Wet			
	(cm)		(No.)	(g/pl)	(cm)		(No.)	(g/pl)
CIAT 899	68	83	40	57	86	91	37	98
CIAT 33110	49	66	38	52	66	78	52	74
CIAT 13996	46	79	51	41	75	113	54	175
CIAT 21913	70	65	32	38	91	79	38	101
CIAT 880	49	61	28	33	75	76	32	71
CIAT 23112	62	58	31	32	81	77	26	71
CIAT 21912	47	56	33	32	70	72	37	104
CIAT 761	46	55	35	27	72	62	25	58
CIAT 442	39	62	21	22	81	67	36	43
CIAT 23750	51	61	30	21	71	69	33	53
CIAT 21911	39	60	22	21	57	65	31	46
CIAT 918	44	58	26	18	63	69	40	85
CIAT 23751	37	60	27	17	71	83	32	67
CIZT 21916	34	50	20	10	48	55	30	30
CIAT 23953	32	55	24	9	41	53	32	35
Mean	48	62	30	29	70	74	36	74
LSD (P<0.05)				28.0				66.1

Pest and diseases were not of major importance during this evaluation phase, but incidence of leaf eaters and suckers was higher in the dry season than in the wet season.

In terms of nutritive quality, in the dry season IVDMD and CP varied significantly ($P<0.05$) among accessions, though in general, with <45% and <16%, respectively, digestibility and CP content (Table 23) were low compared with other forage legumes.

Table 23. Forage quality of *Tadehagi triquetrum* accessions evaluated in the dry season in Quilichao.

Accession	IVDMD	CP	Accession	IVDMD	CP	Accession	IVDMD	CP
	%			%			%	
CIAT 13724	45	14	CIAT 21918	38	13	CIAT 13728	35	14
CIAT 23113	42	15	CIAT 21913	38	13	CIAT 33418	35	14
CIAT 23755	42	14	CIAT 21927	38	13	CIAT 21912	35	14
CIAT 23114	41	15	CIAT 21939	38	13	CIAT 23943	35	14
CIAT 23427	41	15	CIAT 899	38	14	CIAT 21940	35	13
CIAT 21922	41	14	CIAT 23753	38	13	CIAT 23750	34	14
CIAT 23956	41	13	CIAT 23428	38	15	CIAT 23947	34	13
CIAT 23955	41	13	CIAT 23227	37	15	CIAT 13544	34	13
CIAT 13727	41	14	CIAT 13273	37	13	CIAT 761	34	13
CIAT 21958	41	13	CIAT 880	37	13	CIAT 13542	34	13
CIAT 33424	41	13	CIAT 33423	37	14	CIAT 23953	34	15
CIAT 21926	41	14	CIAT 33438	37	14	CIAT 23236	34	14
CIAT 21921	41	12	CIAT 23424	37	14	CIAT 13723	33	14
CIAT 23941	39	13	CIAT 21917	37	13	CIAT 33384	33	13
CIAT 21916	39	14	CIAT 21920	37	14	CIAT 13996	33	13
CIAT 23957	39	13	CIAT 23950	36	14	CIAT 33110	33	16
CIAT 21911	39	14	CIAT 23954	36	13	CIAT 918	33	14
CIAT 23952	39	13	CIAT 21923	36	13	CIAT 23228	33	13
CIAT 13726	39	14	CIAT 21915	36	13	CIAT 465	32	15
CIAT 33456	39	14	CIAT 21919	36	13	CIAT 33397	32	12
CIAT 23426	39	15	CIAT 13270	36	14	CIAT 13277	32	15
CIAT 21979	39	13	CIAT 21930	36	15	CIAT 21928	31	15
CIAT 21914	39	14	CIAT 23945	36	14	CIAT 21929	31	15
CIAT 422	39	14	CIAT 13268	36	14	CIAT 13274	31	14
CIAT 13730	39	14	CIAT 23939	35	14	CIAT 13269	30	14
CIAT 13275	39	13	CIAT 13540	35	13	CIAT 23756	30	14
CIAT 23112	39	15	CIAT 33393	35	13	CIAT 23751	28	13
CIAT 21924	39	14	CIAT 21925	35	14	CIAT 23749	27	13
Mean							36	14
LSD (P<0.05)							13.6	2.3

In addition to the agronomic evaluation, phenological observations were carried out for all 114 accessions (Photos 13 and 14). A Principal Component Analysis was run for 19 variables, to identify related variables and to identify those parameters that describe best the diversity in the collection. The 1st principal component was explained to 77% by the number of flowers/plant, and the 2nd component explained to more than 70% by flowering time and seed set. The 3rd component is related with 58% to the plant height.

Photo 13. Inflorescenses of *Tadehagi triquetrum*.

Photo 14. Ripe pods and seed of *Tadehagi triquetrum*.

Accessions CIAT 23956, 23115, 23228 and 21930 had a particularly high number of flowers, while accessions CIAT 23751 and 23114 were distinguished by their late flowering of 289 and 299 days after transplanting into the field, respectively, with accession CIAT 23114 also having high flower and seed production.

Mostly based on the information of number of inflorescences per plant, days to 1st flower and to 50% flowering, days to seed set and to 50% of seed formed as the most distinguishing traits, five cluster groups were defined (Figure 13).

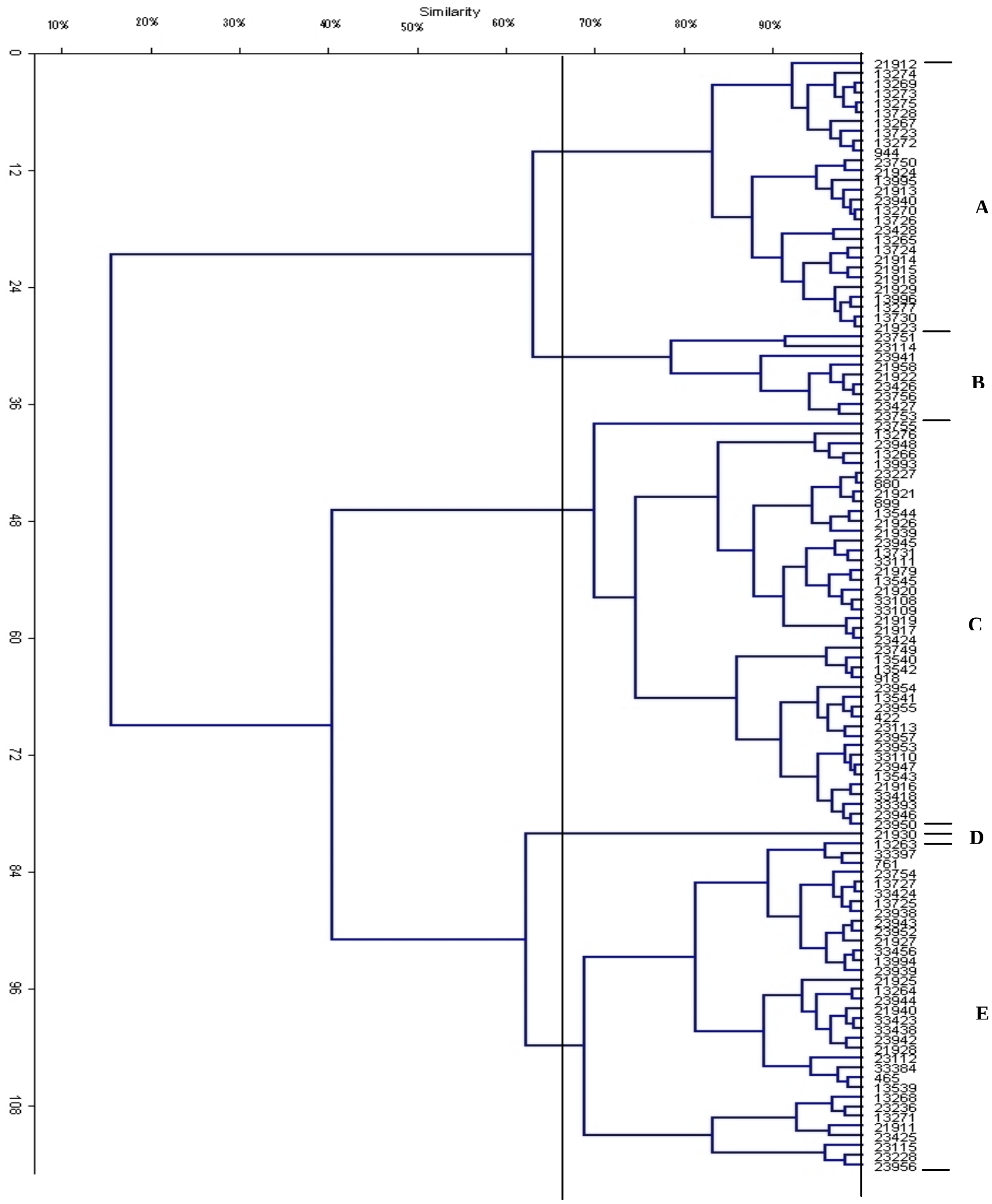

Figure 13. Dendrogram for the classification of 114 accessions of *Tadehagi triquetrum* truncated at the level of five clusters.

The five clusters are as follows:

Group A: Includes accessions CIAT 21912, 21923, 13274, 13269, 13273, 13275, 13728, 13267, 13723, 13272, 944, 23750, 21924, 13995, 21913, 23940, 13270, 13726, 23428, 13265, 13724, 21914, 21915, 21918, 21929, 13996, 13277 and 13730, characterized by intermediate flowering, with the 1st flower emerging 152 days after transplanting and an average of 28 inflorescences per plant. The origin of these accessions is Indonesia, Thailand, Papua New Guinea, China and Vietnam.

Group B: Composed of the nine accessions CIAT 23751, 23114, 23941, 21958, 21922, 23426, 23756, 23427 and 23753. This group is distinguished by late flowering, with the 1st flower emerging 220 days after transplanting; the average number of inflorescences is 96. These accessions were collected in Indonesia, Vietnam and China.

Group C: This group is composed by the highest number of accessions (42), including CIAT 23755, 13276, 23948, 13266, 13993, 23227, 880, 21921, 899, 13544, 21926, 21939, 23945, 13731, 33111, 21979, 13545, 21920, 33108, 33109, 21919, 21917, 23424, 23749, 13540, 13542, 918, 23954, 13541, 23955, 422, 23113, 23957, 29953, 33110, 23947, 13543, 21916, 33418, 33393, 23946 and 23950. The group is defined by very early flowering (45 days after transplanting), with 91 inflorescences per plant. The accessions were collected in Indonesia, Thailand, Vietnam, China and Papua New Guinea.

Group D: This group has only one accession, CIAT 21930, very late flowering with the first flowers after 261 days and a very high number of inflorescences (277). The accession originates from Vietnam, and, in contrast to the other accessions collected mostly below 1000 m asl, had been found as an altitude of 1320 m asl.

Group E: Includes 24 accessions, i.e., CIAT 13263, 33397, 761, 23754, 13727, 33424, 13725, 23938, 23943, 23952, 21927, 33456, 13994, 23939, 21925, 13264, 23944, 21940, 33423, 33438, 23942, 21928, 23112, 33384, 465, 13539, 13268, 23236, 13271, 21911, 23425, 23115, 23228 and 23956 and is characterized by intermediate flowering (first flowers 128 days after transplanting) and a high number of inflorescences (210). The origins are Indonesia, Thailand, Vietnam, China and Papua New Guinea.

Output 2. Forages as high value products developed to capture differentiated traditional and emerging markets for smallholders

2.1 Evaluation of forages for monogastric animals, Colombia

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Rationale

In a frame work of identifying forage options as alternative feeds for monogastric animals, promising (mainly due to quality characteristics) forage options are tested for agronomic adaptation in a number of contrasting sites in Colombia, Nicaragua and DR Congo. Here results from Colombia are reported, results from other locations and on the nutritive value and socio-economic conditions for integration into systems are described elsewhere.

Results and discussion

Multilocational trials were established in the 2nd half of 2009, in the areas of Rosas-El Bordo in Cauca, close to the main production sites. Sites selected were situated at an altitude of 1100 to 1350 m asl, a long dry season, and soils with a pH 5.02-5.23 and very low P levels.

The following 10 herbaceous legumes were sown: *Clitoria ternatea* CIAT 20692, *Desmodium heterocarpon* CIAT 13651, *Centrosema molle* CIAT 15160, *Canavalia brasiliensis* CIAT 17009, *Stylosanthes guianensis* CIAT 11995, *Lablab purpureus* CIAT 21603, 22759 and *Vigna unguiculata* IT95K52-34, IT95K1069-6, IT98K131-2.

In addition the shrub legumes *Desmodium velutinum* CIAT 33443, *Leucaena leucocephala* CIAT 17263 and *Cratylia argentea* CIAT 18516 and the grass *Brachiaria* hybrid Mulato II were established.

In general, the plants are growing well. So far leaf eaters in particular on cowpea and lablab and ants on Leucaena were found (Photos15-16).

Photo15. Planting and establishment of plots at La Sirena, Parraga, Cauca

Photo 16. Planting and establishment of plots at El Peaje, El Bordo, Cauca

2.2 Prececal and cecal *in-vitro* digestibility of different tropical legumes for monogastric animal nutrition

Contributors: J. Torres Jaramillo, C. Montoya, L. E. Muñoz (UNAL Palmira); M. Peters, P. Avila, B. Hincapié, L. H. Franco, S. Martens (CIAT)

Introduction

The rising dependence from importations of proteic sources, the fluctuations of prices, the limited availability of soy as the main protein source on world level and the increased competition for land resources with the emerging biofuel market has affected the availability of protein supply for farm animals. The investigation described here explores some underutilized forage or double purpose legumes as alternative protein source. In this context, *Vigna unguiculata (*cowpea*), Lablab purpureus* and *Canavalia brasiliensis* were evaluated as partial or total substitute of traditional protein sources.

Objective

The objective was to determine the nutritional composition and the *in-vitro* digestibility of tropical legume grains: *Canavalia brasiliensis*, *Lablab purpureus*, and three accessions of *Vigna unguiculata* (IITA1088-4, 9611 and IITA 625) with different seed colors (pink, red and white respectively) and raw or heat treated.

Materials and Methods

Grains of the forage or double purpose legumes Canavalia *brasiliensis* (CB), *Lablab purpureus* (LP), *Vigna unguiculata* (pink, red and white) were provided by the Tropical Forages Program of CIAT. They were compared to extruded soy grain (*Glycine max*) (GM), bought on the local market. The experiment was carried out with untreated, raw materials and heat-treated materials. The different heat treatments were raw (untreated) , boiled and autoclaved; for the boiled treatment two different cooking time (5 and 20 min) were used (Table 24).

Table 24. Different heat treatments of legume grains

Treatment	Raw	Boiled		Autoclaved	
Time (min)	0	5	20	5	20

The chemical composition was determined; the enzymatic hydrolysis of protein (*in vitro*) (120 min with pepsin and 240 min with pancreatin) was monitored by determination of soluble nitrogen and groups of resulting free amino acids. Equally, the pre-cecal digestibility of dry matter (DM), organic matter (OM) and starch was determined in this process. Finally, the cecal *in-vitro* digestibility of the residue of the preceding pre-cecal digestion was determined i.e., final gas production (P_f) and quantification of volatile fatty acids.

The statistical analyses were performed using the Mixed Model procedure of SAS (v 8.0, 2000, SAS Institute Inc., Cary NC, USA). The first analysis measured the effect of the raw legume grains. The second analysis evaluated the effect legumes, heat treatment (raw, boiling [5 and 20 min] and autoclaving [5 and 20 min]) and their interaction was determined using a factorial model (5 x 5). The analysis was completely randomized. When the F-value was significant (P<0.05), the average was compared with an adjusted Tukey test.

Results

The protein was highest in CB and GM (291-367 g/kg DM) vs. white cowpea (208 g/kg). The starch content varied from 316 to 560 g/kg. The protein digestibility was highest (P<0.001) for CB, GM and white cowpea (65, 62, 57 %, resp.) and lower for red and pink cowpea and LP (47, 43, 32 %). This was negatively correlated to the trypsin inhibitory activity (R= -0.8, P<0.5) (LP, red cowpea 26-22 TUI/g, GM, CB 7-14 TUI/g) (Table 25).

Table 25. Chemical composition of soy and the different legume grains

Legume:	CB [a]	LP [a]	Vpink[a]	Vred [a]	Vwhite[a]	GM [a]
Composition (g/kg DM)						
DM (g/kg)	898	897	895	878	906	939
Crude protein (N x 6.25)	291	235	212	216	208	367
Ether extract	17	55	15	15	18	263
Crude ash	30	39	38	38	39	48
Starch	316	403	537	482	563	-
NDF[b]	275	234	210	260	143	117
ADF[c]	174	131	52	75	22	68
Total dietary fibre	313	290	138	213	129	244
Energy (MJ/kg DM)	15.9	17.8	16.0	15.7	16.5	19.9
TIA[d] (TUI/g)	14	26	21	22	24	7

[a] CB, *Canavalia brasiliensis*; LP, *Lablab purpureus*; *Vigna unguiculata* (red, pink, white) y *Glycine max*, extruded soy cake. [b]NDF: Neutral detergent fibre, [c]ADF: Acid detergent fibre, [d]Trypsin inhibitory activity

Differences in the hydrolysis *in-vitro* of DM and between the legume grains control were significant (P <0.001). The highest value was 76% for SE. CB and LP presented the lowest values (54 - 59%) compared with the *Vigna* accessions (P <0.001, Figure 14). The starch digestibility was higher (P<0.001) for the raw materials of pink, white and red cowpea (62, 58 and 52 %), followed by LP and CB (46 and 43 %). It was negatively correlated to the NDF content (r= -0.85, P<0.05) (CB 275 g/kg DM, white cowpea 143g/kg, Figure 14).

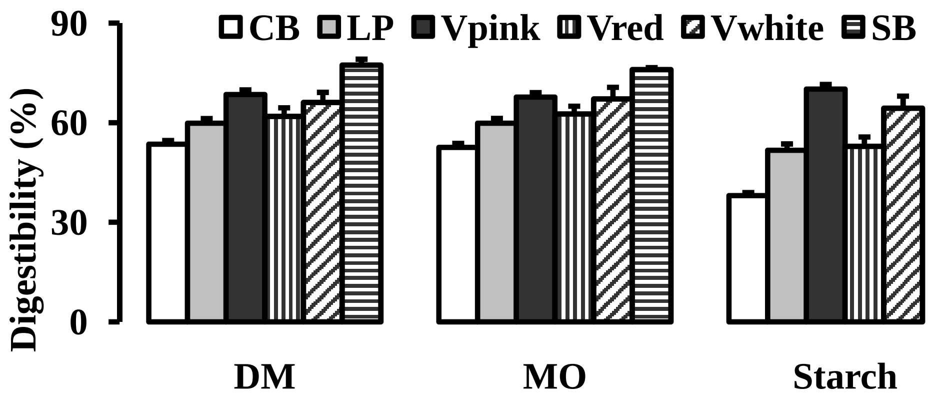

Figure 14. *In-vitro* digestibility of DM and starch of legume grains and control after 360 min of hydrolysis. Bars with different letters differ significantly (P<0.001).

There were differences in soluble nitrogen at time 0 between the raw legume grains (P <0.001). The highest value was obtained for CB and the lowest for SE (37.2 and 11.3% respectively). At 120 min, hydrolysis of the protein in grain legumes differed significantly (P <0.001), CB continued presenting the highest and SE the lowest degree of hydrolysis (38.9 and 15.8%) (Figure 15). The effect of interaction legume x thermic treatment on the protein digestibility showed that the type of thermic treatment influenced the degree of hydrolysis in the legumes differently (P<0.05). In general, after the pancreatin step, the autoclaved grains showed the highest degree of hydrolysis for all legumes (P<0.05), with the exception of pink cowpea. Within legumes, all treatments of LP showed the lowest degrees of hydrolysis (P<0.05, Table 26).

The *in-vit*ro digestibility of DM, OM and starch gave significant differences (P<0.001). Generally, highest digestibilities were obtained after autoclaving for 5 and 20 min (P<0.05, Table 26), with the exception of CB. To rise the digestibility of CB in terms of DM and OM, autoclaving for 5 min and boiling for 5 min in the case of starch was necessary. For cowpea, the treatment ebullition for 5 min improved the starch digestibility. For the cowpeas, 5 min ebullition served as well as autoclaving for 20 min to achieve the same values of digestibility. All thermic treatments improved the digestibility of DM and OM (P<0.05, Table 26).

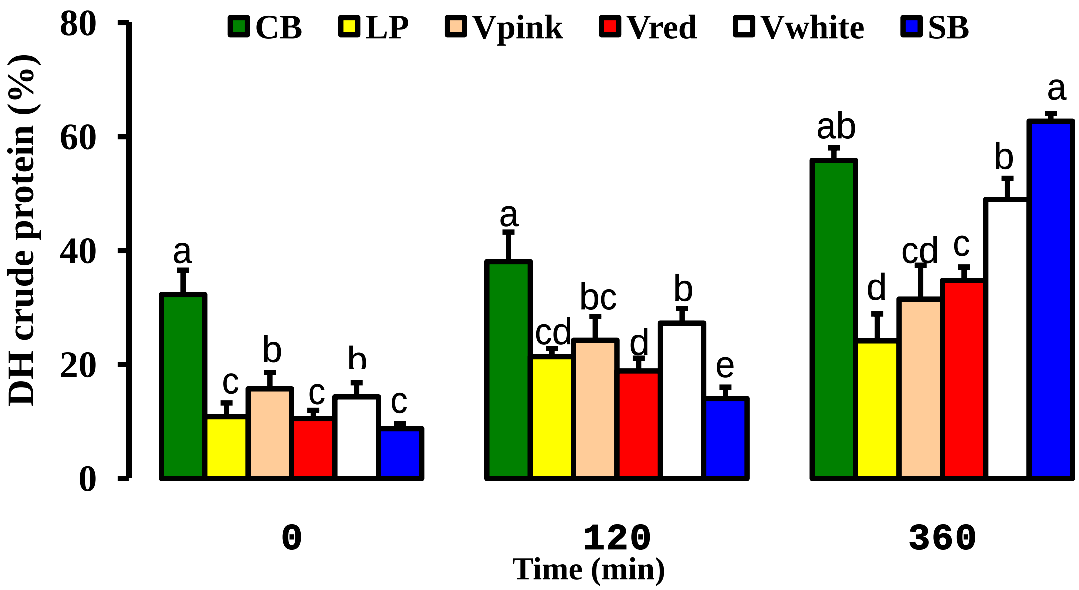

Figure 15. Degree of hydrolysis *in-vitro* of the protein in grains of tropical legumes and soy control (120 min pepsin + pancreatin 240 min). Bars with different letters at 0, 120 and 360 min differ significantly (P <0.001).

The gas production kinetics and the parameters of fermentation of the raw materials resistant to the hydrolisis by Pepsin and Pancreatin are presented in Figure 16.

The final gas production (P_f) was highest for white and red cowpea (P<0.001) and the lowest corresponded to extruded soybean meal and CB. The highest levels of NDF were found in CB and red cowpea (275 and 260 g/kg DM), however, no significant differences (P>0.05) in the degradability of DM and NDF at 72 h of fermentation were observed (84.3 % ± 6.6 and 88.5 % ± 4.2 respectively). There was a significant effect on the interaction between final gas volume (ml) and the latency time (h) (P<0.01). For red cowpea, autoclaving 5 min showed the lowest gas production in comparison with autoclaving for 20 min and 5 min boiling (348 vx. 426 and 429 ml respectively, P<0.05). For the other legumes no significant differences between treatments were observed. Comparing different heat treatments, CB boiled for 20 min or autoclaved for 5 min respectively presented the lowest values and generally the white cowpea showed the highest values of gas production. Referring to the DM degradation, there was a significant effect for legumes and thermic treatments (P<0.01). LP presented lowest degree of degradation compared to the pink and red cowpea (5.2 vs. 7.9 %). For the treatment effect, 20 min autoclaving reduced the degradation compared to the untreated control (5.6 vs. 8.6%).

Table 26. ***In-vitro*** **hydrolysis of protein, DM, OM and starch in tropical legume grains with different heat treatments.**

		Hydrolysis of protein			Digestibility (%)		
		0	120	360	DM	OM	Starch
[1] *Legume* * [2]*thermic treatment*							
CB	Raw	26.4	29.3^{a-e}	50.3^{h-j}	42.6^{l}	47.0^{j}	40.7^{hi}
	E-5	27.1	29.5^{a-c}	56.4^{e-i}	45.0^{kl}	48.0^{j}	51.3^{d-f}
	E-20	28.2	31.8^{a}	65.5^{ab}	44.1^{l}	47.8^{j}	35.4^{i}
	A-5	25.4	30.4^{b}	66.9^{a}	60.3^{c-f}	61.0^{d-h}	53.0^{c-f}
	A-20	23.9	29.3^{a-d}	62.0^{a-e}	43.0^{l}	46.7^{j}	43.2^{gh}
LP	Raw	26.0	29.5^{a-c}	46.0^{jk}	49.0^{jk}	50.0^{j}	42.0^{h}
	E-5	18.4	24.0^{a-g}	49.6^{ij}	49.2^{jk}	51.0^{j}	48.6^{fg}
	E-20	13.7	20.0^{d-g}	49.8^{ij}	52.5^{ij}	55.3^{i}	65.3^{a}
	A-5	9.0	19.0^{fg}	56.9^{d-h}	56.3^{f-i}	58.0^{f-i}	54.6^{b-e}
	A-20	11.0	19.9^{e-g}	53.7^{f-i}	55.6^{g-i}	57.2^{g-i}	67.6^{a}
Vred	Raw	22.0	24.1^{a-g}	51.7^{g-j}	55.0^{hi}	56.0^{i}	52.0^{d-f}
	E-5	13.6	23.0^{a-g}	52.2^{g-j}	59.2^{d-g}	61.0^{d-h}	69.0^{ac}
	E-20	13.5	22.5^{a-g}	63.7^{a-d}	60.0^{c-g}	61.1^{d-g}	58.0^{bc}
	A-5	11.1	19.0^{c-g}	60.5^{a-f}	64.0^{bc}	64.3^{b-d}	67.3^{a}
	A-20	10.3	19.1^{fg}	64.5^{a-c}	62.2^{b-d}	63.6^{b-e}	65.6^{a}
Vpink	Raw	18.7	24.5^{a-g}	41.6^{kl}	46.0^{kl}	49.0^{j}	48.0^{fg}
	E-5	13.7	19.5^{fg}	38.2^{l}	64.0^{b-d}	66.0^{bc}	66.4^{a}
	E-20	8.70	20.4^{c-g}	57.8^{c-g}	58.0^{e-h}	59.5^{e-i}	50.2^{ef}
	A-5	9.50	20.3^{c-g}	61.4^{a-e}	60.0^{c-g}	62.5^{c-e}	65.0^{a}
	A-20	9.80	19.3^{fg}	64.1^{a-c}	65.2^{ab}	67.0^{ab}	70.0^{a}
Vwhite	Raw	23.1	26.0^{a-g}	54.0^{f-i}	55.0^{hi}	57.0^{hi}	56.0^{b-d}
	E-5	17.0	28.0^{a-f}	57.0^{d-h}	61.0^{c-e}	61.6^{c-f}	65.6^{a}
	E-20	9.0	21.7^{b-g}	56.4^{e-i}	58.0^{e-h}	61.5^{c-g}	58.6^{b}
	A-5	12.5	24.6^{a-g}	65.2^{ab}	60.3^{c-f}	63.0^{b-e}	59.0^{a}
	A-20	10.4	18.5^{g}	59.7^{b-f}	69.0^{a}	70.3^{a}	70.0^{a}
Std. error		2.02	1.85	1.30	0.804	013	1.0 4
Statistic analysis							
Legume		0.001	0.001	0.001	0.001	0.001	0.001
Treatment		0.001	0.001	0.001	0.001	0.001	0.001
Legume x treatment		0.072	0.046	0.001	0.001	0.001	0.001

[1] CB, *Canavalia brasilienzis*; LP, *Lablab purpureus*; *Vigna unguiculata* (red, pink, white) [2] Raw; (E-5) boiling 5 min; (E-20) boiling 20 min; (A-5) Autoclaved 5 min; (A-20) Autoclaved 20 min

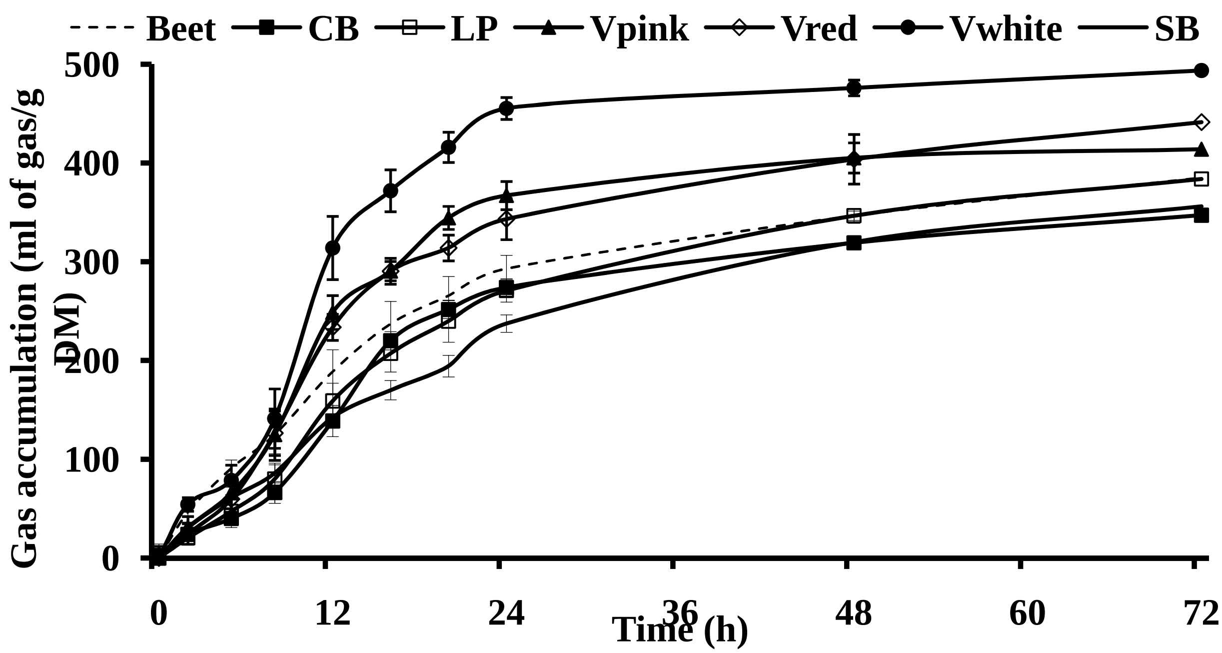

Figure 16. Kinetics of cecal *in-vitro* gas production of the residuals from the hydrolysis with pepsin and pancreatin (SB = extruded soybean meal, CB, LP, pink, red, white *Vigna*), Beet = sugar beet pulp was utilized as internal control.

There were no significant differences in the production of volatile fatty acids (acetic, propionic and isobutyric) among raw legume grains (P>0.05). In contrast to that, the butyric acid production presented significant differences (P<0.0001) with the lowest value observed for the residues of extruded soybean meal. The interactions were only influenced by the effect of the legume (P<0.01, Table 27). In general, the production of each volatile fatty acid were lowest for CB. Additionally, for acetic acid and total organic acid production, red cowpea presented values inferior to pink cowpea .

Table 27. Production of volatile fatty acids (VFA) after *in-vitro* fermentation (72 h after incubation).

[1]*Legume*		[1]Production de VFA (mmol/l)				
		Acet	Prop	Isob	But	VFA_{total}
CB		23.2[c]	11.4[b]	9.0[b]	5.2[b]	49[c]
LP		36.0[a]	14.2[a]	12.0[a]	6.0[ab]	65[ab]
Vpink		33.2[a]	15.2[a]	13.0[a]	7.0[a]	68[a]
Vred		29.0[b]	14.0[a]	11.3[a]	6.3[ab]	60[b]
Vwhite		32.0[ab]	15.2[a]	13.0[a]	7.0[a]	66[ab]
[2]*Thermic treatment* (TT°)						
Raw		30.0	14.2	11.0	6.7	62
Boiled 5 min	(E-5)	31.0	14.0	12.4	6.1	63
Boiled 20 min	(E-20	29.4	14.0	12.0	6.4	62
Autoclave 5 min	(A-5)	30.3	14.1	11.5	6.0	62
Autoclave 20 min	(A-20)	29.3	14.0	11.0	6.0	60
*Legume*TT°*						
B	Raw	24.0	12.0	9.0	5.3	51
	E-5	24.0	11.2	8.3	5.0	44
	E-20	19.0	11.0	8.8	5.6	50
	A-5	25.0	12.0	9.0	5.0	50
	A-20	24.4	11.4	10.0	5.0	63
LP	Raw	31.1	14.2	11.1	7.0	64
	E-5	33.0	14.0	13.0	5.0	61
	E-20	31.0	13.1	12.0	6.0	67
	A-5	34.2	15.0	12.0	6.3	67
	A-20	34.0	15.2	12.2	6.1	62
Vred	Raw	30.0	14.3	11.2	6.8	65
	E-5	31.4	14.4	13.0	6.3	63
	E-20	30.0	14.0	12.3	6.7	54
	A-5	26.1	13.0	9.7	5.4	57
	A-20	27.4	13.5	10.4	6.0	71
Vpink	Raw	34.4	16.2	13.0	7.5	68
	E-5	33.1	15.0	13.1	7.0	69
	E-20	34.0	15.2	13.3	7.0	70
	A-5	35.0	15.7	14.0	6.5	61
	A-20	30.2	14.2	11.0	6.0	60
Vwhite	Raw	29.2	14.0	9.77	7.1	71
	E-5	33.4	16.0	15.0	7.2	71
	E-20	34.0	17.0	14.0	7.0	67
	A-5	32.0	15.4	13.3	6.5	61
	A-20	29.5	14.0	11.4	6.6	61
[3]Std. error		3.31	0.977	1.61	1.13	6.12
Statistic analysis						
Legume		0.001	0.001	0.001	0.003	0.001
Treatment		0.75	0.91	0.24	0.13	0.83
Legume x TTo		0.41	0.35	0.41	0.87	0.44

[1] Ace: acetic, Prop: propionic, Isob: isobutyric, But: butyric, [abc] Values with different letters in the same row differ significantly $P < 0.05$

Discussion

The results indicate that raw white cowpea grain can serve as alternative protein and energy source to extruded soybean meal because of its protein, dry matter, organic matter and starch digestibility and equally for its values in final gas production (P_f) and production of volatile fatty acids. In contrast to that, the other legumes *Lablab purpureus* and *Canavalia brasiliensis* should not be used in feed for monogastrics in raw state since a high presence of antinutritional factors such as lectins (i.e.: concanavalin A and canavanine) could limit their use in animal nutrition. Nevertheless, some antinutritional factors are eliminated by soaking and heating. Also it can be concluded that the type of thermic treatment affects differently digestibility and fermentation variables in each of the legumes. Generally, autoclaving improved the digestibility values without affecting the parameters of cecal fermentation. Summarizing, the results indicate that the selection of thermic treatment depends on the legume species to be used.

2.3 Growth of pigs fed with *Vigna unguiculata* meal as protein supplement

Contributors: P. Sarria, L.F. Rivera, R. Araujo (UNAL Palmira), M. Peters, S. Martens (CIAT)

Introduction

Meat consumption in developing countries has incremented 70 mio t from the beginning of the 1970s to the mid 1990s. The increment in consumption was dominated by pork and chicken meat, not beef. In Colombia, Venezuela and Nicaragua, many rural households are dedicated to pig and poultry production with two concrete objectives: a) household food security and b) the income generation.

Crude protein in animal diets is a main limitation in many animal production systems in the tropics, including monogastric animals Although the purchase of concentrates may allow the smallholder to expand his production, the cash-flow available to smallholders is not sufficient and/or the concentrate is costly or hardly available.

Foliage or whole plant forage and grains of legumes or other plants could serve as economic alternatives for substituting conventional protein sources. It is seen as an option for small and medium enterprises as well as commercial concentrate plants with the advantage no to compete with human nutrition. Various forage legumes are well adapted to marginal conditions in agriculture, especially to acid soils with low fertility and variable water availability .

In this study, the productive behavior of pigs in the phase of 25-60 kg live weight fed with cowpea meal (*Vigna unguiculata*) as protein supplement was investigated.

Materials and Methods

The trial took place on the experimental farm of the National University of Colombia, Palmira, with an average yearly temperature of 24 °C, 1000 msl altitude and an annual rainfall of ~1000 mm. The analyses were performed at the Animal Nutrition laboratory of the university.

The aerial part of cowpea (*Vigna unguiculata* 9611) was harvested at the experimental station of CIAT in Santander de Quilichao between 7 and 8 weeks of growth before flowering. It was sun-dried for 4 days and milled to 3 mm.

Fourteen female pigs (Piétrain-Large White x Landrace-Large White) with an initial average weight of 25.4 kg were utilized for the experiment. They were kept in individual units with feeder and sipper tubes. The trials design was a completely randomized block with 3 treatments and 5 or 4 replicates.

The statistic model was Yij = μ + Ti + Eij , with Y as productive response (growth or consumption or conversion), μ as mean of replicates, Ti as effect of treatment and Eij as effect of experimental error. The 3 treatments were balanced to equally nutritive diets for fattening pigs with high genetic potential and regular performance according to the Brazilian nutritional recommendations :

Control: A mix of maize, soy, wheat bran and vegetable oil was utilized.

Cowpea 15% crude protein (CP): Cowpea meal contributing 15% of the crude protein of the diet was included.

Cowpea 30% CP: Cowpea meal contributing 30% of the crude protein of the diet was included.

Management and feeding

The composition in total percent of the diet is given in table 28 and its nutritional value in table 29.

Table 28. Composition of the diets for fattening pigs with cowpea meal as protein supplement

Ingredients	Control	Cowpea 15% CP	Cowpea 30% CP
Cowpea forage meal	0.0	17.0	32.9
Maize	46.8	45.5	44.0
Soy meal*	14.0	12.5	12.0
Fish meal	5.0	5.0	5.0
Wheat bran	30.0	14.9	0.0
Soy oil	2.1	3.0	4.0
D-L Methionine 99%	0.35	0.35	0.35
L-Lysine HCl 78%	0.25	0.25	0.25
Calcium carbonate	0.74	0.74	0.74
Dicalcium phosphate	0.35	0.35	0.35
Marine salt	0.28	0.28	0.28
Vitamin-mineral premix	0.10	0.10	0.10

*extruded soy bean meal, 46 % crude protein in DM

The diet was offered according to the appetite of the pigs during the week of acclimatization, i.e., 90 g dry matter (DM)/kg liveweight $(LW)^{0.75}$. This quantity was maintained throughout the experiment, distributed in 2 rations per day.

The adaptation period was 7 days, followed by a 49 daysmeasuring period took 49 days.

Table 29. Theoretical nutritive value of the experimental diets, calculated by the composition of each raw material

	Control	Cowpea 15%CP	Cowpea 30%CP
CP, %	18.4	18.1	18.1
ME, kcal/kg	3258	3326	3212
Calcium, %	0.63	0.61	0.59
Available phosphorous, %	0.37	0.31	0.26

The pigs were weighed every week and the feed to be offered was calculated according to weight. The feed was divided in 2 rations per day given at 8:00h and 13:00h. The remainder was recovered 2 hours after feeding.

The data was analyzed using the program SAS 9.1 for Windows 2002-2003. The sources of variation were the treatments by the level of cowpea in the diet and the experimental error.

Results

There were no significant differences between treatments for the variables daily liveweight gain, daily feed consumption in terms of kg DM per kg of metabolic liveweight ($LW^{0.75}$) nor in terms of feed conversion (P>0.05) (Table 30).

Table 30. Performance of swines fed with cowpea leaf meal as protein sources

	Control	Cowpea 15% CP	Cowpea 30% CP	se[1]	CV%[2]	P[3]
No. of animals	5	5	4			
Initial liveweight, kg	28.4	27.1	29.6	1.9	6.8	0.192
Final liveweight, kg	60.0	55.2	58.7	4.6	7.7	0.906
No. of days	49	49	49			
Daily liveweight gain, g	640 ±100	570±30	590±50	68.3	11.3	0.277
Daily consumption, g	1582 ±82	1484 ±91	1590 ±35	76.1	4.9	0.098
Feed conversion	2.49 ± 0.3	2.59 ± 0.1	2.69 ± 0.2	0.21	8.3	0.431
Consumption kg/kg $LW^{0.75}$	84.8 ± 1.84	84.1 ± 2.15	85.1 ± 1.0	1.8	2.1	0.658

[1] Standard error. [2] Coefficient of variation. [3] Probability value: Values with different letters in the same row differ significantly (P<0.05).

Concerning the daily liveweight gain there was no linear response. The response to the control was slightly higher compared to the two cowpea treatments and the treatment with 30% cowpea inclusion got slightly superior responses to the 15% cowpea treatment (Figure 17).

The daily consumption and the ratio of kg DM intake per kg liveweight was slightly higher in the treatment with 30% protein replacement by cowpea and did not show a linear response. It was followed by the control; the lowest was with 15% cowpea level. (Figure 18).

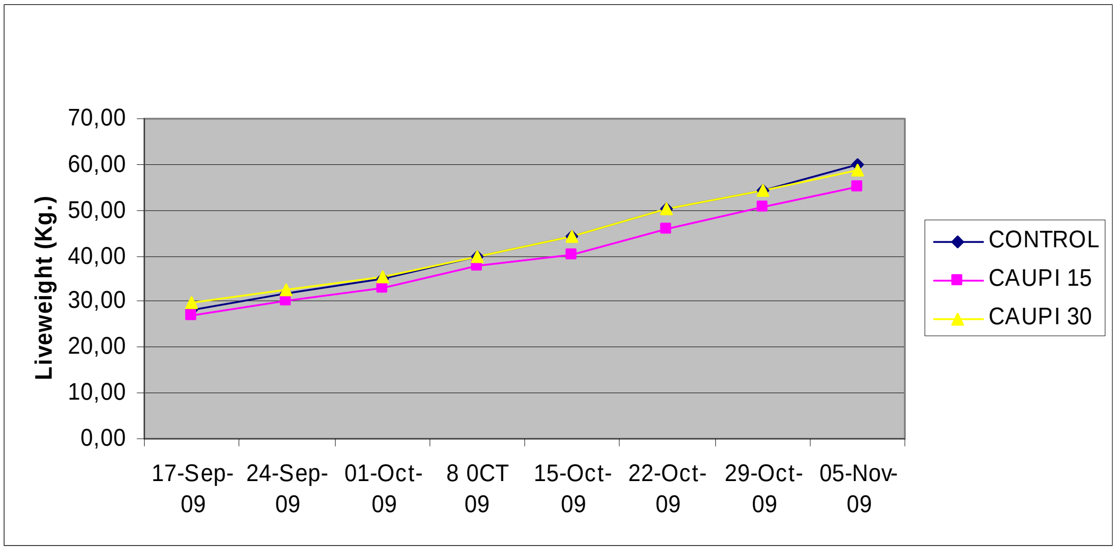

Figure 17. Liveweight gain in growing female pigs

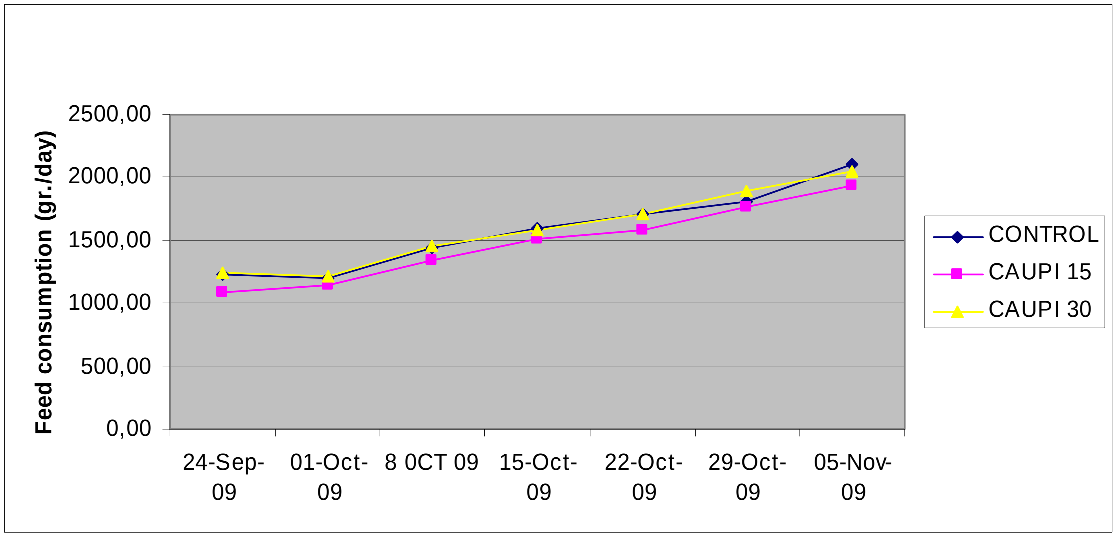

Figure 18. Daily average feed consumption

Although the feed conversion did not differ significantly, there was a linear negative response with increasing cowpea level in the diet. The R^2 was 0.6 (P=0.0007) in the regression equation. That means that the nutrients of the control diet were better utilized by the animal for weight gain which shows a slight disadvantage of cowpea meal.

Discussion

The daily weight gain did not show significant differences when including incrementing quantities of cowpea forage meal as soy substitute even though the foliage has lower concentration of nitrogen, and lower availability of amino acids.

In a previous study the apparent fecal digestibility of DM, energy and fiber was not affected when 30% of protein was replaced with cowpea meal. Only the fecal and ileal protein digestibility was decreased. Cowpea is highly palatable for pigs and has superior digestible protein compared to other forages.

In the presented experiment the daily weight gain of the three treatments was slightly inferior to the theoretically achievable 735 g daily liveweight gain for female pigs with high genetic potential and diets based on maize and soy meal . This can be explained by the fiber content from cowpea and wheat bran which was as high as 5-10%. Results from the literature indicate that more than 5% fiber content in a pig diet has beneficial effects on the digestive tract (small and large intestine) with effects like reduction of cholesterol and blood glucose, maintaining the health of the gastrointestinal tract and augmenting the bioavailability of calcium..

The consumption in g/day did not show any significant differences nor tendencies to decrease with higher cowpea levels. The more precise figure of consumption of DM per kg metabolic liveweight was similar between treatments. In another experiment with cowpea meal with imbalanced diets in 2009, there was even a slightly higher consumption of the diets with 30% cowpea inclusion in pigs between 20-30 kg LW, giving values of 88-91 g DM/kg $LW^{0.75}$. These values are slightly inferior to the theoretical daily intake of 1777 g DM and 100.6 g DM/kg $LW^{0.75}$ for balanced diets based on maize and soy meal.

Conclusions

Up to 30% of dietary protein replacement cowpea forage meal can be included in the diet without affecting productive parameters of fattening pigs in the phase 20-60 kg liveweight. For the finishing phase from 60-120 kg, the same behavior is expected as it is a lesser demanding phase.

2.4 Ensilability of 9 tropical forage species for use in pig nutrition

Contributors: S. Heinritz (Uni Rostock und Hohenheim/CIAT), A. Zeyner, S. Hoedtke (Uni Rostock), S. Martens, P. Avila, L. H. Franco (CIAT)

Rationale

Locally grown high quality forages have the potential to contribute to the protein supplementation of smallholder's pigs. As some of the forages are either annual, have ahigh moisture content and/or are high in anti-nutritional factors such as tannins, in many cases the necessity of processing arises. Besides drying and milling, fermentation may be an option, especially under more humid climate conditions.
This study is carried out in collaboration with the University of Rostock within the BMZ-funded project "More chicken and pork in the pot, and money in pocket: Improving forages for monogastric animals with low-income farmers" (2009-2012).

Materials and Methods

In November and December 2009 Cratylia argentea CIAT 18516 and 18668, Flemingia macrophylla CIAT 21087, Desmodium velutinum CIAT 23985 and Mulato II (CIAT 36087) were harvested at

Quilichao station. Vigna unguiculata 9611 was cut at CIAT Palmira, Leucaena diversifolia was taken from Popayán (Unicauca) and Centrosema brasilianum CIAT 5234 and Stylosanthes guianensis CIAT 11995 came from an on-farm trial in Patía (Cauca). In January 2010 Canavalia brasiliensis CIAT 17009 was cut at Quilichao.

From the shrub and tree legumes Cratylia, Flemingia, Desmodium and Leucaena the most lignified parts were removed before chopping.Vigna unguiculata had to be rolled and pre-wilted for two days to raise the dry matter content from 15 % up to about 30 %. All material got 4 treatments, control, addition of sucrose (2% of fresh weight), lactic acid bacteria (LAB) and LAB + sucrose. The LAB strain had been isolated from a Canavalia-sweet potato silage in 2008 and evaluated with 20 other LAB strains in an in-vitro fermentation test. Three of the best strains were inoculated on a forage legume to determine the survival rate after liophylization of the silage. The selected strain was applied in a concentration of 105 cfu/g fresh matter. Four replicates of each treatment were prepared to be evaluated after 90 days of fermentation, 2 additional replicates were opened after 3 days to determine dry matter and pH as an indicator of the fermentation success. The quicker the pH decreases the better is the inhibition of proteolysis and undesired enterobacteria.

Results and Discussion

Some preliminary results of the pH of 3 days old silages are presented below. Full chemical analysis will be available at the end of 2010.

Table 31.-day-pH of ensiled material with dry matter content

	Control	2% sucrose	LAB	LAB+sucrose	% DMaver
Cratylia argentea	6.7	6.3	5.7	4.7	28
Desmodium velutinum	5.9	5.8	4.5	4.1	37
Flemingia macrophylla	6.0	5.9	5.0	4.7	41
Vigna unguiculata	5.8	5.3	5.2	4.5	32
Mulato II	5.5	4.7	4.5	3.8	35
Leucaena diversifolia	6.5	6.4	5.4	4.2	31
Stylosanthes guianensis	6.0	5.3	5.3	4.1	30
Centrosema brasilianum	6.0	5.0	5.0	4.1	27
Canavalia brasiliensis	6.1	6.0	4.3	4.2	44

The table 31 shows for all 9 forage species very high pH values between 5 and 7 in the control treatment. The addition of sugar slightly improves the situation, more pronounced with the grass than with the legumes. The addition of a source of easily fermentable carbohydrates is often recommended to overcome the high buffering capacity especially in legumes. However, the inoculation of an effective LAB strain shows a higher effect than the carbohydrate source alone. This indicates that the naturally occuring bacterial plant flora is very low in numbers of efficient LAB. The supply of additional carbohydrates (penultimate column) results in a quick metabolisation into lactic acid by the inoculant with the simultaneous decrease of the pH. In the most extreme case the combined treatment resulted in a difference of 2 pH units below the control. This comparison of additives reveals that despite an equally proper handling in airtight bags the same fresh material can result in a bad or a very good silage.

Outlook

The silages will be fully evaluated after 90 days of storage at 25^{o}C, including aerobic stability, tannin and oligosaccharide degradation and in-vitro enzymatic and cecal digestibility for pigs.

Based on the results obtained the CIAT Tropical Forages Program is looking for opportunities to further test the lactic acid bacteria strain and make it available as silage inoculant for small farmers in the tropics.

2.5 Forages for monogastrics in Central Africa

Contributors: B.L. Maass, D. Katunga-Musale, W.L. Chiuri, M. Peters (CIAT)

Rationale

Within the Consortium for Improving Agriculture-based Livelihoods in Central Africa (CIALCA), a need to involve livestock research and development had been perceived by partners of the consortium as most smallholder farmers in the region produce in mixed crop-livestock systems. CIALCA aims at developing and disseminating in partnerships with all stakeholders resilient agro-ecosystems through integration of stress-tolerant and biofortified germplasm, inclusion of locally adapted natural resource management (NRM) options, market-led diversification and intensification, and revitalisation of research for development capacity of all stakeholders. The main entry points are multi-purpose legumes and tropical forage species that will address issues related to declining soil fertility, low income, and food insecurity and malnutrition being major constraints to improved rural livelihoods in the target areas of Democratic Republic of Congo, Burundi and Rwanda. Initially, in view of livelihood and poverty considerations for resource constrained farmers, particular attention is given to small livestock such as monogastric animals.

Material and Methods

To understand major issues of livestock production with emphasis on monogastric animals in South Kivu province of D.R. Congo, 20 villages in seven so-called '*groupements*' were selected mostly along a North to South-West axis, with the town of Bukavu in the center. The survey took place in the hilly agricultural land between the National Park of Kahuzi-Biega in the West and Lake Kivu, at elevations extending from about 900 m asl. in Kamanyola to 1900 m asl. in Burhale. A diagnostic survey approach was employed to rapidly obtain in-depth knowledge of constraints and opportunities in a defined social, economic and natural environment.

Results and Discussion

From the responses of 112 informants, it was concluded that livestock is an integral part of the mixed farming systems in the region, despite their presently low numbers per household. Farmers largely concentrate on small livestock, such as poultry, swine, guinea pigs and rabbits (Photo 17). Livestock mostly served for accumulating household reserves that were strongly invested in school education of the children. The most important issues of animal husbandry appeared to be related to animal diseases, feed resources, mostly in the dry season, and theft.

Major challenges faced by introducing new and more productive forages into the region will be towards the agro-ecological adaptation of such plants with regard to mid-elevations of above 1500 m asl., prolonged growth into the dry season, high biomass-producing species in order to not use too much space of small farm land, and reducing labor demand for women and children for collecting forages.

Photo 17. Monogastric livestock encountered during the diagnostic survey in D.R. Congo in June 2009; (a) swine feeding on cassava leaves, (b) rabbits in a cage, (c) free-roaming chicken, and (d) guinea pigs feeding on *Galinsoga parviflora*.

2.6 Improving forages for monogastric animals with low-income farmers in Nicaragua

Contributors: C. Rodríguez, R. van der Hoek, E. Chavarría, M. Peters (CIAT), M. Mena, J. J. López, M. Tinoco (INTA)

Rationale

Forage and animal production can diversify farm production and income. In smallholder monogastric systems, available feeds are typically farm residues of low nutritional value. Moreover, purchased feed is too costly, distant, or simply unavailable. This activity comprises basic research to identify suitable high-quality feed resources and research to adapt and innovate with forage-feed resources and achieve their integration within smallholder production systems.

Materials and methods

In two municipalities in the Pacific part of Nicaragua (Chinandega and El Sauce) a total of 8 on-farm plots with 6 herbaceous and 6 shrub legumes were established in the *Postrera* of 2009 (second growing season: August, September) (Table 32):

- Herbaceous legumes: *Lablab purpureus* CIAT 21603, *Lablab purpureus* CIAT 22759, *Stylosanthes guianensis* CIAT 11995, *Vigna unguiculata* 9611, *Vigna unguiculata* FHIA, *Vigna unguiculata* Verde Brasil.

- Shrubs: *Cajanus cajan* (Gandúl), *Cratylia argentea*, *Gliricidia sepium* (Madero Negro), *Leucaena leucocephala*, *Morus alba* (Morera), *Trichanthera gigantea* (Nacedero).

The area of each plot was 25 m2 (5x5) with for the herbaceous and shrub legumes a distance of 50 cm resp. 1 m between rows and 25 cm resp. 50 cm between plants. Of each plot with herbaceous legumes, 50% of the biomass was cut (at the onset of flowering) and dried, whereas the other half was destined to seed production to be able to plant larger areas in the next growing season (*Primera* May-June 2010). However, during the cutting process (mainly of *Vigna*) humidity was still high (due to rain) causing moulds and quality loss.

Table 32. Characteristics of on-farm experiments

Farmer	Community	Municipality	Planting Date
Róger Arrieta	Tecomatepe	Chinandega	25-08-09
Mirna Martínez	Tecomatepe	Chinandega	13-09-09
Fausto Carrión	Las 20 mz	Chinandega	28-08-09
Jerónimo Campos	La Grecia	Chinandega	01-09-09
Salvador Parrilla	Salales	El Sauce	03-09-09
Biskmark Valle	Petaquillas	El Sauce	11-09-09
Yolanda Medrano	San Nicolás	El Sauce	17-09-09
CETA	El Sauce	El Sauce	18-09-09

Germination

Germination was seriously affected by drought, especially of the shrubs. Replanting took place where necessary, but germination rates of shrubs remained low.

Biomass production

Herbaceous legumes

Biomass production was determined by taking and drying samples from 1 m2. Apart from this, plant height, cover, vigor, weed incidence and pest and disease resistance were assessed.

The *Vigna* (cowpea) varieties showed in general fast growth and are well adapted to the region. The *Lablab* varieties have a longer growing cycle than *Vigna*. Flowering occurred only in November when humidity is lower and this resulted in better quality of the harvested biomass. Grain production was however low: for seed production a longer growing period is needed.

Stylosanthes guianensis CIAT 11995 being a perennial showed slow initial growth and could therefore not yet be assessed agronomically.

Figure 19 presents the average biomass yields of the different *Vigna* and *Lablab* accessions.

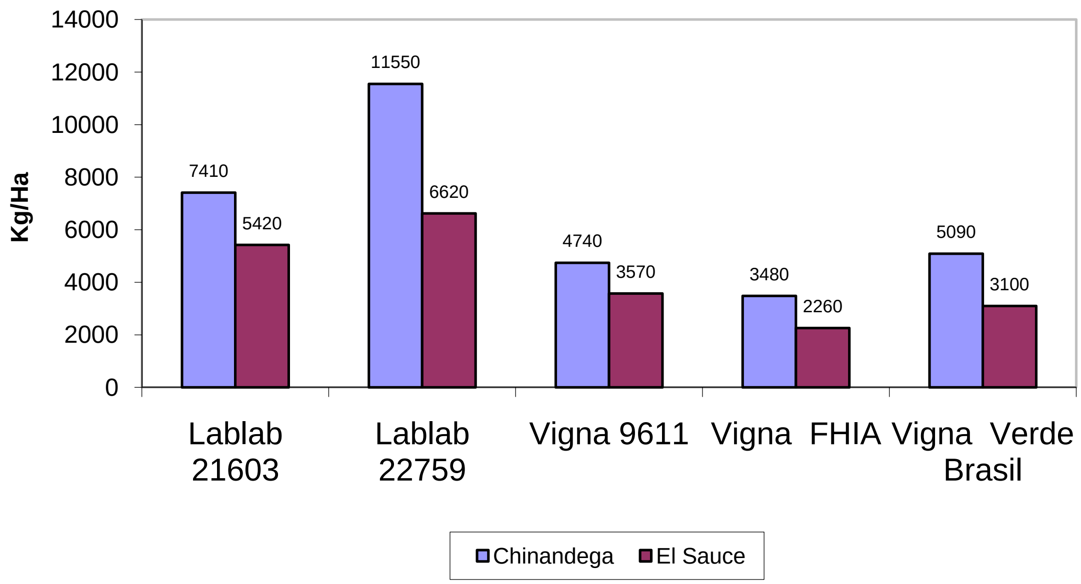

Figure 19. Average Biomass Production (DM) in Chinandega and El Sauce

After a relative slow initial growth the *Lablab* accessions produced the highest quantity of biomass, especially *Lablab purpureus* CIAT 22759, reaching a height of almost 95 cm.

The *Vigna unguiculata* accessions showed a higher initial growth. Especially the FHIA variety produced already grains from week 7 onwards. The other varieties (9611 and Verde Brasil) were somewhat slower (9 weeks), but produced more biomass. At one site (CETA, a farmers field school, in El Sauce), a considerable quantity of seed of *Vigna unguiculata* 9611 was produced and will be used to plant a large area for feeding trials with pigs.

Yields in Chinandega were generally higher than in El Sauce. This is mainly caused by differences in soils (those in Chinandega being volcanic).

Shrubs

Due to late planting (second growing season) and unexpected drought most shrubs performed poorly. Only *Cajanus cajan*, and at some sites *Gliricidia sepium*, showed some growth.

Conclusions and recommendations

- To minimize biomass and quality loss the planting period has to be adjusted to avoid harvesting in humid conditions. Another option is the use of plastic to protect the material against humidity.

- Grain production of *Lablab* is only feasible when planted in the first growing season (*Primera*). In contrast, early maturing accessions like *Vigna unguiculata* FHIA can produce seed during both growing seasons.

- Shrubs have to be panted in the first growing season. Furthermore, for the next cycle most species (except for *Cajanus cajan* and *Gliricidia sepium*) will be produced in a nursery before being transplanted to the field.

Outlook

The following activities are planned for the coming year:

- Increase of the number of participating farmers to around 15. Besides this, two municipalities will be added (Santa Rosa del Peñon, Achuapa)
- Increase of areas to produce sufficient material for experiments with animals (mainly pigs), subsequent feeding trials
- Replanting of shrubs in the *Primera* growing season
- Diagnostic survey among the participating and other farmers

2.7 The use of poultry and swine in smallholder farms in Nicaragua: A value chain analysis

Contributors: F. Holmann (CIAT), S. Burkart (CIAT/U Hohenheim), V. Hoffmann (U Hohenheim)

Highlight

- The nutritional balance for both poultry and pig production shows they are receiving a diet deficient in both energy and protein, with protein being the greatest constraint. Promoting forage legumes to supplement both poultry and pigs can be very profitable to increase both the production of pigs for additional income and the production of poultry meat and eggs for improved family nutrition.

Rationale and background

Poultry and swine production in smallholder farms in Nicaragua is based on the backyard production system. This system is very flexible and of low productivity. It consists of a few chicken (usually below 30) and pigs (usually below 3) receiving small to moderate amounts of maize which is complemented with household waste and other feed sources obtained around the house (i.e., seeds, insects, worms, etc).

Under these conditions, chickens and pigs are usually underfed. Thus, productivity is low. However, this system provides a steady source of animal protein of high quality in the form of eggs and meat for household consumption, and therefore it is improving food security and nutrition. In Nicaragua, chicken are raised mostly for household consumption whereas pigs are raised and sold to obtain additional income for the rural family.

There were about 440,000 pigs in Nicaragua during 2002 with a growth rate of 1.5%/yr. About 157,000 pigs were slaughtered with a carcass weight of about 41 kg/head, producing 6,455 mt of meat in 2002. No pork meat is currently imported. Per capita pig consumption is very low (1.9 kg/yr) compared to 9.9 kg/capita/yr on average for Central America. Thus, the opportunity for growth is high. Most of the meat is produced and consumed in local markets, dominated by local butcheries. It is estimated that there are 3,500 unauthorized butchers and about 300 legal butchers authorized and supervised by the Ministry of Health Therefore, animal health controls are lacking in great parts of the production and this is a constraint to higher meat consumption, especially by the urban population.

Concerning the poultry industry in Nicaragua, around 45.9 million birds were slaughtered during 2008, obtaining a production volume of 90.7 million kg of meat for a per capita anual consumption of 15.7 kg. During the same year the production of eggs was 368.4 million units for a per capita anual consumption of 63.7 eggs. About 10.6% of domestic production is imported. It is estimated that the majority of meat and egg production in the country comes from large poultry farms.

Objective

The objective of this study was to understand the role that poultry and pigs play for smallholder farmers with mixed crop-livestock systems in Nicaragua in terms of family income and food security, and to analyze feeding strategies, resource allocation and market alternatives within a value-chain analysis.

Material and methods

Data for this study came from three surveys and secondary information.

Survey Data

Primary data for this study comes from three survey instruments. The first survey was designed for producers with mixed crop-livestock systems, the second survey for middlemen, and the third one for retailers. The survey for producers asked for information regarding land and labor use, resource allocation, credit use, animal inventories (bovine, poultry, and pigs), feeding management, monogastric production, consumption, and sales. The survey for middlemen asked for information regarding buying and selling prices, animal selection criteria, and supply and demand for poultry and pig products. The survey for retailers asked information regarding consumer prices, consumer preferences, animal health risks, and criteria for buying animals.

Nine producers and six retailers were surveyed during September 20-26, 2009 in the Chinandega and El Sauce area located in the North-Pacific of Nicaragua. No middlemen were found in the area.

Secondary Information

The Ministry of Agriculture, Livestock and Forestry (MAG-FOR) and the Inter-American Institute for Agricultural Cooperation (IICA) provided information about statistics, consumption, production, exports, imports, prices, and marketing. However, information available was mostly for pigs.

Results and Discussion

Survey Analysis - Producers

Land use

Table 33 contains the land use for the surveyed focus group. As shown, the largest land use is for pasture production, followed by forest, and then by agricultural activities led by maize, beans and rice, which are the basic staple food crops of rural families in Nicaragua.

Table 33. Land use of the focus group (in hectares)

Cultivation	Average area in ha for all farmers (n = 9)	Average area in ha for all cultivating farmers (n = 9)
Total	17	17
Pasture	10	11.3 (n = 8)
Maize	0.92	0.92 (n = 9)
Sorghum	0.42	0.80 (n = 4)
Sesame	0.36	1.28 (n = 3)
Beans	0.67	0.67 (n = 9)
Vegetables	0.07	0.64 (n = 1)
Rice	0.64	0.74 (n = 7)
Plantain	0.28	2.56 (n = 1)
Pineapple	0.02	0.16 (n = 1)
Forest	2.77	8.32 (n = 3)

Cattle inventory

Table 34 shows the herd structure found in the sample farms. Mean herd size is 6.6 heads and 89% of farms have cattle. This shows that not many of them put their focus on swine and poultry. Of fhose who have cattle, most (75%) have cows, averaging almost 3 cows per farm (dairy cattle and dry cows together).

Table 34. The cattle livestock composition of the focus group

Cattle stock	Average number for all farmers (n = 9)	Average number for all affected farmers (n = 8)
Total	6.56	7.38
Dairy cattle	1.6	2.33 (n = 6)
Dry cow	1.33	4.00 (n = 3)
Heifer > 2 y	0.78	3.50 (n = 2)
Female calves 0-1 y	0.78	1.40 (n = 5)
Male calves 0-1 y	0.89	2.00 (n = 4)
Young bulls 1-2 y	0.33	1.50 (n = 2)
Young bulls > 2 y	0.11	1.00 (n = 1)
Bulls	0.78	1.75 (n = 4)

Poultry inventory

Table 35 shows that the mean stock of chicken is 31 birds per farm. All farmers have laying hens for egg production, and the rest of the flock is composed of growing animals.

Table 35. The chicken livestock composition of the focus group

Chicken stock	Average number for all farmers (n = 9)	Average number for all affected farmers (n = 9)
Total	31.11	31.11
Laying hens	8	8
Young hens	9.78	11
Broilers	9.11	11.71
Cocks	1.78	1.78

Pig inventory

Table 36 shows that all farmers raise pigs, averaging 2.4 heads/farm. Most of them are fattening pigs (73%).

Table 36. The swine livestock composition of the focus group

Swine stock	Average number for all farmers (n = 9)	Average number for all affected farmers (n = 9)
Total	2.44	2.44
Young female swine	0.67	0.67
Fatteners	1.78	1.78

Household Consumption

Table 37 contains the different products consumed by the rural family and which are produced on the farm. On average, most of the animal protein consumed by the family comes from milk (5.1 kg/day, mostly in the form of cheesse) and eggs (6.1/day), followed by small amounts of chicken (about 1.3/week). No pig meat is consumed as pigs are raised for sale.

Table 37. Home consumption of the producer families

Home consumption	Average for all farmers (n = 9)	Average for all affected farmers
Milk (liters/d)	5.00	7.50 (n = 6)
Chicken (number/week)	1.33	69.3 (n = 9)
Eggs (number/d)	6.1	6.10 (n = 9)
Maize (kg/d)	2.6	2.60 (n = 9)

Labor use

Mostly all labor is provided by family members, especially the male head of the household. Some contract labor is hired during peak periods of planting and harvesting (Table 38).

Table 38. Labor information

Family member	Share farm work of total working time (%)	Working time days/week
Producer	100	-
Spouse	44.4	-
Sons	45.6	-
Other family members	22.2	-
Contract workers (0.44 per farm)	-	0.56

Credit use

About 56% of the producers are using credit. The mean amount received is US$ 623 per family at a 14% interest rate and a lending period that ranges from four months to four years (mean period 35 months). Credit is used mostly for purchasing livestock, especially swine, and feed. Credit institutions utilized are FDL (Fondo de Desarrollo Local), UNAG (Union Nacional de Agricultores y Ganaderos), and COFODEC (Cooperativa para el Fondo de Desarrollo Campesino). Of those producers who did not have access to credit (44%), all would like to access it and would use it mostly for buying cattle and pigs.

Feeding strategy for chicken and pigs

Table 39 shows the amount and types of feed supplements that producers provide to their chickens and pigs to produce meat and eggs. Most of the feed supplement used is maize which is grown on-farm. Concentrate is fed only to pigs and it is acquired in nearby tows. Whey is produced on the farm after making cheese and it is given only to pigs.

Table 39. Amounts of feed supplements offered to chicken and pigs in smallholder farms in Chinandega

Feed Supplement	Chicken	Pigs
Maize (gr/head/d)	78	1217
Concentrate (gr/head/d)	0.0	400
Whey (lt/head/d)	0.0	0.80

Table 40 contains the nutritional requirements for laying hens, growing chicken, and growing pigs in relation to current diets offered to animals. For poultry, maize is the only supplement offered. As can be seen for laying hens, maize contributes to about 72% of the energy needed, 42% of the protein, and 75% of the dry matter consumption. Thus, protein is the limiting factor for increased egg production. For growing chicken, maize contributes to 69% of the energy needed and only 33% of the protein, and 75% of the dry matter consumption. Thus, likewise, protein is the largest constraint for increased meat production.

Table 40. Nutritional requirements for laying hens, growing chicken, and growing pigs in relation to current diets offered by smallholder farms in Chinandega

	Laying Hens [1,7]	Growing Chicken [2,7]	Growing Pigs [3,8]
Recommeded Nutrient Intake and Dry Matter Consumption			
• Metabolizable Energy (kcal/d)	391	219	6400
• Crude Protein (g/d)	20	15	280
• Dry Matter Consumption (g/d)	135	73	2000
Offer of nutrients of current diet			
• Maize [4]			
- Metabolizable Energy (kcal/d)	280 [a]	152	3643
- Crude Protein (g/d)	9	5	96
• Concentrate [5]			
- Metabolizable Energy (kcal/d)	NA	NA	1224
- Crude Protein (g/d)	NA	NA	50
• Whey [6]			
- Metabolizable Energy (kcal/d)	NA	NA	179
- Crude Protein (g/d)	NA	NA	8
Total nutrients offered			
- Metabolizable Energy (kcal/d)	280	152	5046
- Crude Protein (g/d)	9	5	154
- Dry Matter Consumption (g/d)	101	55	1516

[1] 2.5 kg of body weight, 60% production
[2] 750 g of body weight
[3] 35-60 kg body weight
[4] 8.8% Crude Protein and 2,770 kcal ME for poultry and 3,325 kcal ME for pigs
[5] 14% Crude Protein and 3,400 kcal ME for pigs
[6] 13.6% Crude Protein and 3,190 kcal ME for pigs
[7] NRC
[8] NRC
[a] Assuming 75% of dry matter consumption comes from maize, rest is scavanging.
NA: Not available

Concerning pig production, there are three sources of nutrients offered in addition to scavenging: Maize contributes 57% of the energy and 34% of the protein needed, concentrate contributes 19% of the energy and 18% of the protein needed, and whey accounts for 3% of the energy and 3% of the protein needed. The three sources combined account for 79% of the energy, for 55% of the protein, and 76% of the feed intake. Thus, protein is again the largest constraint for an increase in meat production. Therefore, developing legume-based feeding systems that can complement protein intake can significantly raise the food security, nutritional benefits, and additional income.

Marketing Strategy
All producers surveyed have poultry only for household consumption. This appears to be the general rule not only in this region, but in the rest of the country as well. All producers buy weaned pigs (8-12 weeks old), fatten them for about 6 months, and then sell them. Some farmers use microcredit to buy 1-2 weaned pigs and others buy them with their own resources from the sale of crops. Most farmers have pigs year round but all of them have pigs which are sold during the 2-peak-demand-season: Christmas (Nov-Dec) and dry season (Jan-Abr). Demand for pig meat is higher during the dry season due to the sugarcane harvest, the main crop in the area, because sugarcane is harvested by hand, thus the employment rate is high which means that more money is available to buy pig products.

Pigs are sold directly to local butchers. The average farm sales price is US$1.28/kg live weight. The average weight of a swine at farm sale is about 58 kg. Therefore the average farm sales price per pig is around US$ 74 each. Pigs are sold at the farm gate which means local butchers do routine visits to farmers to obtain the pigs.

The trade between the farmers and their clients usually occurs without any problems, merely one producer had problems because he sold a tapeworm-parasitized ('cysticercosis') pig. This is the greatest threat when buying pig meat because it is not suitable for human consumption. In this case, the producer lost his money because the pig could not be sold to consumers after it was slaughtered. All producers said that it would be no problem for them to sell their swine to other buyers and the average of other possible buyers named by them is 5.5 per producer.

Survey Analysis – Retailers
No middlemen were found in the area. All retailers surveyed were small butchers who go around the area choosing and buying their own animals to slaughter. On average, butchers are 48 years old and the focus group consisted of three male and three female retailers. In all cases except one, the head of the household is the male member. About 50% of the retailers received formal education (two hold a bachelor). Four of the retailers are local butchers in villages and two are local butchers in town, all of them slaughter swine and sell the meat immediately the same day (wet market).

They usually slaughter one pig per week (mostly on Saturdays). During the low demand season butchers generally buy pigs which weigh 55-60 kg and during high demand season they buy pigs with a weight greater that 100 kg. Pigs are generally paid in cash the next day after slaughter because of the tapeworm risk. If the slaughtered pig is parasitized, the animal is returned to the producer. Butchers slaughter pigs in the backyard of their houses with no control from the Ministry of Health. Generally, all the meat is sold the same day of slaughter.

Marketing Strategy
The interviewed butchers sold a variety of pork products but no other sources of animal protein (i.e., milk, eggs, chicken meat or beef). Pigs are bought directly from the farmers at the farms. About 50% of the butchers were allowed to pay the pigs up to one week later and also give their customers credit (up to two weeks). The remaining 50% have to pay the pigs in cash and only accept cash from their customers.

In two different periods of the year the demand for pork products increases: November to December (Christmas and New Year's Eve) and January to April (sugarcane harvest). However, the price during these two peak seasons does not increase. What increases is the volume of meat which is traded. That means the weight of slaughtered pigs varies from 55-60 kg in the low demand season up to 100 kg in the high demand season.

Table 41. Average turnover and profit of the processors for a pig of 41 kg live weight

Product	Average sales price (US $)
14.4 kg of pork meat	48.20
0.91 kg of skin	4.32
2.0 kg bones	3.02
0.91 kg of chicharrón	5.76
1 head	1.92
10 liters lard	13.43
4 feet	0.48
Average turnover	77.13
Average purchase price	58.43
Average return	18.70

The purchase price butchers pay varies between US$1.37 to $1.48 per kilo of live weight. The most common pig sold during the time of the interview (low season) was the 41 kg-pig (live weight). A common indicator used by butchers is that a kilo of pig live weight yields 0.34 kg of saleable meat (excluding bones, viscera, heads, and feet). Thus, the amount of saleable meat per pig of 41 kg live weight is about 14 kg and the average sales price per kg of pork meat is US$3.35/kg. Table 41 lists the average return of the different pork products as well as the profit for the processors.

Thus, the retailers do not make any profit only by the meat sale. They are depending on the sale of the byproducts to achieve a positive return. On average one processor slaughters 18 pigs a month but there is a wide range within the sample (from 2 to 92 pigs/month). Excluding the biggest slaughterer most others slaughter around one pig per week.

All processors stated that the most important criterion of the clients for buying pork meat and other pork products is the price. None of the processors ever had problems, neither with his suppliers nor with his clients. If a slaughtered pig is tapeworm-parasitized (‘cysticercosis’) it is returned to the producer. The butchers slaughter the swine in the backyard of their houses without any control by the Ministry of Health. All processors would, if possible, receive more meat from additional suppliers. The average number of additional suppliers named per processor is 8.2.

Credit use

Only 50% of the butchers were using credit. However, 33% would like to obtain credit to buy more pigs to slaughter and 17% said they do not need credit. On average the amount of credit obtained is US$ 679/butcher at an interest rate of 19% with a lending period that varies between 6 and 12 months with 10 months on average. Credit is used for purchasing pigs. Credit institutions are the FDL (Fondo de Desarrollo Local), Asoder (Asociación de Desarrollo Rural) and PrestaNic.

Survey Analysis - City butcheries and supermarkets

City butcheries

At the moment of the interviews none of the city butcheries was selling pork products. They were selling beef, chicken, and eggs. For the future they are planning to purchase pork products from a big slaughterhouse in Managua. Beef is sold for US$ 5.60/kg of sirloin steak, whole chicken at US$ 2.12/kg and eggs for US$0.125/unit.

Supermarkets

Table 42 contains a list of consumer prices in the supermarkets for the most popular cuts. As shown, pork meat is 20% cheaper than beef when the best cut is compared (i.e., sirloin, $4.23 vs. $5.29/kg). Likewise, pork meat is 4.7% cheaper than chicken when the best cut is compared (i.e., sirloin and breast, $4.23 vs. $4.44/kg).

Comparing the prices at the supermarket with those sold by city butcheries, supermarkets sell meat and eggs at significantly lower prices. For example, eggs are 34% cheaper, whole chicken are sold at a 5.2% lower price, and beef is 5.5% cheaper.

The average price small rural butchers charge is US$3.35/kg for pork meat. If we take the average of the pork cuts sold in supermarkets (Table 41) the price is $3.73/kg. Thus, pork meat is priced about 10% lower when obtained through rural butchers. This difference is reflected in the fact that small rural butchers sell meat under lower health and sanitary conditions compared with supermarkets which obtain pork meat from large slaughterhouses which operate under international standards and that the local butcheries do not have to challenge such high transport costs as the supermarkets.

At the moment of the interviews none of the supermarkets had pork products left. It was stated that pork products are sold too fast and that there is not enough supply to meet the demand. This implies that pork meat supply from large farms marketed through large slaughterhouses cannot meet the demand and this represents an opportunity for smallholders to capture parts of this market. However, this requires an increase of the food safety standards by: (a) implementing a health and vaccination plan at the farm level; (b) provide microcredit to smallholders in order to buy more pigs; (c) develop new feeding strategies addressing the protein deficit, which refers to the objective of this project, in order to increase the protein offer of nutrients for higher weight gains and productivity; and (d) modernize municipal slaughterhouses so that small butchers will not slaughter pigs in their houses which do not have the required facilities for proper animal health, sanitary, and environmental handling of meat and waste (i.e., blood, manure, viscera).

Table 42. Consumer prices in the supermarkets

Type	Product	Price (US$/kg)
Chicken	Eggs (unit)	0.082
	Whole	2.01
	Breast	4.44
Beef	Sirloin	5.29
Pork	Sirloin	4.23
	Loin	3.81
	Posta (“tender cut”)	3.17
	Legs (4)	0.36

Conclusions

The survey confirmed that pig production in smallholder farms is an alternative rural families have to obtain additional income using existing resources at the farm level Poultry production is used for household consumption and it is a very important source of animal protein for the family’s nutritional well-being. One surprise of the survey is the use of family labour in this study mostly attributed to the male head of household. This is in contrast to previous diagnostic studies where the major part of labour was provided by women and to some extent children. Further clarification of the differences between studies is required.

Most farmers have pigs year round but all of them have pigs which are sold during the 2 peak demand seasons: Christmas (Nov-Dec) and dry season (Jan-Abr). Demand for pig meat is higher during the dry season as due to the sugarcane harvest employment rate is high during this period. Higher demand in the dry season results in a higher selling weights of pigs requested by buthcers. No middlemen were found in the area surveyed, but but pigs are sold directly to local butchers who usually slaughter one pig per week. Payment is dependent on absence of tapeworm infestation. The use of microcredit is important as it facilitates the acquisition of pigs for fattening, however, it is currently not enough to meet the demand that exists in the region.

Comparing the prices at the supermarket with those of the city butcheries, supermarkets sell meat and eggs at significantly lower prices. However, pork meat is about 10% cheaper when obtained through rural butchers than in supermarkets. This difference is reflected in the fact that small rural butchers sell meat under lower health and sanitary conditions compared with supermarkets which obtain pork meat from large slaughterhouses which operate under international standards, and because of lower transport costs.

The nutritional balance for both poultry and pigs shows they are receiving a diet deficient in both energy and protein, with protein being the greatest constraint. Promoting forage legumes to supplement both poultry and pigs can be very profitable to increase both the production of pigs for additional income and the production of poultry meat and eggs for improved family nutrition.

2.8 The use of poultry and swine in smallholder farms in Colombia: A value-chain analysis

Highlight

- The nutritional balance for both poultry and pig production shows they are receiving a diet deficient in both energy and protein, with protein being the greatest constraint. Promoting forage legumes to supplement both poultry and pigs can be very profitable to increase both the production of pigs for additional income and the production of poultry meat and eggs for increased family nutrition.

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Rationale and background

Poultry and swine production in smallholder farms in Colombia is based on the backyard production system. This system is very flexible but of low productivity. It consists of a few chicken (usually below 30) and pigs (usually below 3) receiving small to moderate amounts of maize and concentrates which are complemented with household waste and other feed sources obtained around the house (i.e., seeds, insects, worms, etc).

Colombia slaughters about 2 million pigs a year for a per capita annual consumption of about 3 kg. The pig industry sector generates about 92,000 jobs in the rural areas of the country, and the primary sector plays an important role demanding about 22% of the national production of cereals (mainly maize and soybeans) for animal feed. The market structure of pork meat takes place mostly locally, with very little integration at the national scale. Most of the slaughter and sale takes place where it is produced.

With regards to poultry production, about 30 million broilers are slaughetered each month for a per capita annual consumption of about 15 kg, five times greater than pork meat. Most of this production takes place in large farms vertically integrated with production, slaughter, and marketing. This puts the poultry sector in better advantage to access urban consumers because they can buy poultry meat with higher health and food safety standards.

There are about 10,000 clandestine slaughterhouses in Colombia, most of them used for small scale pig slaughtering. This poses a high risk for urban consumers as the food safety and quality controls are very weak, thus limiting consumption and growth in the sector.

Objective

The objective of this study was to understand the role that poultry and pigs play for smallholder farmers with mixed crop-livestock systems in Colombia in terms of family income and food security, and to analyze feeding strategies, resource allocation and market alternatives within a value-chain analysis.

Material and methods

Data for this study came from three surveys and secondary information.

Survey Data

Primary data for this study comes from three survey instruments. The first survey was designed for producers with mixed crop-livestock systems, the second survey for middlemen, and the third one for retailers. The survey for producers asked for information regarding land and labor use, resource allocation, credit use, animal inventories (bovine, poultry, and pigs), feeding management, monogastric production, consumption, and sales. The survey for middlemen asked for information regarding buying and selling prices, animal selection criteria, and supply and demand for poultry and pig products. The survey for retailers asked information regarding consumer prices, consumer preferences, animal health risks, and criteria for buying animals.

Eight producers and three retailers were surveyed during November 18-20, 2009 in the Timbio and Parraga areas located in the Department of Cauca, South of Colombia.

Secondary Information

The Ministry of Agriculture of Colombia provided information about statistics, consumption, production, exports, imports, prices, and marketing.

Results and Discussion

Survey Analysis - Producers

Land use

Table 43 contains the land use for the surveyed focus group. As shown, the largest land use is for pasture production, followed by fruits, and then by agricultural activities led by maize, sugarcane, plantains, and cassava, all basic staple food crops of rural families in Colombia.

Table 43. Land use of the focus group (in hectares)

Cultivation	Average area in ha for all farmers (n=8)	Average area in ha for all cultivating farmers
Total	3.4	3.4
Pasture	1.4	11 (n=1)
Maize	0.25	1 (n=2)
Cassava	0.125	1 (n=1)
Plantain	0.19	0.75 (n=2)
Fruits and Tomatoes	0.75	3 (n=2)
Coffee	0.07	0.5 (n=1)
Sugarcane	0.25	2 (n=1)

Cattle inventory

Table 44 shows the herd structure found in the sample farms. Only one farm had cattle (18 heads), all others had none, mainly due to the small mean farm size of 3.4 ha.

Table 44. The cattle livestock composition of the focus group

Cattle stock	Average number for all farmers (n=8)	Average number for all affected farmers (n=1)
Total	2.25	18
Dairy cattle	0.75	6
Dry cow	0.63	5
Heifer > 2 y	0.25	2
Heifer 1-2 y	0.13	1
Female calves 0-1 y	0.25	2
Male calves 0-1 y	0.25	2

Poultry inventory

Table 45 shows that the mean stock of chicken is close to 22 birds per farm. Most farmers have laying hens for egg production (75%), and the rest of the flock is composed of growing animals

Table 45. The chicken livestock composition of the focus group

Chicken stock	Average number for all farmers (n=8)	Average number for all affected farmers
Total	21.6	28.3 (n=6)
Laying hens	5.6	7.5 (n=6)
Young hens	5	10 (n=4)
Broilers	10.6	17 (n=5)
Cocks	0.6	1.7 (n=3)

Pig inventory

Table 46 shows that all farmers raise pigs, averaging close to 63 heads/farm. About 37% of the herd are fattening pigs, and close to 18% are adult females. The remaining herd is composed of growing females for reproduction.

Table 46. The swine livestock composition of the focus group

Swine stock	Average number for all farmers (n=8)	Average number for all affected farmers
Total	62.75	62.75
Adult female swine	11	12.6 (n=7)
Young female swine	22.4	35.8 (n=5)
Fatteners	23	30.7 (n=6)
Boars	0.6	1.25 (n=4)

Household consumption

Table 47 presents the different products consumed by the rural family and which are produced on the farm. No pig meat is consumed as pigs are raised for sale and milk consumption is very low because most farms do not have cattle. Thus, most of the animal protein comes from the consumption of eggs and chicken.

Table 47. Home consumption of the producer families

Home consumption	Average for all farmers (n=8)	Average for all affected farmers
Milk (liters/d)	0.25	2.00 (n=1)
Chicken (number/week)	0.44	0.59 (n=6)
Eggs (number/d)	4.88	6.50 (n=6)

Labor use

All labor for all farms visited consists of solely the owner of the farm. No involvement of other family members were found. This might result from the fact that farms are very small and thus, the routine chores can be done by only one individual. This is however in contrast with previous diagnostic studies where the major part of labour is attributed to women and some extent children. Further clarification is needed (Table 48).

Table 48. Labor information

Family member	Share farm work of total working time (%)
Producer	100
Spouse	0.00
Sons	0.00
Other family members	0.00
Contract workers	None

Credit use
About 88% of the producers are using credit. On average, the amount of credit of the receiving farmers is US$10,520/farmer. Five of seven credit takers have an interest rate which consists of the inflation rate (5%) plus an additional 2% interest. The other 2 credit takers are facing an interest rate of 26% on average. The average lending period is 50 months. Credit is mainly used for purchasing livestock, especially swine, equipment and infrastructure. Credit institutes are Finagro, Banco Agrario, Caja Agraria, Banco Caja Social, and Mundo Mujer.

Feeding Strategy for Chicken and Pigs
Table 49 shows the amount and types of feed supplements that producers provide to their chickens and pigs to produce meat and eggs. Most of the feed supplement used for chicken is maize which is grown on-farm. Concentrate is fed to both chicken and pigs and it is acquired in nearby towns. In addition to concentrates to feed pigs, cassava starch is an important source of energy to feed pigs because it is cheap and plentiful in the region.

Table 49. Amounts of feed supplements offered to chicken and pigs in smallholder farms in Cauca

Feed Supplement	Chicken	Pigs
Maize (g/head/d)	52	0
Concentrate (g/head/d)	36	1074
Cassava starch (g/head/d)	0	869

Table 50 presents the nutritional requirements for laying hens, growing chicken, and growing pigs in relation to current diets offered to animals. For poultry, maize and concentrate are offered. As can be seen for laying hens, both maize and concentrate contribute to about 55% of the energy needed and 43% of the protein. Thus, protein is the most limiting factor for increased egg production. For growing chicken, maize and concentrate contribute to 97% of the energy needed and only 57% of the protein. Thus, likewise, protein is the largest constraint for increased meat production.

Concerning pig production, there are two sources of nutrients offered in addition to scavenging. Concentrate contributes 51% of the energy and 48% of the protein needed, and cassava starch contributes 34% of the energy and only 7% of the protein needed. These two sources combined account for 86% of the energy, for 55% of the protein, and 87% of the feed intake. Thus, protein is again the largest constraint for an increase in meat production. Therefore, developing legume-based feeding systems that can complement protein intake can significantly raise the food security, nutritional benefits, and additional income.

Marketing Strategy
Although the participating smallholders produce a variety of different products related to livestock production (swine, chicken, eggs, milk) almost the only product they sell out of this range are pigs. Only one producer (the female producer) is selling chicken as well. The chickens are sold at farm level (directly on the farm) to private clients. The demand for chicken rises in May (Mother’s day) and December (Christmas). The price for the chicken is in all periods of the year the same, US$3.04/kg. The producer never experienced problems with clients and could sell the chicken to 10 additional clients.

Table 50. Nutritional requirements for laying hens, growing chicken, and growing pigs in relation to current diets offered by smallholder farms in Cauca

	Laying Hens [1,7]	Growing Chicken [2,7]	Growing Pigs [3,8]
Recommeded Nutrient Intake and Dry Matter Consumption			
• Metabolizable Energy (kcal/d)	391	219	6400
• Crude Protein (g/d)	20	15	280
• Dry Matter Consumption (g/d)	135	73	2000
Offer of nutrients of current diet			
• Maize [4]			
- Metabolizable Energy (kcal/d)	130	130	NA
- Crude Protein (g/d)	4.1	4.1	NA
• Concentrate [5]			
- Metabolizable Energy (kcal/d)	84	84	3,287
- Crude Protein (g/d)	4.5	4.5	135
• Cassava Starch[6]			
- Metabolizable Energy (kcal/d)	NA	NA	2,213
- Crude Protein (g/d)	NA	NA	19
Total nutrients offered			
- Metabolizable Energy (kcal/d)	214	214	5,500
- Crude Protein (g/d)	8.6	8.6	154
- Dry Matter Consumption (g/d)	79	79	1,749

[1] 2.5 kg of body weight, 60% production
[2] 750 g of body weight
[3] 35-60 kg body weight
[4] 8.8% Crude Protein, 2,770 kcal ME for poultry and 3,325 kcal ME for pigs
[5] 14% Crude Protein, 2,595 kcal ME for poultry and 3,400 kcal ME for pigs
[6] 2.4% Crude Protein and 3,250 kcal ME for poultry and 2,830 kcal ME for pigs
[7] NRC
[8] NRC
NA= Not available

Swine is sold for many uses: (a) to other producers (as piglets), (b) to local butchers, (c) to restaurants; and (d) to intermediaries who distribute them. There are two periods during the year when the demand for swine is greater: December (Christmas and New Year's Eve) and June. The average farm sales price per kg of swine live weight (fatteners) during the year is US$2.17 and in the peak season it is US$ 2.31.

The average weight of a swine (fattener) at farm sale is 89 kg. Therefore, the average farm sales price per swine is US$162 during the year and US$207 in peak season. The average weight of a piglet is 9 kg and they are sold in both periods at the same price ofUS$56 each. Four farmers sell piglets (on average 78/year) and six farmers sell fatteners (on average 95/year).

The swine trade is located at the farm sites or at local and town markets. The trade between the farmers and their clients happens without any problems as no producer had complaints. All producers said that it would be no problem for them to sell their swine to other buyers and the average of other possible buyers named by them is 7.4 per producer.

Survey Analysis – Retailers

On average the retailers are 39 years old and the focus group consists of three male retailers. All retailers received formal education (two went to University). Only one retailer is member of a community based organization and the local slaughterhouse. One retailer is a local butcher, another one runs a restaurant and the third one is a local butcher and runs a restaurant as well.

Marketing strategy

The local butchers and restaurant owners are selling a variety of pork products but no other animal products. The swine are bought directly from the farmers or from slaughterhouses. All processors are allowed to pay the swine by credit (8-15 days) but none of them gives his customers credit (all transactions in cash). In two different periods during the year the demand for swine and pork products increases: December (Christmas and New Year's Eve) and June. Neither the sales prices nor the quantities of pork products rise in these peaks. But the purchasing price for swine rises from averaging US$2.46/kg to US$2.62/kg live weight. The processors buy on average 249 swine/year with an average weight of 90kg. Table 51 shows the prices for the products of one of the local butchers.

Table 51. Product prices for a local butcher in Timbío

Product	Sales price (US$/kg)
Haunch	2.54
Sirloin	2.79
Loin	2.29
Bacon	1.40
Head	4.06
4 Feet	5.08

The most important criteria of the clients for buying pork meat and other pork products are the color of the meat, the tenderness and that the meat has a low fat content. The price does not seem to play an important role. None of the processors ever had problems with his suppliers but one had a problem with a customer: the meat was not stored in a fridge and therefore not fresh enough. The butchers slaughter the swine in the backyard of their houses without any control by the Ministry of Health. All processors would, if possible, receive more meat from additional suppliers. The average number of additional suppliers named per processor is 13.

Credit use
Only one retailer is using credit, to one it is unavailable although he would like to receive one for buying more pigs and the third processor does not need any credit. The amount of credit of the receiving processor is US$ 45,708 at an interest rate of 25% and the lending period is 7 years. Credit is used for purchasing swine and labor. The credit institute is the Banca Caja Social.

Survey Analysis - City butcheries and supermarkets

City butcheries
The surveyed team contacted an ex-student from a local university whose family runs a butchery and provided detailed information of the cost of buying an average 100 kg pig and its value after being slaughtered (Table 52).

Table 52. Value of an average 100 kg pig before and after slaughtered

Cost of buying pig on farm and transport to butchery	Amount (US$)
Pig purchase per 100 kg pig live weight	228.54
Weight fee	1.52
Slaughtering fee at slaughterhouse	16.25
Transport from slaughterhouse to butchery	1.52
Total costs/pig of 100 kg	247.83
Value and yield of pig	**Amount (US$)**
Head (4 kg)	8.13
Feet (2.5 kg)	6.35
Sirloin (12 kg)	73.13
Haunch without bones (16 kg)	90.40
Legs (9 kg)	50.28
Loin (12 kg)	54.85
Dorsal (3.5 kg)	8.89
Fat (1 kg)	2.54
Neck (5 kg)	17.78
Bacon (5 kg)	15.24
Ears (0.5 kg)	1.27
Bones (4 kg)	5.49
Viscera (17 kg)	17.27
Blood (8 kg)	6.50
Total revenue/pig of 100kg	358.10
Turnover/pig of 100kg	**110.27**

This information supports another source (Asoporcicultores 2000. Asociación Colombiana de Porcicultores. Mercadeo de la carne porcina en Colombia. Bogotá), which reports that from a 100 kg (live weight) pig, about 24 kg is viscera and 76 kg is carcass. The carcass is composed of 42 kg of meat, 17 kg of fat, 13 kg of bones, and 4 kg of leather.

The supermarkets and street markets

Table 53 contains a list of consumer prices in two of the largest supermarket chains in the country and from the street markets of Popayan, Cauca, for the most popular cuts.

As shown, pork meat is more expensive than chicken when the best cuts are compared, depending on the location. In the street markets it is 7% more expensive and in the supermarkets it has a 27% to 37% higher price.

Comparing the prices at the supermarket with those sold in the street market, in general, the prices for the best cuts are lower in the street market than at supermarkets. Likewise, prices for the low-quality cuts are higher in the supermarkets compared with the street markets. The reason for this is because it is a common strategy used by retailers based on the profile of the consumer. Since most poor people buy their meat in the street markets, retailers try to sell poor-quality cuts for the most they can obtain and sell the high-quality cuts cheaper due to the low-buying power of consumers. On the other hand, the contrary occurs in supermarkets. Here, most middle to high-income costumers buy their meat and thus, supermarkets try to obtain the best price that they can get from the high-quality cuts and are willing to sell the poor-quality cuts cheaper in order to rotate meat quickly and avoid spoilages.

Table 53. Consumer prices in the supermarkets and street markets (US$ per kg)

Product	Éxito	Carrefour	Street Markets
Chicken			
Whole chicken	3.54	3.54	3.05
Chicken brisket	5.57	6.30	5.69
Pork			
Bacon	2.64	2.03	2.54
Milanesa	6.72	7.11	4.57
Sirloin	7.61	7.89	6.09
Loin	5.18	4.83	4.57
Ears	1.98	2.44	2.54
Feet	2.85	3.00	2.03
Dorsal	2.78	2.39	2.03
Viscera	1.22	NA	1.02

Conclusions

Pig production in smallholder farms is an alternative that rural families have to obtain additional income using existing resources at the farm level such as family labor, household waste, maize grown on-farm, and complemented by small amounts of feed concentrate. Poultry production is used for household consumption and it is a very important source of animal protein for the family's nutritional well-being.

Most farmers have pigs year round but all of them have pigs which are sold during the 2 peak demand seasons: Christmas (December) and June. Pigs are sold directly to local butchers or slaughtered and marketed directly through restaurants. Comparing the prices at the supermarket with those of the street market, pork meat is more expensive than chicken when the best cuts are compared, depending on the location.

The market structure of pork meat takes place mostly locally, with very little integration at the national scale and limited attention to food safety standards. On the other hand, most of the poultry production takes place in large farms vertically integrated with production, slaughter, and marketing. This puts the poultry sector in better advantage to access urban consumers because they can buy poultry meat with higher health and food safety standards.

The nutritional balance for both poultry and pig production shows they are receiving a diet deficient in both energy and protein, with protein being the greatest constraint. Promoting improved legumes to supplement both poultry and pigs can be very profitable to increase both the production of pigs for additional income and the production of poultry meat and eggs for increased family nutrition.

In the street markets it is 7%

The gender relation in pig and poulty production in different studies are contradicting thus further and more detailed studies are required to clarify this aspect.

Output 3. Forages integrated into smallholder crop-livestock systems: realizing livelihood and environmental benefits

3.1 Enhancing livelihoods of poor livestock keepers through increased use of fodder

3.1.1 *Ex-ante* and *ex-post* analysis of using legumes: the dilemma of using legumes as forage for animal nutrition during the dry season or as green manure for soil improvement

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

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Rationale

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

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

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

In the past, several alternatives have been used to correct feed shortage or deficiencies during the dry season. These have included the use of net energy sources, ranging from forage sugarcane to legumes, the latter contributing protein and complementing energy sources and available grasses. However, the competitiveness of using legumes for animal nutrition versus their use to improve soil quality and, as a result, crop productivity, has seldom been analyzed.

This study therefore assesses the economic and environmental benefits of (1) a short-term alternative, which consists of establishing legumes for use as supplement, mixed with crop residues, to increase milk production and farmer incomes during the dry season when milk prices are higher; and (2) a medium-term alternative, which consists of establishing legumes as green manure at the same sites where maize and beans are planted and then incorporate these legumes into the soil to improve its fertility and, accordingly, improve agricultural productivity in subsequent years.

Objective

This study aims to (1) perform an *ex-ante* analysis of the expected economic and environmental benefits of using the tropical legume, *Canavalia brasiliensis* (*Canavalia*), either as green manure to improve agricultural productivity or as forage to improve milk production during the dry season; and (2) compare these with *ex-post* results in order to evaluate the accurateness of *ex-ante* analysis to anticipate economic and environmental effects of different management practices in production systems of Nicaragua, and (3) compare these benefits with the subjective perception of producers living in hillside areas of Nicaragua that have mixed maize-beans-livestock production systems regarding these new legume-based alternatives.

Current Status of Research on *Canavalia*

Use as green manure

The effect of nitrogen fertilization on subsequent crops is greatest when legumes are used as green manure. However, the N available due to decomposition of crop residues may be released before the roots of the new crop are developed and can properly tap this source. The N can therefore be lost due to volatilization, denitrification, or leaching.

When *Canavalia* was established at the end of the rainy season for subsequent growth during the dry season and then incorporated into the soil, the increase in productivity of the following maize harvest corresponded to an application of 50 kg N/ha. Although this suggests that *Canavalia* residues could supply significant amount of N, the amount of N symbiotically fixed has not yet been determined.

Use of Canavalia *as supplement for animal nutrition*

The biomass of maize and bean stubble is the most important forage reserve for animal nutrition during the dry season. Although the available dry matter (DM) of these stubbles is relatively high, its low protein content (~ 4%) and digestibility (~ 40%) reduce animal productivity significantly, leading to both lower milk productivity and animal weight loss as compared with the rainy season. The nutritional value of maize and bean stubble can be improved significantly by introducing legumes such as *Canavalia*.

The advantage of *Canavalia* is that it is very tolerant to drought and readily accepted by cattle and sheep. Recent results showed a level of crude protein from 20% to 25% with a high digestibility of around 80%.

Materials and Methods

Ex-ante and *ex-post* economic evaluation

Data were collected from a survey of 10 producers of the Pire river watershed, located in the Department of Estelí in northern Nicaragua. The survey, conducted in September 2007, aimed to collect information on land use, animal inventory, use of inputs, and use of family and contracted labor to estimate animal and crop production costs (i.e., maize and beans), productivity, and income from the sale of milk, meat, maize, and beans.

The survey also gathered information on how producers perceive the use of *Canavalia* and what their expectations are to justify the adoption of *Canavalia*, based on the following:

(a) the minimum amount of milk that should be produced in excess of the average dry-season production for producers to adopt *Canavalia* as feed supplement; or

(b) the amount of fertilizer (i.e., urea) that producers considered that could be saved, while maintaining the same maize and bean production, to adopt *Canavalia* as green manure.

Based on average survey results, in 2008 an *ex-ante* economic evaluation of the economic benefits that would be produced if this legume was cultivated as green manure or used as animal supplement, was conducted. Later in 2009, and after an experimentation phase of using *Canavalia* as forage and as green manure,, an *ex-post* analysis was conducted by adjusting input values according to field measurements.

Both the *ex-ante* and *ex-post* analyses were conducted using a decision support tool called ECOSAUT (Model for Economic, Social and Environmental Evaluation of Land Uses) in which outputs obtained with SWAT (Soil and Water Assessment Tool) model are inputs . This optimization model uses linear programming to evaluate land uses under multiple criteria—social, economic, and environmental. These decision-making criteria or variables are defined according to the production system (land use) evaluated and the evaluation objective. Thus, the agroecosystem was accordingly simulated to better understand the effects that the incorporation of *Canavalia* will have on producers' income and if the expectations that producers expressed during the 2007 field visit were fulfilled.

Ex-ante *analysis*

To conduct the *ex-ante* evaluation, the following scenarios were analyzed over a 5-year period:

- ***Scenario 1. Baseline***

This is the traditional land use scenario of the farms visited during the survey. For this study, the baseline is defined as a farm type showing the average values of production costs, income, and productivity obtained in the survey. The land use system is mixed—maize and beans are grown and both milk and meat are produced. The farm area is 12 ha, of which 10 ha are sown to Jaragua grass *(Hyparrhenia rufa)* and 2 ha are planted to maize and beans. The Jaragua grass is not fertilized and its biomass production decreases during the dry season, from 1.6 to 0.6 t DM/ha. Milk production also decreases during these months. Rainfall in the region is bimodal. Maize is planted first, at the onset of the rains (June). Once the maize has formed ears, the plants are folded for drying and beans are grown in half of the area (1.0 ha), using these dry stalks as support. Beans are planted at the end of the first rainy season or the beginning of the second rainy season, around September-October, and are harvested at the beginning of the dry season (December-January).

- ***Scenario 2.* Canavalia *for animal nutrition***

This scenario also corresponds to a combined crop/livestock production system, but *Canavalia* is also grown, intercropped with maize in the area where beans are not planted (1.0 ha). In this case, the legume is used for livestock nutrition during the dry season to increase on-farm milk production. This *ex-ante* evaluation assumed an annual production of *Canavalia* of 2 t DM/ha. The same distribution of land in pastures and grasses as found in the baseline is maintained.

- ***Scenario 3.* Canavalia *for soil improvement***

This scenario corresponds to the same scheme described in Scenario 2 above, with the difference that the legume is incorporated into the soil to improve fertility and, as a result, improve the productivity of subsequent plantings of maize and beans. It was assumed that the incorporation of *Canavalia* contributes 64 kg N/ha and replaces the traditional application of N in the form of urea (52 kg/ha) in maize and bean crops. It is only necessary to continue applying the complete fertilizer (12-30-12 NPK) at 82 kg/ha.

In the *ex-ante* analysis two additional scenarios were assessed: i) *Canavalia* for animal feeding with sorghum and ii) *Canavalia* in rotation with maize to improve soils throughout the farm. The first scenario was developed initially because many producers (especially those with more livestock) plant sorghum at the end of the rainy season in order to have sufficient biomass to feed livestock during the dry season, in addition to maize stubble. The main objective is to produce biomass as source of forage for livestock. As a result, producers use a high planting density to maximize forage production and not grain production. The second scenario explored the maximum potential of the farm in terms of generating income by gradually substituting the area (2 ha/yr) currently under Jaragua grass with a rotation of maize and *Canavalia* over a 5-year period. The purpose of this scenario is to explore the contribution of *Canavalia* as a mechanism to improve soil fertility and make the system more sustainable by subsequently introducing improved pastures, such as *Brachiaria brizantha* cv. Toledo, as well as an energy source, for example sugarcane.

However, any of these two scenarios were tested again in the *ex-post* analysis as they were not subject of field experimentation. The initial three scenarios mentioned above were *ex-post* analyzed and the results are then contrasted here with the *ex-ante* results.

Ex-post *analysis*

For the baseline, information about beans and maize productivity used for the *ex-ante* analysis was adjusted for the *ex-post* analysis based on measurements obtained in the field trials during 2007-2008

For the scenario 2, field experimentation to evaluate the impact of supplying *Canavalia* for animal nutrition and milk productivity was conducted in the “Santander de Quilichao” CIAT research station in Colombia. This station provided to some extent similar environmental conditions to the Nicaragua research sites. The results from this study were used to adjust milk productivity values used in the *ex-ante* analysis. Data on *Canavalia* productivity and maize productivity when rotated with *Canavalia* were obtained from field trials.

For the scenario 3, data from field trials was statistically analyzed to see if there were differences in maize productivity across treatments: i) the traditional maize-bean rotation and ii) the maize-*Canavalia* rotation. The effect of different treatments was analyzed for the maize grain yield harvested in 2007 and 2008 by applying an ANOVA analysis using STATISTICA (Version 7; 2004). Unfortunately data of soils does not cover a period of time long enough to determine possible changes due to the incorporation of *Canavalia* to the soil. So the *ex-post* analysis for this scenario is focused on the probable improvements on maize productivity after including the legume in the rotation as green manure and not in the biophysical and environmental effects.

Ex-ante *environmental analysis*

The environmental *ex-ante* evaluation was focused on the effects that the incorporation of *Canavalia* into the crop rotation might have on environmental externalities such us sediment and water yields.

This analysis was conducted applying SWAT (Soil and Water Assessment Tool) for an area with biophysical conditions similar to those found in the visited farms. These conditions refer to soil, climatic and topographic characteristics that were collected for the study area.

The *ex-ante* analysis was conducted in two phases according to the availability of basic information. The first phase was conducted in 2008 using mainly secondary data and the second phase aimed to improve the assessment by increasing the input of primary local data. The second phase conducted in 2009 is not considered here as an *ex-post* analysis as the soil sampling conducting in the field occurred during the experimentation of the *Canavalia* rotations and then did not capture the effects of this management alternative on soil characteristics. Therefore, an *ex-post* analysis will require soil sampling in plots with continued application of these practices and after a period of time that is long enough to capture these types of effects on soils.

For the first phase the value of soil characteristics considered were obtained from the analysis of local soil samples conducted by the soil research component of this project. It includes information of texture and total C for the superficial soil horizon. In addition some information about soil type units was extracted from the Land Use Plan of Estelí (Plan de Ordenamiento Territorial) and used to complement the information on texture and organic matter for subsurface soil horizons.

Using the soil texture information, the hydraulic conductivity, available water content and bulk density values were derived using the Soil Characteristic Tool of Saxton and Rawls that is applicable to mineral soils. In table 54, the values used in the first phase of the *ex-ante* analysis are shown.

Table 54. Soil characteristics used for the ex ante environmental analysis (first phase)

Horizon	Depth (cm)	Bulk Density (g/cm^3)	Available Water Content (cm/cm)	Saturated Hydraulic Conductivity (mm/hr)	% C	% Clay	% Silt	% Sand
A	0-20	1.13	0.15	22.44	23.4	28	32	40
B	20-70	1.32	0.1	1.2	6	54	18	28

In the second phase, soil characteristics were obtained through direct measurements in the study area conducted by this project. Data for saturated hydraulic conductivity, percentages of sand, clay and silt, and carbon content were provided for 9 different sites and horizons. In addition, available water content was calculated based on the percentage of water content obtained in the lab at different pressures and provided also by field trials. Bulk density values were obtained using the Soil Characteristic Tool and the granulometric information collected in the field.

Two sites were selected for this *ex-ante* analysis as they were representative of the variation found across the 9 sites. Thus one of them is a sandy loamy soil quite similar to the other 4 sampled sites, and the other is a clayey soil similar to the other 5 sites. Thus, these represent two fairly contrasting soils in terms of texture. Table 55 shows the values of soil characteristics used for the *ex-ante* analysis (second phase) and from the two selected sites.

Table 55. Soil characteristics for two soil types used for the *ex-ante* analysis using SWAT modeling

Horizon	Depth (cm)	Bulk Density (g/cm3)	Available Water Content (cm/cm)	Saturated Hydraulic Conductivity (mm/hr)	% C	% Clay	% Silt	% Sand
Site 1								
1	0-10	1.5	15.0	11.30	1.14	13.6	23.0	63.4
2	10-35	1.5	12.8	8.06	0.64	12.4	16.6	71.0
3	35-45	1.5	14.6	7.93	0.72	12.4	19.3	68.3
Site 2								
1	0-10	1.3	5.1	0.04	2.33	52.9	24.2	22.9
2	10-35	1.2	6.6	0.00	1.26	67.6	20.8	11.6
3	35-50	1.4	8.0	0.00	0.70	27.2	45.7	27.1

The climatic data used in the two phases of the *ex-ante* analysis consisted on daily values of precipitation, maximum and minimum temperature; and mean monthly temperature, radiation and wind velocity. The data sets for the period of January 1987 - December 2006 were obtained at INETER (Instituto Nicaragüense de Estudios Territoriales).

The topographic data was directly obtained from the Digital Elevation Model of the River Pire watershed at a resolution of 90 m. To do this, an area of 154 ha was selected near the farms where experiments on *Canavalia* were conducted, and data for each geographical location were captured using GPS during the field visit in 2007.

The climatic, soil and topographic data were integrated in SWAT to derive the values of sediment and water yields, surface runoff, lateral flow, percolation, evapotranspiration, and soil water for the following land use scenarios: 1) traditional maize-beans-pasture system, 2) maize rotated with *Canavalia* whose residues are left on the soil surface as green manure, 3) maize rotated with *Canavalia* that is grazed after 90 days of growth.

In Figure 20, the schedule of planting specified in SWAT for each scenario is shown. It is worth to note that these scenarios were assessed for the portion of land that is only planted with maize and not followed by another crop such as beans (see description of scenarios 1-3, section 4).

<table>
<tr><th>Land use scenario</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Ago</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td>Traditional maize rotation</td><td colspan="5">Fallow</td><td colspan="4">Maize</td><td colspan="3">Fallow</td></tr>
<tr><td>Maize rotated with Canavalia as green manure</td><td colspan="5">Fallow with residues of Canavalia</td><td colspan="4">Maize</td><td colspan="3">Canavalia</td></tr>
<tr><td>Maize rotated with Canavalia as forage</td><td colspan="5">Fallow</td><td colspan="4">Maize</td><td colspan="3">Canavalia-grazing</td></tr>
</table>

Figure 20. Crop rotations scenarios evaluated in the *ex-ante* environmental evaluation

Results

Tables 56 to 59 present the average production costs of maize, beans, milk, and meat as well as average values of productivity, farm area distribution in different land uses, use of family and contracted labor, and herd composition. These values came from the field survey conducted with farmers in 2007.

Ex-ante economic assessment

Table 56 shows the values for each scenario used for the *ex-ante* evaluation of potential economic benefits derived from the incorporation of *Canavalia* into the land use system of producers of the Pire river watershed.

- ***Benefits of* Canavalia *under the current land distribution scheme (Scenario 1 versus Scenarios 2 and 3)***

Based on the results obtained, the incorporation of *Canavalia* as green manure (Scenario 3) slightly decreased the net income as compared with the baseline (5%). The opposite occurred when the legume was used as animal feed (Scenario 2) because the net income of producers was increased by 5% (Table 56).

The urea applied in the baseline scenario was replaced in Scenario 3 with the incorporation of the legume into the soil. The reduction in net income obtained by using *Canavalia* as green manure can be attributed to the fact that, although the incorporation of the legume reduces the cost incurred for purchasing fertilizers, the requirement of contracted labor to plant the legume increases and the purchase of legume seed implies an additional cost. As a result, the benefit represented in reduced fertilizer costs does not compensate for the additional cost of planting the legume.

On the other hand, the increased income due to the incorporation of *Canavalia* for animal nutrition can be attributed to the increase in milk production, specifically during the dry season. Milk production during the dry season increased from 2 to 3 L/day, representing a 26% increase in the annual production compared to the baseline. In addition, the increase in income is not only due to a greater volume of milk produced during the dry season, but also the higher price of milk during this time of scarcity (US$ 0.27/L during rainy season compared to 0.32/L during the dry season).

Therefore the benefits of using *Canavalia* as animal feed are related to the increases in milk production and not to increases in stocking rate or meat production, which instead are maintained.

Table 56. Characteristics of production systems in each scenario evaluated (annual value) during the *ex-ante* analysis.

Characteristic	Scenario 1 Baseline	Scenario 2 *Canavalia* for animal nutrition	Scenario 3 *Canavalia* as green manure
Net income	2,994	3,169	2,849
Income due to maize[1]	1,098	1,098	1,147
Income due to beans[2]	798	798	807
Income due to milk[3]	1,277	1,692	1,261
Income due to meat[4]	631	641.48	631
Family labor[5]	266	266	266
Contracted labor[6]	90	141.05	135
Crop/grass distribution (ha/year)			
Beans	1	1	1
Maize	2	2	2
C. brasiliensis as green manure	----	---	1
C. brasiliensis for animal nutrition	----	1	---
Sugarcane	---	---	---
Cratylia argéntea	---	---	---
Sorghum	---	---	---
Jaragua grass	10	10	10
Brachiaria brizantha	---	---	---
Milk production (L/year)	4,470	5,740	4,470
Milk production (L/day per cow)	3	3.7	3
Meat production (kg/year)			
No. cows/year[7]	7	7	7

1 Calculated with a sale price to producer of US$270/t and a productivity of 2.4 t/ha per year intercropped in the same plot with beans. The same productivity is expected if maize is grown with *C. brasiliensis* as green manure (2 t DM/ha). If used as green manure, *C. brasiliensis* replaces 100% of the urea traditionally used. The estimated contribution of N of *C. brasiliensis* is equivalent to 38 kg N/ha, which surpasses current levels of application of urea (128 kg/ha per year). If *C. brasiliensis* is used as forage, it does not have any impact on maize productivity and is assumed to have 20% protein content, 50% protein digestibility, and 2.0 Mcal of metabolizable energy/kg.

2 Sale price to producer is US$660/ton and productivity is 1.3 t/ha per year. A similar productivity is expected if beans are grown after *C. brasiliensis* is incorporated into the soil as green manure.

3 Sale price to producer is US$0.27/L during the rainy season and US$0.32/L during the dry season.

4 Sale price to producer is US$1200/t.

5 Family labor is the total of annual day's work required for all farm activities minus the number of day's work contracted per year indicated by producers during the field visit.

6 Price of contracted day's work is US$2.70.

7 Calculated taking into account that a cow requires 0.034 t digestible protein/semester and 2400 Mcal metabolizable energy/semester.

Ex-post economic assessment

Table 57 shows the variables for which values were adjusted for the *ex-post* analysis based on the results obtained in the field trials during 2007-2008. It is noticeable that assumptions made in the *ex-ante* analysis about milk production when *Canavalia* is used for animal production, maize productivity, and *Canavalia* productivity were very similar to the values obtained during field experiments. However, there are some changes with respect to bean productivity for which the reported productivity by farmers in 2007 is far from what was measured in the field during the same year. This seems to be related with an atypical low rainfall amount that year and the incidence of some pests and diseases.

With this low productivity the ECOSAUT model showed that the optimal solution did not include the production of beans. However, as we were aware that the reported low value can be quite atypical, we also simulated a scenario where beans are cultivated as mentioned by the farmers in the survey. It is probable that even under atypical conditions farmers still cultivate some beans for food security purposes.

With respect to maize production costs, the *ex-post* analysis was conducted using a higher value as any reduction on the application of urea was reported during field trials and it is uncertain at this moment at what proportion this can be reduced throughout the time as *Canavalia* is used as green manure for longer periods of time.

Table 57. Comparison of values adjusted for the *ex-post* analysis

Variable	Ex ante	Ex post
Canavalia productivity (t/ha)	2	2
Maize production costs (when rotated with *Canavalia*)	64	99*
Milk production (L/day per cow) – Baseline	3	3
Milk production (L/day per cow) - *Canavalia* for animal nutrition	3.7	3.45**
Maize productivity t/ha (baseline and *Canavalia*-based rotation)	2.3	2.4
Beans productivity (t/ha)	1.3	0.16

* The urea was not suspended due to the incorporation of *Canavalia* in the rotation

** Separate studies indicate that a 15% of milk production increase was obtained when *Canavalia* was used for animal nutrition

Note: Same prices were assumed in the *ex-ante* and *ex-post* analyses

With respect to maize grain productivity in the traditional and in the maize-*Canavalia* rotations, it was found that the type of rotation did not have any effect (Table 58). For this reason the scenario 3 was not taken into account in the economic benefits assessment as the use of the legume as green manure did not improve maize productivity and therefore we did not test the effects of reduced N fertilizer input as assumed in the *ex-ante* analysis.

Table 58. Effects of rotations on maize grain productivity

	2007 (p value)	2008 (p value)
Site	.001*	.000*
Treatment**	0.882	0.404
Size x Treatment	0.425	0.572

*Significant at 5% (p = 0.05).

** Treatment: Traditional maize-bean-pasture rotation vs. Maize-*Canavalia* rotation.

In the scenario 2 where *Canavalia* was used as animal feed, the economic net return increased by 8% with respect to the baseline. This increment is mainly due to a 28% improvement of milk productivity. This improvement is marked during the dry season, whith an increased from 3 to 3.45 L/day. The increment on number of cows per hectare increases slightly, from 6.7 to 7.3, so the main reason of improving milk-related income is due to the increase in milk productivity (Table 59).

Table 59. Characteristics of production systems in each scenario evaluated (annual value) during the *ex-post* analysis

Characteristic	Scenario 1 Baseline (*ex-ante*)	Scenario 1 Baseline (*ex-post*)	Scenario 1 Baseline (*ex-post*) (with beans)	Scenario 2 *Canavalia* for animal nutrition (*ex-ante*)	Scenario 2 *Canavalia* for animal nutrition (*ex-post*)	Scenario 2 *Canavalia* for animal nutrition (*ex-post*) (with beans)
Net income	2,994	2,368	2,187	3,169	2,550	2,366
Income due to maize[1]	1,098	1,098	1,098	1,098	1,098	1,098
Income due to beans[2]	798	none	45.6	798	none	45,6
Income due to milk[3]	1,277	1,277	1,278	1,692	1,641	1,641
Income due to meat[4]	631	631	631	641.48	642.86	642.86
Family labor[5]	266	266	266	266	266	266
Contracted labor[6]	90	33	90.38	141.05	56.12	141,12
Crop/grass distribution (ha/year)						
Beans	1	0	1	1	0	1
Maize	2	2	2	2	2	2
C. brasiliensis as green manure	----	----	----	---	---	
C. brasiliensis for animal nutrition	----	----	----	1	1	1
Sugarcane	---	---	---	---	---	---
Cratylia argentea	---	---	---	---	---	---
Sorghum	---	---	---	---	---	---
Jaragua grass	10	10	10	10	10	10
Brachiaria brizantha	---	---	---	---	---	---
Milk production (L/year)	4,470	4,470	4,472	5,740	5,549	5,549
Milk production (L/day per cow)	3	3	3	3.7	3.45	3.45
Meat production (kg/year)						
No. cows/year[7]	6.7	6.7	6.7	7.3	7.3	7.3

SWAT modeling

The results from SWAT modeling showed that the incorporation of *Canavalia* –regardless if it is used for green manure or forage— increases both, the sediment and water yield. Also the lateral flow and percolation are improved. Thus, these two options have the same effects in terms of water and sediment yields as well as on the other water balance variables (runoff, lateral flow, soil water, percolation and evapotranspiration) (Table 60). However there is a different effect on surface runoff of incorporating this legume depending on the soil type. Surface runoff is increased in the clayey soil rather than been reduced as occurred in the sandy loamy soil (tables 60 and 61).

In addition, the incorporation of *Canavalia* improves the retention of water in the soils at the end of the simulated 20 yr-period (Table 61). This improvement occurs especially during the dry months (Figures 21-23).

The trend of these simulation results is very similar to that obtained in the first phase *ex-ante* analysis. The only discrepancy is in the surface runoff which was predicted to decrease with the *Canavalia* scenario during the first phase *ex-ante* analysis. However the type of soil in that initial analysis was a clayey loam and loamy soil similar to the soil type 2 for which similar results were obtained in the second *ex-ante* analysis.

It is worth noting that the first attempt to model the hydrological effect of the incorporation of the legume was done using secondary and very general data where many of the parameters were predicted and therefore with a high level of uncertainty. In the second attempt the availability of data for local soil profiles has permitted to distinguish the effect of the legume in different types of soils and with lower uncertainty as most of the soil data came from direct measurements.

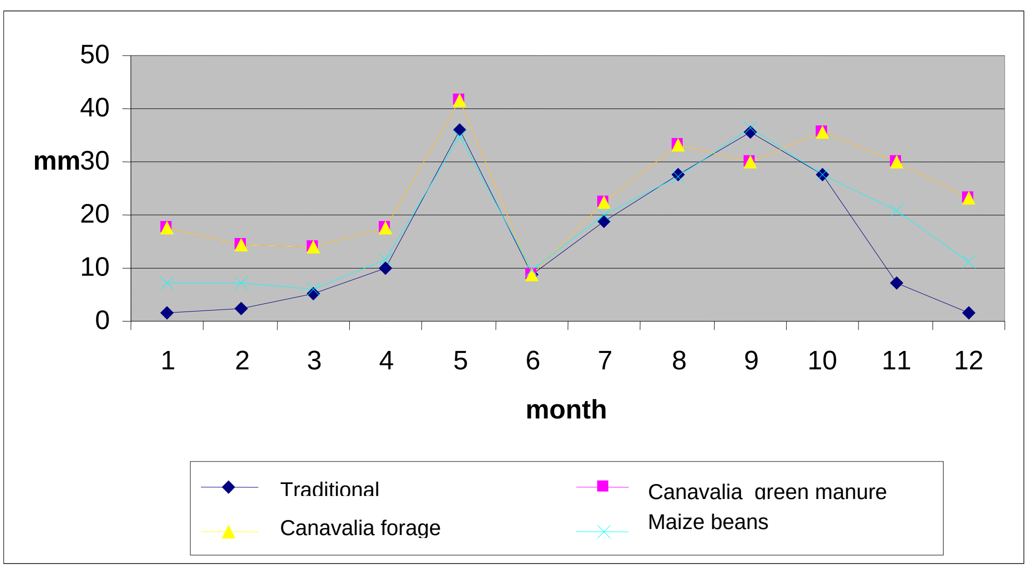

Figure 21. Soil water (mm) in soil type 1. Mean monthly values.

Table 60. Results of SWAT modeling for different maize-based systems for a 20-year period in two different soil types

Land use scenario	Evapo-transpiration	Surface runoff	Lateral Flow	Percolation	Sediment yield	Water yield	Soil water (mm)
Soil type 1							
Traditional maize rotation	---	---	---	---	---	---	310
Maize rotated with *Canavalia* as green manure	-3.82%	-14.34%	6.98%	37.41%	49.12%	7.92%	420
Maize rotated with *Canavalia* as forage	-3.82%	-14.34%	6.98%	37.41%	49.12%	7.92%	420
Soil type 2							
Traditional maize rotation	---	---	---	---	---	---	174
Maize rotated with *Canavalia* as green manure	-6.57%	16.46%	19.14%	184.32%	49.61%	29.85%	341
Maize rotated with *Canavalia* as forage							

Table 61. Water balance for a 20-yr period: Traditional maize-pasture rotation vs. *Canavalia*--based **rotations**

	Soil type 1			**Soil type 2**			**First ex-ante analysis**		
	Traditional maize rotation	**Maize rotated with *Canavalia* as green manure or forage**	**Difference**	**Traditional maize rotation**	**Maize rotated with *Canavalia* as green manure or forage**	**Difference**	**Traditional maize rotation**	**Maize rotated with *Canavalia* as green manure or forage**	**Difference**
Surface runoff (mm)	1057.571	905.95	-151.619	2736.419	3186.77	450.346	1495.481	1208.603	-286.878
Lateral flow (mm)	3260.10	3487.74	227.636	11.35	13.53	2.173	440.61	457.245	16.635
Groundwater (mm) + percolation	901.54	1238.81	337.27	238.21	677.29	439.079	1953	2271.633	318.633
Water yield (mm)	5219.214	5632.50	413.287	2985.985	3877.583	891.598	3889.091	3937.481	48.39
Evapotranspiration (mm)	11824.27	11372.50	-451.767	14054.19	13130.82	-923.363	13147.45	13112.64	-34.809

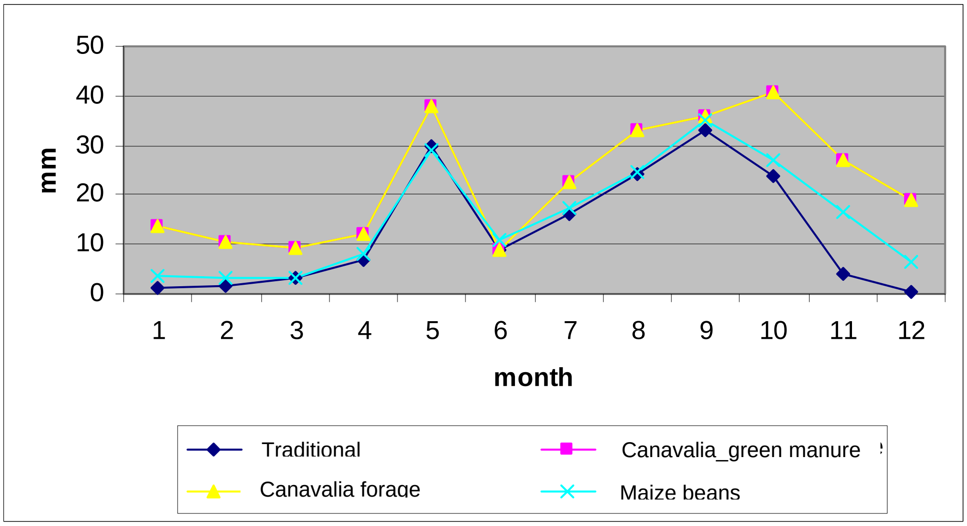

Figure 22. Soil water (mm) in soil type 2. Mean monthly values.

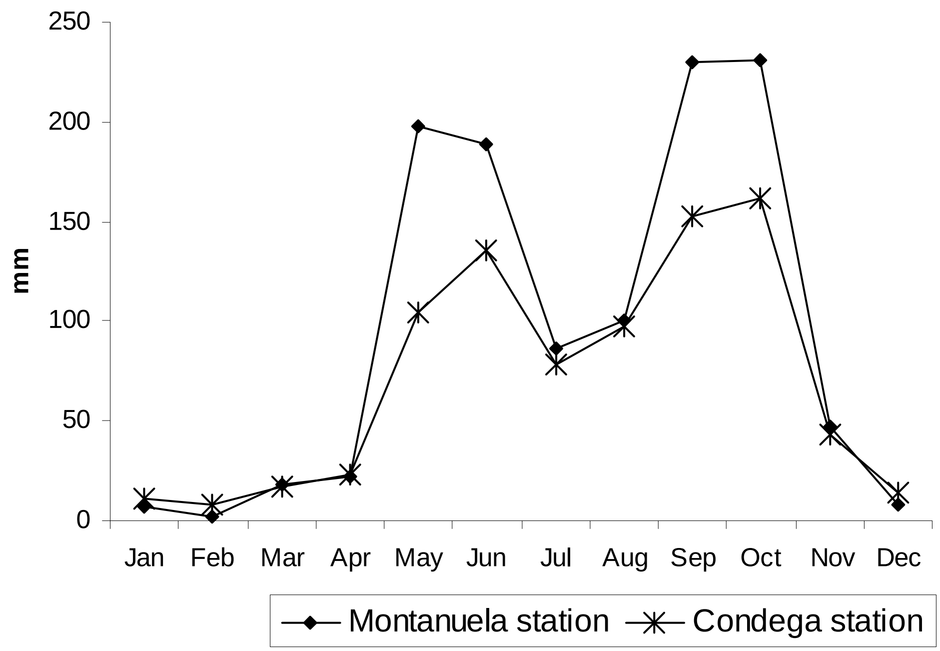

Figure 23. Average monthly precipitation (mm) for two stations near the study area

It is especially meaningful that water yield increase occurs also during the dry months. In Figures 24 and 25, the difference on monthly water yields between traditional maize-based system and *Canavalia* system is shown for the two soil types.

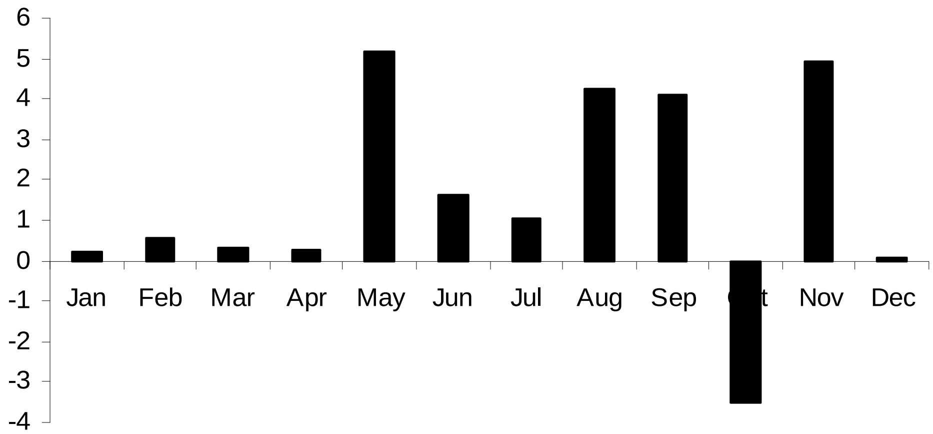

Figure 24. Annual average difference on water yield (mm) from changing traditional maize-pasture rotation to maize-legume rotation in soil type 1.

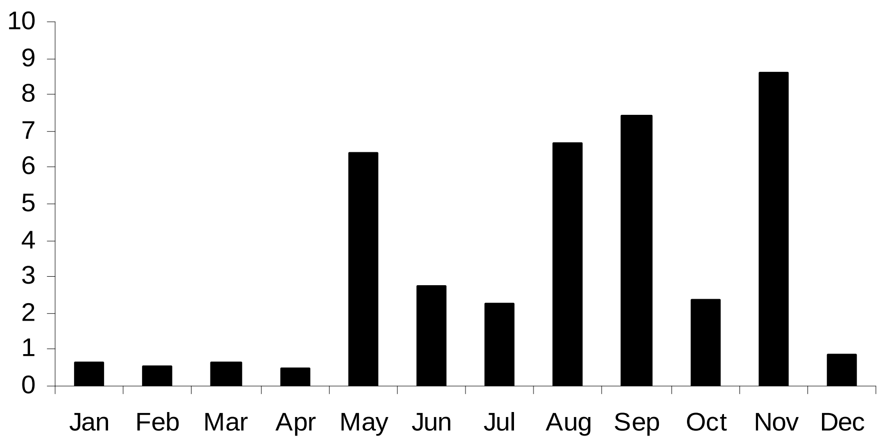

Figure 25. Annual average difference on water yield (mm) from changing traditional maize-pasture rotation to maize-legume rotation in soil type 2.

Contrasting this with soil moisture measurements done only for dry months (November-January) it was found that the improvement is significant for only soil type 1 (sandy clay loam) ($p<0.05$). Instead, in clayey soils the treatment has no significant effect on soil moisture content (Figure 26, Table 62). However, these measurements were taken once and it is unknown whether it has an effect for the whole year and also for multiple years.

Table 62. Effect of soil type, rotation type (treatment) and month on soil moisture (at 10 cm soil depth) content

Effect	SS	Degree of Freedom	MS	F	p
Site-soil type	283	2	141.6	23.98	.000*
Treatment	.	1	0.2	0.04	0.839
Month	1058	2	529.1	89.59	0.000*
Site*treatment	43	2	21.5	3.63	.029*
Site*month	52	4	13.1	2.22	0.069
Treatment*month	.	2	0.1	0.01	0.991
Site*Treatment*month	5	4	1.3	0.22	0.924

*Significant at $p<0.05$

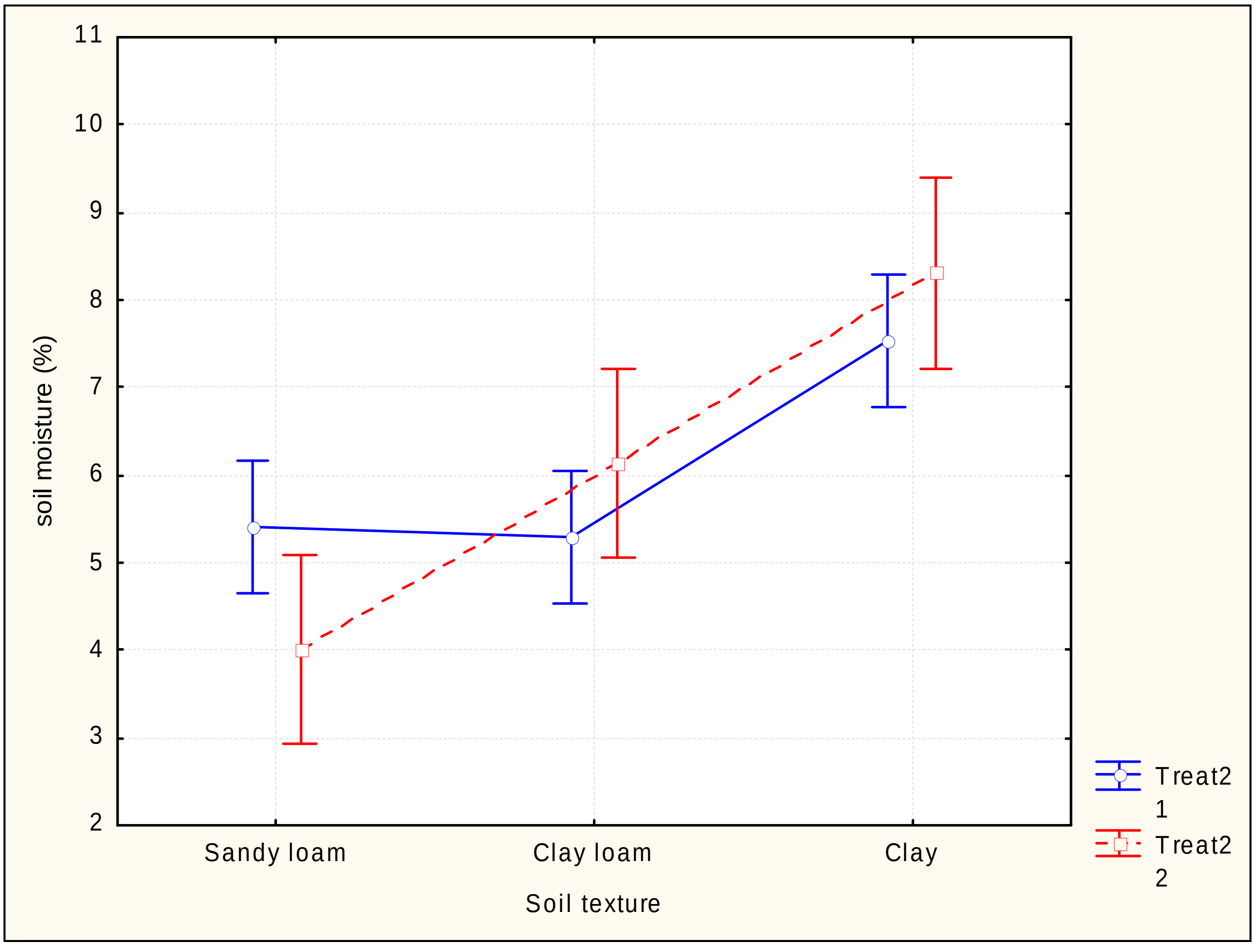

Figure 26. Soil moisture in different soil types and rotations (treatment 1: Maize-*Canavalia* rotation; treatment 2: Traditional maize rotation). (Vertical bars denote 0.95 confidence intervals).

With respect to sediment yield it increased with the *Canavalia*-based rotations, and this particularly occurs during the wettest months when *Canavalia* is sown (Figure 27 and 28).

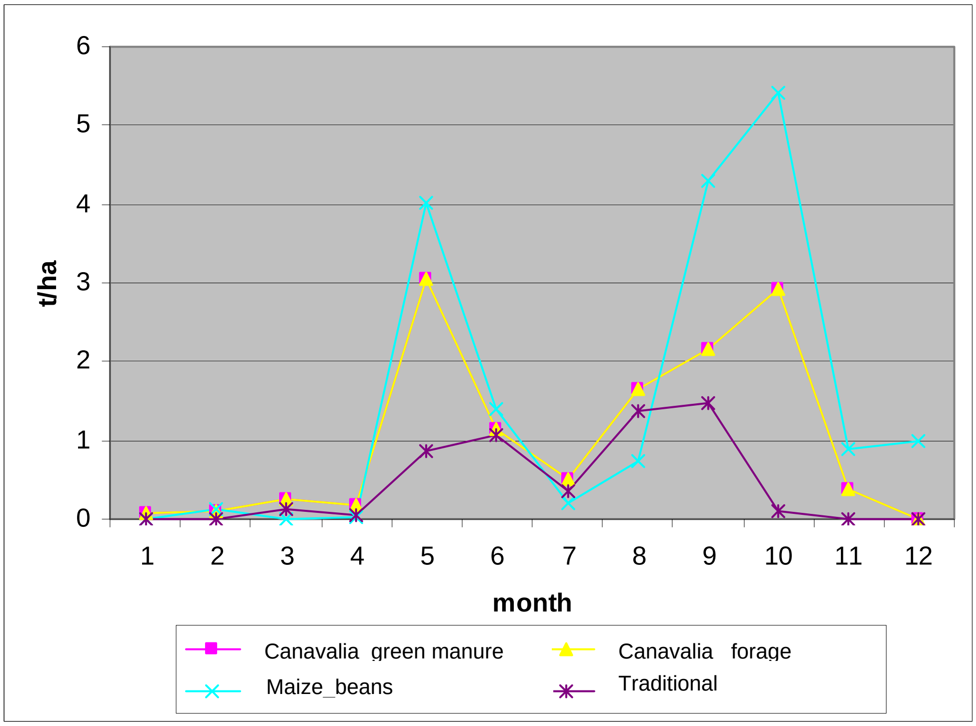

Figure 27. Sediment yield (mm) in soil type 1. Mean monthly values.

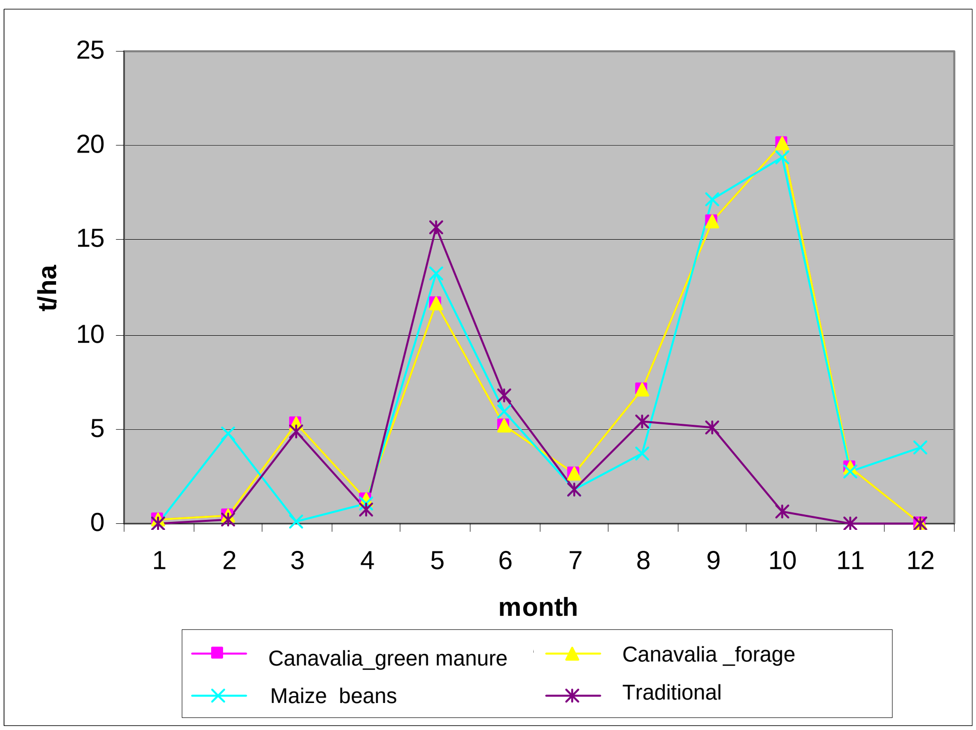

Figure 28. Sediment yield (mm) in soil type 2. Mean monthly values.

It is worth noting that the effect of *Canavalia* varies throughout the years as there is a great variation on annual rainfall (Figure 29). The lowest rainfall was registered in 1992 with 493 mm/yr and the highest in 1998 with 1384 mm/yr. During the wettest year the average sediment yield for the traditional maize rotation was 17 and 68 t/ha/yr in the sandy loamy and clayey soils, respectively; and for the *Canavalia*-based scenarios it was 68 and 289 t/ha/yr. In the driest year it was for the traditional rotation system 0.35 and 8.9t/ha/yr for the sandy loamy and clayey soils, respectively and 1 and 5.7 t/ha/yr for the legume-based scenarios in the two mentioned soil types.

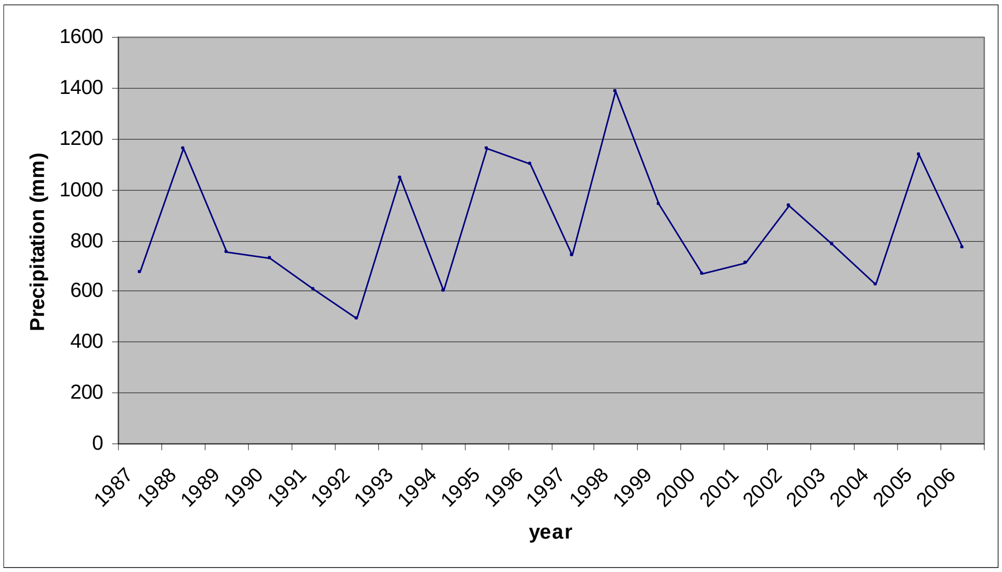

Figure 29. Annual rainfall 1983-2005

Discussion

Feasibility of incorporation *Canavalia* to the current maize-based rotations

Is it feasible to achieve the proposed *Canavalia*-based rotations? One prerequisite is stability in the prices of maize, beans, and milk, which helps producers perceive greater economic security to incur in the initial investment that this type of change requires. The aversion of producers to assume the risk implicit in the increase of area planted to crops or the introduction of new crops and pastures was confirmed during the field visit, when producers said that price instability was the principal limitation to increasing the area planted to crops. This was corroborated by the fact that the area on farms dedicated to crops is very similar, regardless of the variations in total farm size. For example, either a 17-ha farm or an 8-ha farm will always have 2 ha planted to crops. In farms under 5 ha, the area planted to crops is only slightly less.

Another factor that could limit the feasibility of incorporating the proposed changes in these scenarios is the local availability of labor. Contracted labor would necessarily increase from 90 to 384 man-days as compared with the baseline, or the family labor dedicated to agriculture activities would increase by more than 100%.

Another factor that could currently be hindering the expansion of the agricultural area and the purchase of livestock are the high interest rates reported by producers. These rates range between 10% and 26% in real terms. As a result, the system never generates sufficient surplus to support higher investments in the future. The effective term is substantially reduced, which especially affects long-term investments in livestock.

***Ex ante* vs. *Ex post* analysis**

The income change in percentage terms of incorporating *Canavalia* for animal production in the traditional rotation are very similar to predicted changes in the *ex-ante* analysis, and mostly explained by the fact that input data used during the *ex-ante* analysis was very close to the values actually measured in the field during the trials. In absolute terms, the *ex-ante* analysis overestimated the net revenues of the simulated baseline and scenario 3 by an 26%. This overestimation is explained by the difference of bean productivity reported by the farmers during field surveys in 2007 and the measured productivity by actual experiments. Thus the economic methodology for estimating *ex-ante* impacts of introducing *Canavalia* as forage showed a good performance and this is a function of the accurateness of available secondary data, especially data related to expected crop and milk productivity increases. However, it is clear that *ex-ante* analysis approaches and tools can not anticipate atypical behavior of some variables as was the case of the bean productivity that decreased below the levels reported by the farmers.

With respect to scenario 3 which consisted of using *Canavalia* as a green manure, it was evident that the *ex-ante* estimations did not match with the results from the field trials. However this is due to the assumptions behind the use of the legume as green manure rather than to the tool used. It was assumed – based on previous studies– that the incorporation was going to reduce fertilization costs. However this effect was not shown by the one-year experiments. It could be necessary to extend the experimental time period to confirm whether or not *Canavalia* can reduce N fertilization by improving N soil content and further more if the accumulated effect of the legume on soil quality has repercussion on subsequent crop harvests.

Environmental impacts

The results from SWAT modeling permit to quantify the environmental effects that the incorporation of *Canavalia* would have on environmental externalities that are important to society such as sediment and water yields[1]. It is clear that the main benefit of incorporating this legume to the current land use system is that the water yields could be increased particularly during drier months when water yield is most important as an externality. This effect is related with the increase on water percolation and lateral flow and the reduction of evapotranspiration.

However this is not the case for sediment yield. According to the simulation results, the sediment yield is increased when *Canavalia* is either planted as forage or as green manure even though the surface runoff is reduced in clayey soils. This occurs mainly during the wettest months when *Canavalia* is sown. In the baseline the soil is covered with weeds and pastures that invade the land once the maize starts drying out.

The benefits of improving water yields should be valuated to determine if that increment at the watershed level could be significant if *Canavalia* is introduced in several farms.

On the other hand, the lack of differences between using the *Canavalia* as a green manure or as forage could be due to differences in rainfall behavior. It was simulated that both, the cut of green manure and its subsequent deposition on soil surface or the grazing of the legume, occurs after December when the crop biomass is large enough for these purposes. Since in December the rainfall is minimal; the impact of having a cover crop is insignificant because the soil is not exposed to the impact of rain drops.

In consequence, from the farmer perspective, the environmental benefits of incorporating *Canavalia* to its current land use system could be the increment of soil water as *Canavalia* is grown especially in sandy loamy soils. However these predicted and partially tested impacts need to be verified during the implementation of the *Canavalia*-based scenarios in the selected farms. Also, at least for the period of

[1] Water yield (mm H_2O). Total amount of water leaving the land and entering main drainage. Water yield= Surface runoff + Lateral flow + Groundwater + Transmission losses. Transmission losses are minimal in this case.

time that field trials were conducted, there was not any significant effect of *Canavalia* on subsequent maize harvests so that improvement on soil water cannot be related to increases in maize productivity.

It is worth noting that SWAT results were not calibrated as water flows were not measured, such as surface runoff, lateral flow, percolation and evapotranspiration. Thus, these results only could indicate the trend of the effects of incorporating *Canavalia* in the rotations but the absolute values cannot be taken for granted as the model was not calibrated with measured data.

In the same sense, the results of the modeling exercise demonstrated that the trend of results is consistent in the different *ex-ante* analysis attempts but the absolute numbers changed as input data are varied. Thus, the utilization of this model should not only involve calibration but also should try to improve the quality of input data as the model showed to be very sensitive to this (first phase vs. second phase SWAT simulations).

Apart from the farm-level effects, the aggregated effect of having several farms under the *Canavalia*-based scenarios in the watershed could be greater and significant in terms of water yield improvement. For this purpose it is still indispensable to obtain soil data for all existing soil types in the watershed and river flow measurements in order to run and calibrate SWAT at this scale.

This step will be crucial to establish the trade-offs between increasing sediment yields vs. water yields. In case of confirming the potential increment on total water yields after the incorporation of *Canavalia* to the production systems, it will be necessary to compare the total benefits of introducing the legume to the system (economic farmer benefits derived from improvements in dairy or maize productivity + society benefits derived from water yield improvement) with the cost for the society derived from total sediment yield increase.

To conclude, the improvement on measured data and a hydrological modeling at the watershed scale will permit to determine accurately the impacts on water and sediment yield in order to establish the trade off between these two environmental externalities derived from different land use scenarios.

Producers' expectations regarding the benefits of *Canavalia* and its adoption potential

In the survey, producers expressed that they would be willing to adopt *Canavalia* as green manure if the use of fertilizers was reduced by 112 kg urea/year (i.e., 51 kg N/ha) and 112 kg NPK/year (i.e., 12-30-12). Taking into account that legume productivity in this *ex-ante* evaluation was considered to be 2 t DM/ha per vegetative cycle and that this legume presents 20% protein, producers' expectations would be satisfied because this represents 64 kg N/ha (without counting the N fixed through *Rhizobium*). However, this hypothesis could not be tested in the *ex-post* analysis as the N fertilization was not suspended in any treatment during field trials.

Regarding the adoption potential of *Canavalia* as animal feed, producers said that they would be willing to incorporate this forage into their systems if the daily milk production increased by 1.95 kg/cow/day during the dry season, which is almost a 100% increase (currently the reported production during dry season was 2.1 kg/cow/day). If Scenario 1 (baseline) is compared with the other scenarios, the incorporation of *Canavalia* alone increases daily milk production, but does not succeed in meeting producers' expectations. Production barely increased by 15% in Scenario 2. However, on-farm milk production can be increased beyond the expectations of producers by increasing the carrying capacity of farms as a result of incorporating other technologies such as sugarcane and improved pastures. These alternatives were analyzed during a preliminary *ex-ante* analysis.

Conclusions

According to *ex-ante* and *ex-post* analysis results, the use of *Canavalia brasiliensis* for animal nutrition permits to increment milk productivity. According to the *ex-post* assessment this represents an increase of farmers' net income by 8%. However, the use of this legume as green manure did not represent any increase of farmers' net income as neither subsequent maize grain productivity increased nor a reduction in nitrogen fertilizer application was confirmed. This was opposite to anticipated effects of this scenario during the *ex-ante* evaluation. The absolute income simulated in the *ex-ante* analysis of using the legume as animal feed was different for that obtained in the *ex-post* results due mainly to an atypical low bean productivity measured during the experimental period and far from what is used to be harvested by farmers in regular years.

Although results showed that from the economic perspective it is more favorable to use *Canavalia* to feed livestock, the obtained milk increases seems to be unable to meet farmers' expectations. Probably, the adoption of this forage legume crop should be combined with a strategy to increase the carrying capacity of farms as a result of incorporating other energy sources such as sugarcane and improved pastures.

On the other hand, the simulated environmental benefits of cultivating *Canavalia* as forage or green manure are related to increments on water yields and soil moisture during dry season. However, the magnitude and significance of this effect is affected by the type of soils, the effects being significantly higher for soil moisture and for water yield in sandy loamy soils than in clayey soils. Nevertheless, these results need to be calibrated with longer-term field measurements. Also it was demonstrated that modeling results are very sensitive to the level of uncertainty of input data (primary vs. secondary data) but still the trends of predictive results are maintained.

As a final comment it needs to be clarified that *Canavalia brasiliensis* is a forage option targeted at environments with a marked and extended dry season. In humid environments, *Canavalia brasiliensis* is likely to have a strong weed potential and thus could have negative environmental and economic impacts.

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

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

Rationale

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

Materials and Methods

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

The following forage options are being evaluated:

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

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

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

The trials are utilized for agronomic and participatory evaluations, with the aim to facilitate farmer selection for adaptation, innovation and adoption.

Farmer training

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

Results and discussion

The sets of herbaceous forage legume accessions of *Canavalia* spp (eight accessions: CIAT 905, 7648, 7969, 7971, 17009, 17462, 19038 and 21012) and *Lablab purpureus* (six accessions CIAT 22759, 22663, 22604, 22598, 22768 y 21603) established readily (Photos 18 and 19).

While establishment of herbaceous species was good, for the shrub *Desmodium velutinum* (six accessions: CIAT 33443, 23982, 23996, 13953, 23981 y 13218, Photo 20) and *Leucaena diversifolia* (nine accessions: CIAT 21242, 17503; I-45/87/09, IL16570, IL 15551, IL505; K782, K787 and control *L. leucocephala* CIAT 2188) replanting was necessary; establishment problems were related to germination problems and, in the case of *Leucaena*, leaf cutter ants.

The trial sites were selected to represent a range of contrasting altitudes, soils and rainfall. Tables 63, 64 and 65 show first results of the collections of *Canavalia* spp. and *Lablab purpureus.*

Photo 18. Multilocational trial of *Canavalia* spp. in Patía, Cauca

Canavalia

Between sites, a large variation in soil cover and DM yield was encountered for the *Canavalia* accessions for the first two vegetation periods. Establishment was vigorous in all locations, and soil was covered rapidly. No significant differences for DM yield and soil cover between accessions were found during this time, with the exception of the site El Limonar, where significant ($P<0.05$) differences were found in the rainy season (Table 63).

Across sites, highest DM yields were recorded in El Limonar and La Cocha and lowest in Porvenir. The Porvenir site is characterized by a greater slope and less moisture retention in a location with lower rainfall. In the rainy season highest yields were recorded for accessions CIAT 905, 17462, 17009 and 19038, all with more than 4 t DM/ha in 8 weeks of regrowth . During the dry period yields were substantially lower; equally soil cover decreased to below 70%, with accession CIAT 21012 most severely affected.

Table 63. Multilocational evaluation of *Canavalia* spp. in Patía, Cauca: Soil cover and DM yield after 8 weeks of regrowth in the wet period.

Accessions	Sites							
	La Cocha		El Limonar		Porvenir		Versalles	
	Cov %	DM Kg/ha	Cov %	DM Kg/ha	Cov %	DM Kg/ha	Cov %	DM Kg/ha
CIAT 905	98	5238	98	5368	80	3216	97	4042
CIAT 17462	92	4134	97	4143	70	2289	96	3672
CIAT 7648	68	3864	94	5266	80	2596	100	3690
CIAT 7971	93	3819	93	3893	58	2436	93	3356
CIAT 17009	90	3737	99	4657	78	3195	95	3573
CIAT 19038	73	3263	95	4134	73	2619	98	3797
CIAT 7969	90	3150	96	3409	68	2696	99	3845
CIAT 21012	60	1925	73	2571	67	2037	82	2392
Mean	83	3641	94	4233	72	2636	95	3545
LSD (P<0.05)	37.734	3573.941	17.468	2378.474	40.734	1746.623	26.969	2681.515

It was observed that *Canavalia* grew best in slightly shaded environments, however without light limitation for growth.

Lablab

In the multilocational trial of *Lablab*, only at La Cocha significant ($P<0.01$) differences between accessions in soil cover were recorded. At the other locations neither DM yield nor soil cover was significantly different between accessions. Though establishment was initially vigorous, later on plants were severely affected by leaf eaters. At Porvenir, *Lablab* did not perform well (Table 64), largely due to soil conditions apparently unfavorable for *Lablab*,and steep slope and thus high levels of erosion resulting in very low plant densities.

In contrast at La Cocha average yields where high (2763 kg DM/ha in 8 weeks). Soil cover at the Punto location was low, however reduction of DM yields was not as drastic as at Porvenir. Accessions CIAT 22768, 22663 and 22759 yielded more than 2.9 t/ha in La Cocha, with substantially lower yield at the other sites.

Table 64. Multilocational evaluation of *Canavalia* spp. in Patía, Cauca: Soil cover and DM yield after 8 weeks of regrowth in the dry period

Accessions	Sites							
	La Cocha		El Limonar		Porvenir		Versalles	
	Cov %	DM Kg/ha	Cov %	DM Kg/ha	Cov %	DM Kg/ha	Cov %	DM Kg/ha
CIAT 7971	67	2560	73	2717	50	1707	43	3160
CIAT 7969	53	2173	70	3027	40	1587	57	2000
CIAT 905	53	1893	78	2707	58	1400	57	3093
CIAT 17462	63	1747	67	2827	43	1013	52	2200
CIAT 17009	50	1560	65	2760	57	1133	63	2733
CIAT 7648	49	1520	73	2813	50	1067	63	2907
CIAT 19038	25	740	50	1600	37	760	33	3107
CIAT 21012	8	740	58	2880	43	1480	28	2027
Mean	49	1696	67	2666	47	1268	50	2653
LSD (P<0.05)	58.358	1752.331	32.526	1381.630	42.786	1279.088	44.015	1992.793

Photo 19. Multilocational trial of de *Lablab purpureus* in the Valle del Patía, Cauca.

Photo 20. Multilocational trial of *Desmodium velutinum* in Limonar

Table 65. Multilocational evaluation of *Lablab purpureus* in Patía, Cauca: Soil cover and DM yield after 8 weeks of regrowth

Accessions	Sites							
	La Cocha		El Limonar		Porvenir		Punto	
	Cov %	DM Kg/ha	Cov %	DM Kg/ha	Cov %	DM Kg/ha	Cov %	DM Kg/ha
22768	77	3355	62	1080	12	1140	67	2299
22663	75	3252	62	1253	20	800	20	1336
22759	87	2984	71	880	15	680	60	1435
21603	68	2778	38	1173	4	180	43	1380
22598	38	2353	55	1680	20	653	32	973
22604	30	1853	70	1547	18	720	40	707
Mean	63	2763	60	1269	15	724	45	1355
LSD (P<0.05)	11.869	1612.997	30.631	1262.093	22.517	730..561	96.153	1717.919

3.3 Evaluation of adaptation of a core set of tropical forage legumes in D.R. Congo, 2009

Contributors: B.L. Maass, D. Katunga-Musale (CIAT)

Rationale

During previous research by the Consortium for Improving Agriculture-based Livelihoods in Central Africa (CIALCA), as well as during a recent diagnostic survey on livestock production in South Kivu province of D.R. Congo, feed resources, especially during the dry season, were among the most important issues for animal husbandry. Improved forage legumes and grasses, adapted to low fertility sites of tropical America have been developed by CIAT; however, their adaptation to similar agro-ecological locations in Africa is unknown.

Material and Methods

To appreciate general and specific adaptation of tropical forages in Africa, eleven herbaceous and four shrub legume accessions have been established in small plot trials at four locations, Kamanyola, Mulungu, Nyangezi, and Tubimbi, in South Kivu province of D.R. Congo (Table 66). This trial aims to identify the best adapted legumes for further participatory on-farm evaluation in the region. To assess wider knowledge about genotype-environment interaction, the experiment has also been established in Colombia and Nicaragua.

Table 66. Some characteristics of the locations for forage evaluation in South Kivu province, D.R. Congo

Location	*Altitude (m asl)*	*Soil / fertility*	*Slope*	*Climate*
Mulungu (INERA)	1700	Recent volcanic	Almost plain	Sub-humid
Nyangezi	1650	Poor	Steep	Relatively dry
Tubimbi	1100	Intermediate	Partly steep	Sub-humid
Kamanyola	900	Good	Plain	Relatively dry

Results and Discussion

Despite the relatively recent establishment of the trial, it was apparent that, among the herbaceous legumes, *Lablab purpureus* and *Canavalia brasiliensis* are those with the best adaptation across all four sites, while all the 3 *Vigna unguiculate* accessions included in the trial heavily suffered from fungal diseases. More differential adaptation is noticeable according to site with accessions of *Stylosanthes guianensis*, *Centrosema molle*, *Clitoria ternatea*, *Desmodium uncinatum* (i.e., local check) and *Macroptilium atropurpureum*. Finally, the accessions tested of *Desmodium heterocarpon subsp.ovalifolium* was weak throughout. At the end of the year, the establishment of shrubs was still too recent to assess their potential adaptation.

Regarding the sites, Kamanyola obviously offers the most productive environment, followed by Mulungu and Nyangezi. Plants in Tubimbi had not established well as yet (Photo 21).

Photo 21. Evaluation of herbaceous forage legumes at four sites in South Kivu province of D.R. Congo; (a) Mulungu, (b) Nyangezi, (c) Tubimbi, and (d) Kamanyola.

3.4 Development of low input systems such as organic farming by optimizing the use of legumes in a dry region of Nicaragua to improve soil fertility, yield, human nutrition and farm income - Use of legumes in low input systems

Highlight

- The major partner Universidad Nacional Agraria implemented various legume-based experiments involving three staff members and six students.

Contributors: G. Bonilla (UNA), E. Perez (UNA), C. Ruiz (UNA), Freyer (BOKU), R. van der Hoek, A. Schmidt and M. Peters (CIAT)

Rationale

The objective of this project jointly carried out by the University of Natural Resources and Applied Life Sciences (BOKU), Vienna, Austria, the Universidad Nacional Agraria (UNA), Managua, Nicaragua, and CIAT is to develop options based on legumes as green manure and animal feed. More specifically, the targets are as follows:

(a) On-station trials:

1. To find out the impact of different legume species/varieties, planted in the dry season, on soil organic matter after a four-year rotation.
2. To study the performance of different legume species/varieties in terms of root biomass, above ground biomass, nitrogen fixation and the effects on subsequent maize performance.

(b) On-farm trials:

3. To investigate the impact of cover crops/green manure (CCGM) improved residue grazing in the dry season on subsequent maize performance in comparison with non-grazed CCGM rotations, as well as their labor and economic impacts.
4. To analyze the impact of CCGM species/varieties on subsequent maize performance, as well as their labor and economic impacts.
5. To implement support strategies for farmer/researcher to farmer training/knowledge transfer, experience exchange - combining on station trial knowledge with farmer specific knowledge (site specific techniques) accompanied by B.Sc./M.Sc. students and local farmer organizations

Activities

Based on the above, the Universidad Nacional Agraria as the main implementing institution has developed the following activities:

1. Evaluate 16 genotypes of forage legumes in trial plots at two experiment sites in the Pacific region of Nicaragua.

These experiments took place at two sites: the Ranch Ebenezer in Niquinohomo, Masaya, and the UNA research farm Finca Santa Rosa. They included a complete randomized block with 16 treatments and three replicates. The Ranch "Agropecológico en Especies Menores" Ebenezer (RAEME), is situated in the municipality of Niquinohomo, Masaya Department, at an altitude of 400 masl, with average rainfall of 1,200 mm, most of which occurs in the period from July to November. Soils are clay loam with an effective depth of 40 cm. The "Finca Santa Rosa" of the Universidad Nacional Agraria is situated just outside Managua, with an area of approx. 140 ha. Soils are volcanic, deep with a good permeability. In 2005 and 2006 average rainfall varied between 1400 and 1900 mm. The experiment was established at the beginning of the first growing season (*Primera*) in May 2008 with the planting of the maize. The legumes were planted at the beginning of the second growing season (*Postrera*) in September of the same year. Harvest of both maize and legumes took place during the first months of 2009.

Legume development differed considerably per site. Though at both sites legumes performed quite well, at Niquinohomo the maize harvest failed due to drought.

Tolerance to pests (Table 67). At both sites, *Centrosema plumieri* was most resistant. The *Vigna* and *Lablab* accessions were in general quite heavily affected; *Canavalia brasiliensis* was intermediate.

Damage was defined as the percentage of affected plants.

Table 67. Pest incidence of legumes in Santa Rosa and Niquinohomo

	Santa Rosa		Niquinohomo	
Treatment	% damage	Duncan*	% damage	Duncan*
Canavalia brasiliensis	62	bc	49	d
Centrosema plumieri	21	d	7	e
Clitoria ternatea	73	abc	66	bc
Lablab purpureus 2	78	ab	80	a
Lablab purpureus 21603	77	ab	49	d
Lablab purpureus CPI106471	66	abc	66	bc
Lablab purpureus CPI-676	79	a	82	a
Lablab purpureus CQ- 2975	80	a	83	a
Vigna umbellata 24360	64	abc	60	cd
Vigna umbellata 26469	70	abc	80	a
Vigna unguiculata IITA 131-2	64	abc	63	bc
Vigna unguiculata IITA 284/2	67	abc	74	ab
Vigna unguiculata IITA 390/2	59	c	53	cd
Vigna unguiculata 9611	70	abc	55	cd
Vigna unguiculata Verde Brasil	59	c	49	d

*different letters denote significant differences ($p < 0.05$, Duncan's multiple range test)

Because of their high palatability, legumes are usually quite heavily affected by pests and reduction of damage is difficult to achieve. However, even in cases of substantial pest damage, legumes often still reach acceptable production levels (biomass, grains).

Biomass production

Table 68 presents the legume biomass production and average N content. *Lablab purpureus* 2 showed highest yields in Santa Rosa, whereas performance of *Vigna umbellata* CIAT 26469 was lowest. In Niquinohomo *Vigna unguiculata* Verde Brasil showed the highest average, in contrast to *Vigna unguiculata* IITA 390/2. *Canavalia brasiliensis* did quite well at both sites, as well as the cowpea accessions *Vigna unguiculata* Verde Brasil and *Vigna unguiculata* IITA 284/2.

Table 68. Legume biomass production (DM, in kg/ha) at Santa Rosa and Niquinohomo, and average N content

Treatment	Santa Rosa	Niquinohomo	N content (%)	Duncan*
Canavalia brasiliensis	2017	950	2.94	a b
Centrosema plumieri	554	79	2.07	c d
Clitoria ternatea	439	8	2.70	a b c
Lablab purpureus 2	3140	962	2.74	a b c
Lablab purpureus 21603	2454	693	2.81	a b c
Lablab purpureus CPI106471	1656	399	2.34	a b c d
Lablab purpureus CPI-676	1866	622	3.00	a
Lablab purpureus CQ- 2975	1865	269	2.77	a b c
Vigna umbellata 24360	1746	290	1.97	c d
Vigna umbellata 26469	91	4	1.63	d
Vigna unguiculata IITA 131-2	1931	635	1.80	d
Vigna unguiculata IITA 284/2	1446	1124	1.81	d
Vigna unguiculata IITA 390/2	131	197	2.14	b c
Vigna unguiculata 9611	846	177	2.19	a b c d
Vigna unguiculata Verde Brasil	1772	1486	2.34	a b c d
Vigna unguiculata FHIA	386	214	2.02	c d

Nodulation

Lablab purpureus 2, *Vigna unguiculata* FHIA and *Vigna unguiculata* Verde Brasil showed highest numbers of nodules and highest root biomass, in contrast to *Clitoria ternatea* and *Centrosema plumieri*.

Legume N content

N content varied considerably among the different legumes. The *Vigna umbellata* accessions showed relatively low contents (under 2%), whereas *Lablab purpureus* accessions contained up to 3% of nitrogen, with *Canavalia brasiliensis* and *Clitoria ternatea* also in the upper range. Cowpea accessions showed intermediate results.

Effect of forage legumes on agronomic maize parameters

The main objective of this experiment is the evaluation of the effect on maize of intercropping with legumes. The following production indicators were evaluated: plant height (Table 69), stem diameter, germination rate and incidence of pests and diseases

Table 69. Maize height (cm) and yield (kg/ha)*

	Santa Rosa		Niquinohomo		
Treatment	height	Duncan**	height	Duncan**	yield
Canavalia brasiliensis	138.53	c d e	61.74	e f g	3690
Centrosema plumieri	125.54	f e g	70.03	b c d e	1789
Clitoria ternatea	159.2	a b	74.92	b c	2561
Lablab purpureus 2	139.21	c d e	86.73	a	3286
Lablab purpureus 21603	144.07	c	66.43	d e f	3633
Lablab purpureus CPI106471	150.6	b c	71.31	b c d	3543
Lablab purpureus CPI-676	151.46	b c	72.85	bc	2424
Lablab purpureus CQ- 2975	148.84	b c	67.8	c d e f	3580
Vigna umbellata 24360	117.18	f g	64.47	d e f	3118
Vigna umbellata 26469	128.87	d e f	64.71	d e f	2284
Vigna unguiculata IITA 131-2	160.23	a b	65.35	d e f	4127
Vigna unguiculata IITA 284/2	167.98	a b	77.08	b	2434
Vigna unguiculata IITA 390/2	142.52	d c d	61.23	f g	2675
Vigna unguiculata 9611	137.46	c d e	59.78	f g	2620
Vigna unguiculata Verde Brasil	139.9	c d e	71.41	b c d	3137
Vigna unguiculata FHIA	113.73	g	65.65	d e f	2787
no intercrop (local check)	120.03	f g	55.54	g	1832

*only at Santa Rosa
**different letters denote significant differences ($p < 0.05$, Duncan's multiple range test)

In Santa Rosa, intercropping with *Vigna unguiculata* IITA 284/2 provided best results, in contrast to the combination with *Vigna unguiculata* FHIA and *Vigna umbellata* 24360. At the Niquinohomo site *Lablab purpureus* 2 (Dl) and *Vigna unguiculata* IITA 131-2 were most promising, whereas intercropping with *Vigna umbellata* 26469 and *Centrosema plumieri* appeared to be least beneficial.

A striking general result was that at both sites the local check (maize without intercropping) showed poorer results in comparison to intercropping with any legume.

Effect on yields

Maize yield was measured at both sites, but due to drought in Niquinohomo the maize yields were very low, not representative and therefore not taken into consideration. Results of Santa Rosa (Table 69) show considerable differences in maize yields, but according to a first analysis these differences are not statistically significant ($p<0.05$). The issue will be further looked into.

Highest yields were obtained when intercropping with *Vigna unguiculata* IITA 131-2, *Lablab purpureus* CIAT 21603, CPI 106471 and "2", as well as with *Canavalia brasiliensis.* As with plant height, results of the local check and *Centrosema plumieri* were poorest, indicating that there is indeed an effect of the legumes on maize yield.

Some general conclusions and observations

- The Santa Rosa site presented better results than Niquinohomo (drought).
- *Vigna unguiculata* Verde Brasil and *Lablab purpureus* 2 showed in general best results (agronomic characteristics, production, nodulation and biomass N content).
- Least performing legumes were *Vigna unguiculata* IITA 390/2, *Vigna unguiculata* FHIA and *Vigna umbellata* CIAT 26469.
- In general, maize performed best when intercropped with *Lablab purpureus*, especially accessions CQ-2975 and CIAT 21603. Maize without intercropping showed poorest results.
- These results are still preliminary. Additional analysis (including soil) will provide more insight, e.g., regarding nutrient fluxes.

2. Evaluate the effect of four genotypes of leguminous shrubs/trees at El Plantel, research farm of UNA, on soil fertility and maize production.

The trial was established in June 2008 at the UNA "El Plantel" farm, characterized by an annual rainfall of 1100 mm with a rainy season of six months (May to November). Soils are Mollisols of volcanic origin, with intermediate soil depth and well drained.

Four leguminous shrubs were planted as alley hedgerows: *Gliricidia sepium*, *Leucaena leucocephala*, *Caesalpinia violacea* and *Erythrina* sp. *Canavalia brasiliensis* was planted between the hedges. Soil samples were taken and analyzed. Two students are involved and presently analyzing the results that will be the basis of their thesis entitled: "Evaluation of four leguminous shrubs intercropped with annual species under drought conditions at the farm El Plantel, Tipitapa, Nicaragua". Results will be available shortly.

3. The effect of four forage legumes (*Vigna unguiculata* (2 varieties), *Lablab purpureus* and *Canavalia brasiliensis*) (on-farm) on soil fertility and animal production (milk production of small ruminants) .

As in activity 1, the experiments will take place at the Ranch Ebenezer and the Finca Santa Rosa. Twelve lactating goats are used. Feed will consist of grass and a legume supplement (1-1.5 kg/day). The total duration is 90 days and in a cross-over design each forage legume is evaluated during two weeks (after an adaptation period of one week) in groups of three animals. Students have been selected and work is in progress.

4. Participatory Rapid Appraisal (PRA) and training workshop on use of both introduced and local herbaceous forage legumes and leguminous shrubs for improvement of soil fertility and animal feed in Pacora, San Francisco Libre, Managua).

The objective of the appraisal and workshop was to obtain and share information on native and introduced forage legumes. The appraisal included the use of participatory tools like group meetings, semi-structured interviews and field visits. The workshop consisted of training on use of forage legumes. The activities were facilitated by university teachers who participate in the project.

In addition, a student from the University of Potsdam - BOKU carried out an experiment on the behavior of *Canavalia brasiliensis* and *Vigna unguiculata* and their effect on maize during the growing period and after mulching.

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

Highlights

- With an above ground biomass production up to 5300 kg ha^{-1} for four months of growth, *Canavalia brasiliensis* (canavalia) has the potential to improve soil fertility and feed availability. Biomass production was significantly affected by the carbon and nitrogen (N) contents of the soil surface horizon, the amount of clay and stones in the whole profile, and the soil depth.
- Canavalia makes important N input to the crop-livestock system through symbiotic N_2 fixation, with on average 20 kg N fixed ha^{-1}in a few months under grown under drought conditions. Canavalia increases the N balance of the maize-canavalia rotation when used as green manure, but bears the risk of soil N depletion if used as forage, unless N is recycled to the plot by animal manure.
- Canavalia benefits substantially to the subsequent crop: 12% of canavalia residue N was recovered in the following maize crop and most of it remained in the soil, thus building up soil N stocks.
- Based on the positive results in 2007 and 2008, grazing trials with farmers were extended to other regions.
- Preliminary evaluation of a core collection of different canavalia accessions identified *Canavalia brasiliensis* CIAT 7972, CIAT 19038 and CIAT 17462 showing higher soil cover and biomass production than CIAT 17009, the accession commonly used in Nicaragua (control).

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Rationale

In smallholder farming systems of the Nicaraguan hillsides, intensification of land use resulted in soil nutrient depletion leading to a decline in agricultural productivity. Nitrogen (N) is considered as the most limiting nutrient in the traditional maize-bean-livestock system. Furthermore, farmers lack adequate forage options to feed their livestock, particularly during the dry season. We are testing the hypothesis that integration of the underutilized and drought tolerant cover legume, *Canavalia brasiliensis* (canavalia) into the traditional maize-bean-livestock system either as green manure or as animal feed can overcome soil fertility decline, produce more dry season feed of better quality and increase milk production during the dry season.

Materials and methods

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

An in-depth N study was carried on a 6 year-old on-station trial in San Dionisio (Department of Matagalpa, 12°46'N, 85°49'W), at 560 m asl, on a 10% slope. Soil was a clay loam classified as Ultic Tropudalf.

Green manure on-farm trials

The objectives were (i) to determine the soil and topographic factors that influence canavalia above ground biomass production, and (ii) to compare the soil surface N budget at plot level of the traditional maize/bean (M/B) rotation with the maize/canavalia (M/C) rotation.

Maize was planted during the first rainy season and beans during the second rainy season. Both crops were harvested in November. Canavalia was planted during the second rainy season and cut four months later in January, at the beginning of the dry season.

On six farms, soil and topographic properties were linked to canavalia above-ground biomass production. The description of soil profiles and canavalia root system at ten contrasting sites completed the observations.

On four farms and during two cropping years (2007 and 2008), we assessed the soil surface N budget of M/B rotation and compared it with the budget of M/C rotation, with different cutting intensities of above ground biomass of canavalia to simulate grazing. Nitrogen input variables were mineral fertilizer N, N input with seeds and symbiotic N_2-fixation that was estimated using the ^{15}N natural abundance method. The estimation of N output from the system was based on N removed with harvested parts of maize, bean and canavalia.

Livestock on-farm trials

Based on the positive results in 2007 and 2008, the grazing trials with farmers integrating canavalia in the traditional maize-bean system were extended to the Nueva Segovia region, in collaboration with INTA and a local farmers' cooperative, UGAQ. As in the foregoing years, two plots of around 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 (January 2010) lactating cows will enter the maize fields and graze first the plots with the maize stover (and weeds/legumes) followed by the maize plots with canavalia. Each treatment will last eight days. Biomass,and milk production and quality will be measured.

N dynamics on-station trial

In a 6 year-old on-station trial, microplots were installed in M/C rotation plots to determine the N fertilizer value of canavalia residues for maize. The direct ^{15}N labelling technique was used, where ^{15}N labelled amendments are added to an unlabelled soil, to trace the fate of amendment N in the soil-plant system. In June 2008, ^{15}N-labelled canavalia residues and ^{15}N-labelled mineral fertilizer were applied on the microplots. Microplots were then planted with maize, and harvested five months later.

Evaluation of accessions of canavalia

At two sites (San Dionisio, Santa Teresa) trials were established with 12 accessions of canavalia (including the control CIAT 17009 used in this project) being evaluated on agronomic characteristics and fertilizer value (effect on subsequent maize production). Each trial consisted of three replicates of 3x4 m plots with the following treatments:

- 12 accessions - *Canavalia brasiliensis* CIAT 17009, CIAT 17462, CIAT 19038, CIAT 20303, CIAT 7648, CIAT 7969, CIAT 7971, CIAT 7972, CIAT 808, CIAT 905, *Canavalia* sp. CIAT 21013, CIAT 21014
- 5 fertilizer levels (without canavalia), of 0, 40, 80, 120 and 160 kg/ha urea

Results and discussion

Green manure on-farm trials

Canavalia above ground biomass production for both years varied between 448 and 5,357 kg ha^{-1}, with an average of 2,117 kg ha^{-1}, after four months of growth. Soil depth, carbon and N content of the soil surface horizon and amount of clay and stones in the whole profile affected significantly canavalia biomass production. Even when canavalia is less productive on shallow and stony soils it could still make a contribution to improving soil fertility and feed availability. However, a marked increase in agricultural production will not occur on these less productive areas in the short term without additional inputs of mineral fertilizer or animal manure, or with other soil conservation measures.

Canavalia fixed on average 64% and 74% of N from the atmosphere in 2007 and 2008, respectively. Farmers applied between 38 and 68 kg N ha^{-1} in the form of mineral fertilizers. Output through maize harvest was on average 43 kg N ha^{-1}. Nitrogen output by beans remained under 10 kg ha^{-1} due to low yields. The different proportions of removal of canavalia biomass had marked impact on the N balance. On average, when 0% of canavalia was removed from the field, N surplus was 29 kg N ha^{-1}. In contrast, complete removal of canavalia biomass led to an average N deficit of 6 kg N ha^{-1}. The M/B rotation showed an average N surplus of 15 kg N ha^{-1}, mainly due to the fact that output through bean grains was low.

Evaluation of accessions of Canavalia

Preliminary results are promising with some accessions (especially *Canavalia brasiliensis* CIAT 7972, 19038, 17462) showing higher soil cover and biomass production than the control *Canavalia brasiliensis* CIAT 17009 (Figures 30 and 31).

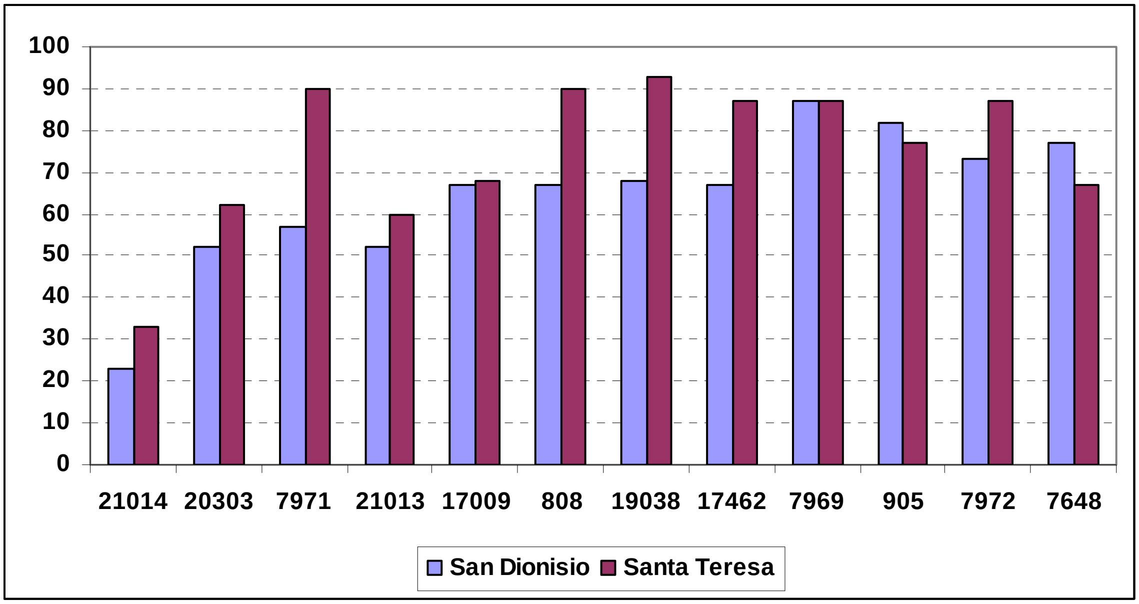


Figure 30. Soil cover (%) of different canavalia accessions

There were however considerable differences between the two sites, caused by different climatic and soil conditions. These GxE interactions will be described in detail in the final results of this research.

Outlook in 2010: The experiments will be continued by assessing subsequent maize production on the canavalia plots, in addition to the plots with 5 levels of N-fertilizer. Also, the most promising accessions will be planted in larger areas for further green manure and feeding trials.

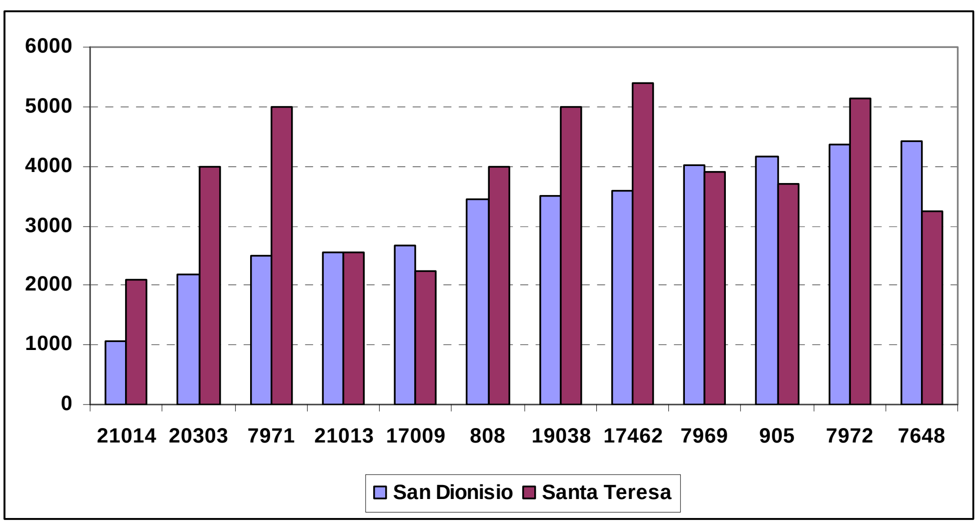


Figure 31. Dry matter biomass production (kg/ha) of different canavalia accessions

N dynamics on-station trial

Maize took up on average 1.0 g N m^{-2} from canavalia residues and 2.6 g N m^{-2} from mineral fertilizer, respectively, corresponding to N recovery of 12% and 32% from amendment. Most of the amendment N remained in the soil. Combined total ^{15}N recovery in maize and soil at harvest was highest for canavalia residues with 98%, followed by mineral fertilizer with 83% (Figure 32). These results show that canavalia residues represent a valuable source of N for the subsequent maize crop. A part of N in the residues is probably retained in specific soil organic matter fractions, and will slowly become available for crops with time.

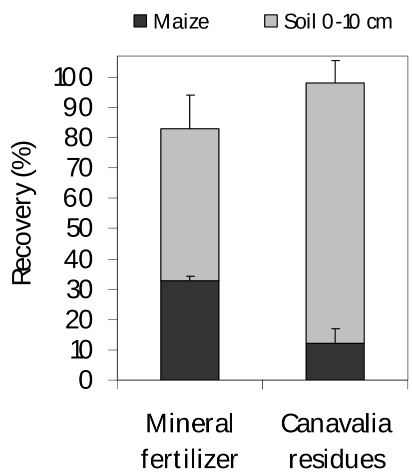


Figure 32. N recovery in maize and soil (0-10 cm) from mineral fertilizer and canavalia residues applied as amendments. Error bars represent the standard deviation (n=3).

Conclusions

Canavalia has the potential to improve the productivity of the crop-livestock system of the Central American hillsides. It can produce high amounts of biomass, makes substantial N input into the system, benefits the subsequent crop and improves milk yields. However, there are still knowledge gaps to be filled in order to be able to make the most of canavalia qualities. Indeed, farmers will most likely let cows graze canavalia during the dry season to increase milk production, which bears the risk of soil N depletion. There is potential for N recycling on the plot through animal manure, but management by farmers is needed and the fertilizer value of this manure needs to be studied. An option would be to leave canavalia regrowth during the dry season as green manure to mitigate soil N depletion. The question of the biophysical trade-offs of using canavalia as forage or as green manure still needs to be complemented with N budget studies for different rotational sequences over several years and with studies aiming at optimizing N use efficiency at farm level.

Farmers continue showing a clear interest in continuing with this new dry season forage/green manure legume technology. The focus for the coming year will therefore be on validation trials and on seed production with strong farmer involvement in the region, with a leading role for the Nicaraguan national agricultural research institute, INTA-Nicaragua.

3.6 Biological nitrification inhibition (BNI) in tropical grasses

Highlight

- New evidence is found for the existence and active regulation of a nitrification inhibitor (or inhibitors) release from tropical pasture root systems. Exploiting the biological nitrification inhibition (BNI) function could become a powerful strategy towards the development of low-nitrifying agronomic systems, benefitting both agriculture and the environment.

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

Contributors: M.P. Hurtado (CIAT), M. Rondón, (IDRC, Canada) I.M. Rao, M. Ishitani, D. Moreta, J. Miles and C.E. Lascano (CIAT), G.V. Subbarao, T. Ishikawa, T. Watanabe and O. Ito (JIRCAS, Japan)

Rationale

Globally, the doubling of agricultural production over the past four decades has been associated with a 7-fold increase in the use of nitrogen (N) fertilizers. It is widely recognized that less than 40% of the applied N fertilizer is recovered by the crops. The economic value of the "wasted N" is currently estimated as US$17 billion just from the cereal production systems alone. As a consequence of loss of N to leaching, surface runoff and nitrous oxide emissions, the current and future intensified use of N in agricultural systems will continue to have major detrimental effects on ecosystems and climate change. Nitrous oxide is a very potent greenhouse gas and its global warming potential is 296 times higher than that of carbon dioxide, and around 13 times higher than that of methane.

Nitrification is a key process in the global nitrogen cycle. It generates nitrate through microbial activity and could enhance losses of fertilizer N by leaching and denitrification. In the mid-1980s, CIAT researchers found that nitrification rates in grass.alone pastures planted with a widely adapted tropical grass, *Brachiaria humidicola*, were markedly lower than those observed under legume alone pastures or bare soil conditions. This phenomenon to suppress soil-nitrification by releasing inhibitors from roots of this tropical grass was later characterized and named by JIRCAS and CIAT researchers as "biological nitrification inhibition" (BNI).

Genetic variability for BNI has been observed for diverse accessions of *B. humidicola* and other tropical grasses under greenhouse conditions, as part of collaborative research between JIRCAS and CIAT. As a continuation of these research efforts, a long term field experiment was established at CIAT-Palmira with two main objectives: (i) to validate the phenomenon of BNI under field conditions; and (ii) to test the hypothesis that BNI is a cumulative factor in soils with forage grasses that release the BNI activity from root exudates. Given the vast areas that are currently under cultivation with tropical forage grasses, an understanding of the BNI process and the possibility of managing it to (i) improve N use efficiency, and (ii) reduce nitrate pollution of surface and ground waters as well as reduce net impact on global warming through reduced emissions of nitrous oxide, could have potentially global implications. Different tropical forage grasses with a varying degree of BNI activity were selected for the experiment and a soybean crop and a tropical grass (*P. maximum*) that lacks the BNI activity were also included as controls. Results from the past 5 years are summarized in this report.

Materials and Methods

A field experiment was established on August 30, 2004 and continued until November 2007 at CIAT (International Center for Tropical Agriculture) headquarters (3º 30'N, 76º 21'W) on a Vertisol (Typic Pellustert), pH 7.4, with an annual mean rainfall of about 1000 mm, annual mean temperature of 26 ºC, and an elevation of 965 m asl. The six treatments were: 1. *B. humidicola* reference/standard cultivar CIAT 679), 2. *B. humidicola* high BNI-activity germplasm accession CIAT 16888, 3. *Brachiaria* hybrid cv. Mulato (improved grass cultivar, intermediate level of BNI activity), 4. *Panicum maximum* (no/low-BNI activity from roots), 5. Soybean cv. ICAP 34 (stimulatory effect on *Nitrosomonas* activity from roots), and 6. control (bare soil, no plants). The experimental unit was a 100 m^2-plot. The treatments were replicated three times in a randomized complete block experimental design. For each soybean crop cycle, fertilizer was applied twice: for the first application (4 weeks after planting), plots were fertilized (kg ha^{-1}) with: 48 N, 48 K, 16 P, 0.4 Zn and 0.4 B and for the second application (8 weeks after planting) only N was applied at 48 kg ha^{-1}. The pasture grass plots and the bare soil plots also received the same amount of fertilizers at the same time. Pastures were cut twice a year, coinciding with the harvesting of the soybean crop. Weeds were controlled with glyphosate on the control plots and on the soybean plots before planting. During the soybean growing cycle weeds were controlled manually. For soil sampling to determine nitrification rates and N_2O emissions, and AOB (ammonia-oxidizing bacteria) and AOA (ammonia-oxidizing archaea) gene quantification, two 1 m^2 quadrants within each experimental unit were marked as permanently treated sampling subplots.

Soil sampling and determination of nitrification rates: To minimize spatial variability in applied N, the fertilizer was applied as ammonium sulfate solution in water to the sampling subplots. Three years after establishing the pastures (November 2007), soil samples were collected from sub-plots at 1 day and 30 days after fertilizer application. Five soil samples were collected with an auger from the top 10 cm soil layer in each subplot and then samples were pooled to obtain a composite sample for each experimental unit. The rhizo-plane soil (i.e., soil that is adhered to the roots) was manually separated from the bulk soil and used for the determination of nitrification rates. Quantification of AOB and AOA functional genes was carried out from the same rhizo-plane soil sample sets collected at one day after fertilization of subplots.

Nitrous oxide emission measurements in the field: Periodic measurements of nitrous oxide (N_2O) emissions from the sampling subplots were performed at monthly intervals from September 2004 to November 2007. When fertilizer was applied, gas sampling was done 1 day after application of fertilizer to the subplots using the static chamber technique. Four circular PCV collars were permanently installed at the beginning of the field study in each experimental unit. Prior to each gas sampling, cylindrical PVC chambers (0.03 m^2, 10 cm height) were clamped and air-tightly sealed to the collars. Air samples were then collected from each chamber at 0, 10, 20 and 30 min after chamber installation using 20 mL disposable syringes fitted with plastic stopcocks (Cole Palmer Instruments Co.). Samples were analyzed for N_2O on a gas chromatograph equipped with an electron capture detector (ECD). Nitrous oxide flux was determined from concentration plotted against time. The change in volumetric concentration was converted to a mass flux by using the ideal gas law, taking into account recorded changes in temperature within the chamber over the sampling interval. The results presented are the cumulative amounts of nitrous oxide expressed in mg N_2O-N m^{-2} y^{-1} from September 2004 to November 2007.

AOB and AOA gene quantification from field soil samples: AOB and AOA gene quantification was done by Real-Time PCR using the primer combinations amoA-1F/amoA-2R, amoA19F/ amoA643R, BACT1369F / PROK1541R and Arch20F / Arch958R for AOB *amoA* gene, AOA *amoA* gene, Bacteria SSU rRNA gene, and Archaea SSU rRNA gene, respectively. For molecular analysis, soil DNA from soil samples was isolated using the FastDNA® SPIN for soil kit (MP Biomedicals), quantified by fluorescence with the PicoGreen® dsDNA quantification reagent (Molecular Probes) and then electrophoresed into a

1% agarose gel to check its quality. Copy number of four target genes; i.e., Bacteria Small-Subunit (SSU) rRNA gene, ammonia-oxidizing bacteria (AOB) *amoA* gene, Archaea SSU rRNA, and ammonia-oxidizing archaea (AOA) *amoA* gene were quantified through Real-Time PCR using the specific primer combinations stated above. The *amoA* gene, which codifies for the active subunit of the ammonia mono-oxygenase enzyme, was used as a functional marker to determine the effect of the root exudates on the functional activity of AOB and AOA in terms of gene abundance into those populations.

The bacteria and archaea SSU rRNA genes were included in the analysis to track changes into the entire bacteria and archaea populations when subjected to the compounds released from roots, thereby determining the specificity of root exudates components (brachialactone) on the ammonia-oxidizing microorganisms. The SSU rRNA genes were also used to establish indirectly the AOB and AOA *amoA* genes predominance within total bacteria and archaea populations respectively. All target genes were quantified with the SYBR® Green I as a fluorescent dye. Real-Time PCR reactions were performed in triplicate in a 20 µl volume containing 20 ng soil DNA, 0.5 µM of each primer and 10 µl of Brilliant® SYBR® Green QPCR Master Mix (STRATAGENE). Non-template control (NTC) consisted of water instead of DNA. Cycling conditions were as follows: 1) 95ºC – 5 min; 2) 95ºC – 1.5 min; 3) 55ºC – 1.5 min; 4) 72ºC 1.5 min; 5) plate read; 6) incubate at 83ºC for 1 sec; 7) plate read; 8) go to step 2 for 40 more times; 9) melting curve from 65ºC to 95ºC, read every 0.2ºC, hold 1 sec; end product specificity was confirmed by melting curve analysis and visualization in agarose gels. Standards for quantification were made from a dilution series of a known amount of plasmid DNA (pGEM®-T Easy Vector System I, Invitrogen) containing the specific PCR product amplified from *Nitrosomonas europaea amoA* gene, soil AOA *amoA* gene, *E. coli* SSU rRNA gene, and soil archaea SSU rRNA gene using the primer sets mentioned earlier. Standard curves using plasmid DNA were generated over seven orders of magnitude ranging from 0.9×10^3 to 4.9×10^9 copies of template. Amplification efficiencies were between 70-93% with r^2 values between 0.981 and 0.997. All Real-Time PCR experiments were carried out in a DNA Engine OPTICON™2 Continuous Fluorescence Detector thermocycler (MJ Research) and analyzed with the MJ OPTICON Monitor ™ Analysis Software version 3 (BIO-RAD). Raw data (gene copy number per Real-Time PCR reaction) were corrected for soil gravimetric moisture content and then expressed as gene copy numbers g^{-1} dried soil by employing an algebraic standard operating procedure.

Results and Discussion

Field studies at CIAT, Palmira, Colombia indicated a 90% decline in soil ammonium oxidation rates (Figure 33) due to extremely small populations of nitrifiers [AOB (ammonia-oxidizing bacteria) and AOA (ammonia-oxidizing archaea)] (determined as *amoA* genes) in *B. humidicola* plots within three years of establishment (Figures 34a and 34b).

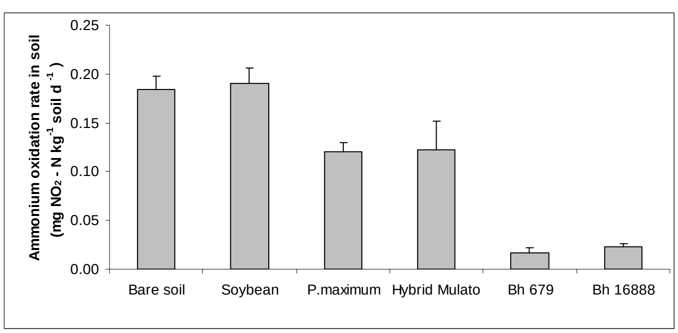
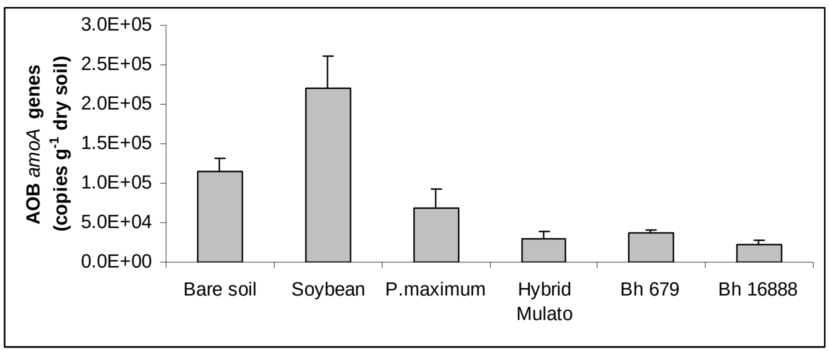
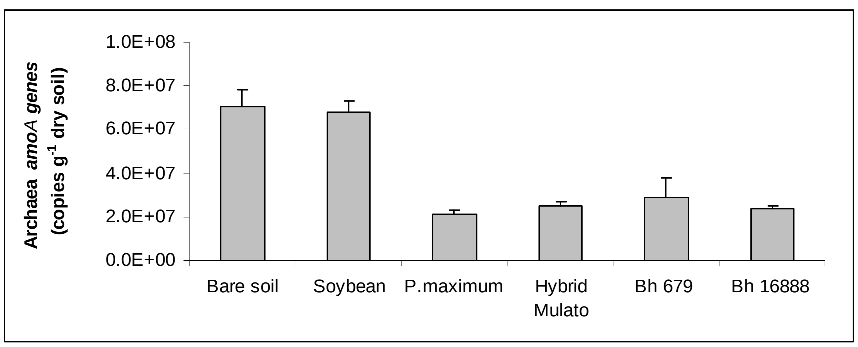


Figure 33. Soil ammonium oxidation rates in field plots planted with tropical pasture grasses and soybean [over 3 years from establishment of pastures (Sept. 2004 to Nov. 2007); for soybean two planting seasons every year and after six seasons of cultivation].

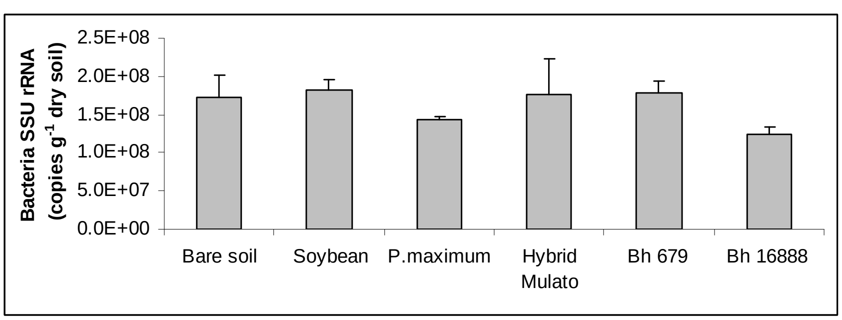
Ammonium nitrogen availability was relatively high across field plots during the experimental period of 2004 to 2007, suggesting that the extremely low nitrifier populations observed in *B. humidicola* plots should not be due to lack of soil ammonium nitrogen. There was little effect however on the total soil bacterial population (expressed as gene copy number) (Figure 34c), indicating the highly specific nature of the inhibitory effect towards the ammonia-oxidizing populations. Nevertheless, the archaea population in general is suppressed by *Brachiaria* sp. and *Panicum* sp. pastures (Figure 34d), indicating that inhibitors produced by the root systems of these pastures may not be entirely specific to ammonium-oxidizing archaea. Nitrous oxide emissions were also suppressed >90% in field plots of *B. humidicola* compared with plots of soybean, which lacks BNI capacity or control plots (plant-free field-plots) (Figure 35). Two other pasture grasses, *Brachiaria* spp. hybrid cv. Mulato and *P. maximum* that have a low to moderate level of BNI capacity (5 to 10 ATU g^{-1} root dwt d^{-1}), showed only an intermediate level of inhibitory effect on soil ammonium oxidation rates (Figure 35).



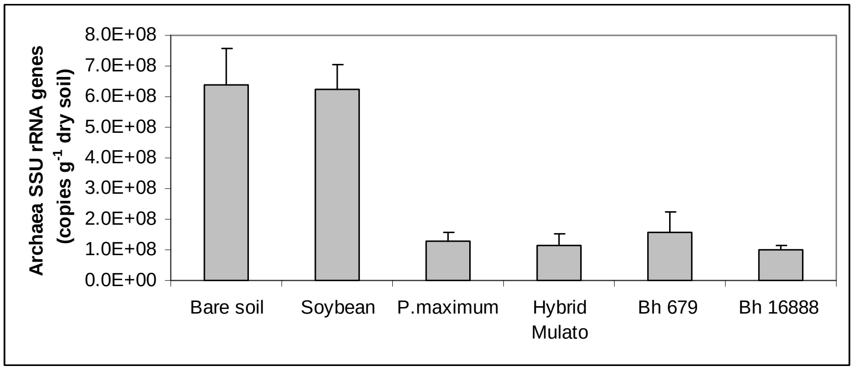
a. Copy number of AOB *amoA* genes



b. AOA *amoA* genes



c. Bacterial small-subunit (SSU) rRNA genes



d. Archaea SSU 16S rRNA genes

Figure 34. Influence of tropical pasture grass cultivation (in field plots, over 3 years: September 2004 to November 2007) on soil microorganism population at 1 day after ammonium sulfate fertilization

Nitrous oxide emission measurements in the field: Results on the behavior of the net fluxes of N_2O-N for the period from September 2004 to November 2007 showed significant differences (LSD, $p<0.001$) (Figure 35). The bare soil plot (with 417,4 mg N_2O-N m^{-2} y^{-1}) and soybean plot (with 394,4 mg N_2O-N 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-N, which were of 154,5 mg N_2O-N m^{-2} y^{-1} and 40,69 mg N_2O-N m^{-2} y^{-1} for CIAT 679 and CIAT 16888, respectively.

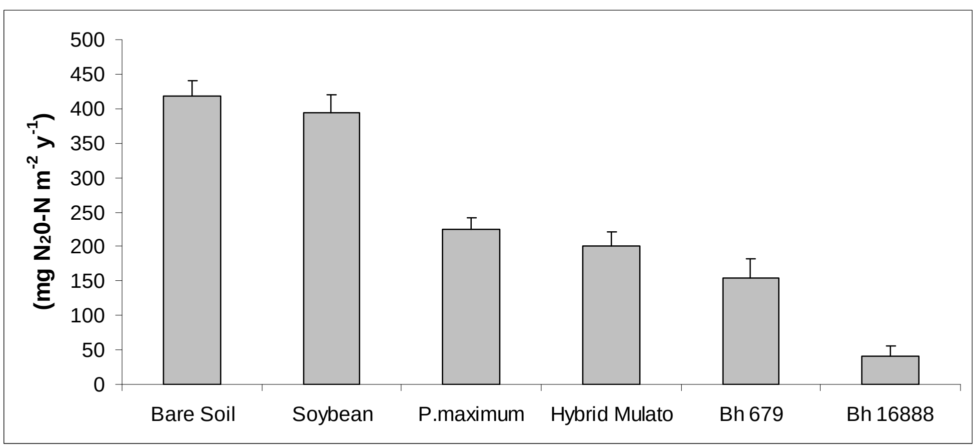


Figure 35. Cumulative nitrous oxide emissions (mg N_2O-N m^{-2} y^{-1}) from field plots of tropical pasture grasses (monitored monthly over a three year period, from Sept. 2004 to Nov. 2007). Bare soil = control (plant-free) plots; Soybean; *P. maximum*; *Brachiaria* hybrid Mulato; Bh 679 = *B. humidicola* CIAT 679 (standard cultivar); Bh 16888 = *B. humidicola* CIAT 16888 (a germplasm accession). Values are means $\pm$ SE.

Conclusions and future perspectives

Long-term collaborative research work between JIRCAS and CIAT resulted in the discovery of an effective nitrification inhibitor in the root-exudates of the tropical forage grass *Brachiaria humidicola*. Named 'brachialactone' by researchers from JIRCAS and NFRI, this inhibitor is a novel cyclic diterpene with a unique 5-8-5-membered ring system and a γ-lactone ring. It contributed 60 to 90% of the inhibitory activity released from the roots of this tropical grass. Release of brachialactone from roots is shown as a regulated plant function, triggered and sustained by the availability of ammonium in the root environment. Brachialactone release is restricted to only those roots that are directly exposed to ammonium in soil. These results provided new evidence for the existence of a plant-controlled mechanism where nitrification inhibitors are produced and delivered by roots to soil-nitrifier sites. This is the first time that a biological molecule providing a major portion of the BNI activity from *Brachiaria* root systems has been identified, characterized, and its release shown to be a tightly controlled physiological function. This solves nearly three decades of mystery surrounding the low nitrification rates found in *Brachiaria*-dominated tropical pastures.

Using a transdisciplinary approach that involved gene quantification and greenhouse gas measurements under field conditions, we demonstrated that within 3 years of establishment, *Brachiaria* pastures have suppressed soil nitrifier populations, along with nitrification and nitrous oxide emissions. Nitrous oxide emissions were suppressed >90% in field plots of *Brachiaria humidicola* CIAT 16888 compared with plots of soybean, which lacks BNI capacity or control plots (plant-free field-plots).

Our results suggest potential differences in N_2O emissions among plant species linked to their differential BNI capacities; however such differences are not presently considered by the Intergovernmental Panel on Climate Change in their estimations or projected N_2O emissions from agricultural systems. For example, South American savannas occupy about 250 million ha (Mha), largely under native grass or pastures of introduced *Brachiaria* spp. These could be of low nitrifying and low N_2O emitting systems. If these grasslands are converted to soybean and maize, crops that lack BNI capacity there could be major implications for N_2O emissions. About 11 Mha of pastoral land in the Cerrados region of Brazil have already been converted to soybean and maize, and an additional 35 to 40 Mha could suffer such conversion. Such land-use changes could have major consequences on N_2O emissions from this region.

Given the current environmental concerns it is desirable to develop new technologies and approaches for combating the rampant and rapid nitrification in agricultural systems and reduce N pollution and improve nitrogen use efficiency. Development of improved forage grasses for low nitrifying pasture-based production systems is possible given the significant genetic variability found for the BNI function within *Brachiaria* spp. A fundamental shift towards NH_4^+-dominated crop nutrition can be achieved by using crops and pastures that have high BNI capacity or integrating annual crop production with a high BNI-capacity forage component, will result in low-nitrifying agronomic production systems, benefiting both agriculture and the environment.[2]

[2] Subbarao, G. V.; Nakahara, K.; Hurtado, M. P.; Ono, H.; Moreta, D. E.; Salcedo, A. F.; Yoshihashi, A. T.; Ishikawa, T.; Ishitani, M.; Ohnishi-Kameyama, M.; Yoshida, M.; Rondon, M.; Rao, I. M.; Lascano, C. E.; Berry, W. L.; Ito, O., 2009, Evidence for biological nitrification inhibition in Brachiaria Pastures. *Proceedings of the National Academy of Sciences*, vol. 106, issue 41, pp. 17302-17307.

3.7 Participatory evaluation of *Brachiaria* grass options in Rwanda

Highlight

- Improved *Brachiaria* grasses were tested with participation of farmers in contrasting drought and acidic soil environments in Rwanda. In both environments, farmers have adopted the new forage alternatives by increasing the size of their plots and forming cooperatives to produce planting materials of the best bet *Brachiaria* options. The five *Brachiaria* options which had been selected by farmers for multiplication are *Brachiaria* hybrid cv. Mulato II, *B. brizantha* cv. Toledo and cv. Marandu, *Brachiaria* hybrid BRO2/1485 and *B. decumbens* cv. Basilisk. These grass options were chosen by farmers under both stress conditions because of their adaptability to drought and acid soils and producing high forage biomass throughout the year. The *Brachiaria* options are now replacing the commonly used forage grass (Napier), e.g., on erosion control ridges.

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

Rationale

Shortage of animal feed is a major constraint for livestock development in Rwanda. Growing grasses of non-improved forage species and lack of appropriate technologies to manage natural resources contribute to the problem of fodder shortage for smallholder farmers in Rwanda. The deficiency in both quality and quantity of feeds has arisen from shrinking pasture lands, poor quality of both natural and commercialized feeds, water shortage and limited use of crop by-products. Agriculture in Rwanda, including Bugesera and Nyamagabe districts, is based on smallholder mixed crop-livestock farming systems with land holdings of ≤ 0.76 hectare for the majority of farmers. To address this issue, the Rwanda Agricultural Research Institute (ISAR) in collaboration with the International Center for Tropical Agriculture (CIAT) is evaluating *Brachiaria* grass options with farmer participation in contrasting drought (Bugesera district) and acidic soil (Nyamagabe district) environments in Rwanda. This work is part of a BMZ-GTZ, Germany funded project "Fighting drought and aluminium toxicity: Integrating functional genomics, phenotypic screening and participatory evaluation with farmers to develop stress-resistant common bean and *Brachiaria* for the tropics". This report summerizes progress from two major activities carried out in 2009: (i) monitoring and evaluation of farmer early adoption of the new *Brachiaria* varieties and hybrids; and b) facilitating farmers who have *Brachiaria* to form a cooperative based on production of *Brachiaria* planting material. A comprehensive final assessment of the results from four years of work on participatory evaluation of improved *Brachiaria* grass options in Rwanda will be made during 2010.

Materials and Methods

To continue the work with already established farmer groups that were exposed to *Brachiaria* grass options, a survey on the early adoption by farmers was carried out. This survey started by asking farmers who have established *Brachiaria* grass the area that he/she has extended this new forage option. From there, farmers indicated to new farmers that acquired planting materials of *Brachiaria* grass and also to their neighbours.

Results

In the drought (Bugesera) conditions and acidic soils (Nyamagabe), monitoring and evaluation of early adoption of the new *Brachiaria* grass options showed the following: Among farmers who established *Brachiaria* grass in the acidic soil area, 41.6% of them increased the size of plot to 0.04 ha per farm (Photo 22). In the drought area, 66.6% of farmers who had *Brachiaria* grass increased their plot up to 0.1 ha per farm (Photo 23).

Photo 22. Selected *Brachiaria* grass cultivars (cv. Marandu, cv. Mulato 2) were multiplied on a large plot by the farmer Halerimana Theoneste in Nyamagabe district (acid soils).

Photo 23. Selected *Brachiaria* grass cultivars (cv. Mulato 2, cv. Basilisk) were multiplied on a large plot by the farmer Tumushime Monique in Bugesera district (drought prone).

During the assessment of farmers who adopted *Brachiaria* grass, it was observed that in the drought area, some farmers came and took planting material from their neighbors without prior consultation. This has been a constraint to define exactly the number of the new *Brachiaria* adopters. This situation was similar in the acidic soil area where new farmers could acquire *Brachiaria* grass without asking to the owners. However, five farmers who got *Brachiaria* without asking the owner in the acidic soil area, have been identified and visited; all of these planted the new forage options on erosion control bounds (Photo24).

Photo 24. *B. brizantha* cv. Toledo planted on contour ridges between crops in acidic soil area.

Employing the knowledge obtained with the evaluation of *Brachiaria* grasses, a number of farmers in both districts formed cooperatives with the objective of multiplying and selling planting material of *Brachiaria*. In Bugesera district (drought area), the established cooperative has 15 members. It is called "Cooperative of crop-livestock owners aiming at multiplying *Brachiaria* grass in Bugesera (KOABBU: acronym in local language)". This cooperative has multiplied *Brachiaria* hybrid Mulato 2, cv. Toledo, hybrid BRO2/1485 and cv. Marandu on 0.35 ha.

In the acidic soil area (Nyamagabe district), the cooperative formed has 12 members. It is named "Cooperative of growers of *Brachiaria* of Nyamagabe (KOABNYA: acronym in local language)". This cooperative has started to multiply *Brachiaria* hybrid cv. Mulato 2, cv. Basilisk, cv. Toledo and cv. Marandu on a plot of 0.4 ha (Photo 25) with the aim to increase it by the next cropping season (March-April 2010).

Photo 25. Large plot of *Brachiaria* grass of the cooperative KOABNYA.

Conclusions

Monitoring and evaluation of *Brachiaria* grass options in the contrasting environments of Rwanda has enhanced the awareness of smallholder farmers about new forage alternatives in both drought prone and acidic soil environments.. The interest of farmers for *Brachiaria* is increasing as reflected by replacement of the commonly used forage grass (Napier) by *Brachiaria* on erosion control ridges. At the same time farmer cooperatives are set up based on multiplying *Brachiaria* planting material for feeding their animals and selling fodder to other dairy farmers so as to generate income. Marketing of this product remains to be a challenge. Efforts are directed towards organizing study tours and training farmers in different districts for scaling up of *Brachiaria* technology for wider adoption.

3.8 Dissemination and facilitation of communication through the forage web site

Contributors: M. Peters, E. Hesse, J.M. Burbano and B. Hincapie (CIAT)

The CIAT forage web site integrates information from different sources with the aim to improve dissemination of result of tropical forage research to research institutes, partners, donors, development practitioners and farmers.

The general objectives are:

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

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

Since the end of 2009 a new design is implemented that includes dynamical participation through blogs (Photo 26). Attached links to a number of blogs published between 2009 and early 2010 http://ciatlibrary.blogspot.com.

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

- Consult general information about the program
- Provides contacts of different forage experts
- Consult the forages database
- Browse the catalog of electronic and printed products
- Download PDF files containing publications and documents

- Access additional information, such as staff list, links to partners and donors.

Photo 26. Screen of the forages web site home and page of products.

Figure 36 shows the number of visits to the web site between January and December 2009, differentiated for the English and Spanish versions and number of documents downloaded. A total of 664,589 hits were recorded in the English version and 183,378 for the Spanish version, with an average of 55,382 and 15,282 hits per month, respectively.

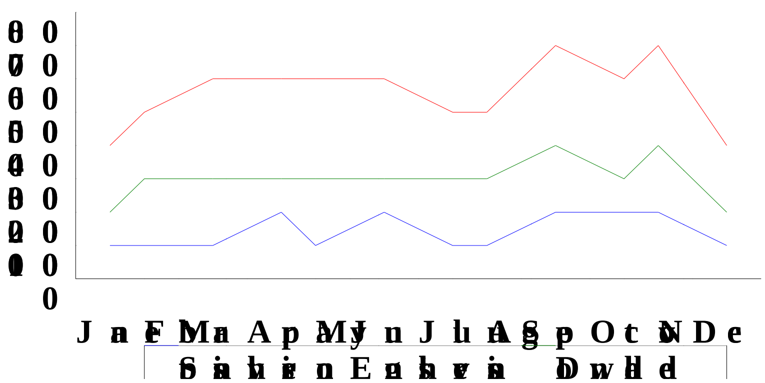


Figure 36. Number of visits to the forage web sites and document downloaded.

In Table 70 downloads of documents from the forage web page are shown, with a total of 363,349 documents downloaded in 2009.

Table 70. Download of documents from Tropical Forages Web site (January to December, 2009)

Downloads	Number
Technical Bulletin: Pasto Toledo (*Brachiaria brizantha* CIAT 26110)	70,636
News: Efecto Mezcla Leguminosas	59,728
Journal: Pasturas Tropicales	42,341
Book: Evaluación Agronómica de Pastos Tropicales	37,750
Working Document: Annual Report	37,151
Technical Bulletin: Cultivar Mulato II	30,825
Technical Bulletin: Cultivar Veranera (*Cratylia argentea* (Desvaux) O. Kuntze)	23,529
Technical Bulletin: Producción artesanal de semillas de Pasto Toledo	17,741
Others	43,648

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

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

In one knowledge system (SoFT – Selection of Forages for the Tropics) much of the accumulated information on species adaptation, its use and management of the last 50 years from across the tropical world is brought together, with information sourced from scientific literature, the plethora of reports, and from unpublished information gleaned directly from agronomists with extensive tropical experience. A comprehensive bibliography and information/fact sheet written for each material of forage in the database is included for an interactive query.
In July 2005 the Selection of forages for the tropics (SoFT) web site was launched in collaboration with CSIRO, QDPI, ILRI and the University of Hohenheim; it can be accessed under URL http//:www.tropicalforages.info.

Since then, the site has been very well accepted by users around the world, with 154,044 in the year 2008, and 202,251 in the year 2009, which equals to on average 12,837 and 15,828 pages visited per month (Fig. 39a). Currently the site is most frequented by users from Australia, Brazil, Mexico, Indonesia, and Colombia in the descending order (Fig. 39b). However. there are also frequent visits recorded from countries in Latin America (e.g., Paraguay, Argentina, Bolivia and Nicaragua), Asia (e.g., Malaysia and Thailand) and Sub-Saharan Africa (e.g., South Africa). Notable is that users include not only research and governmental but also a high number of Non Profit organizations and educational establishments.

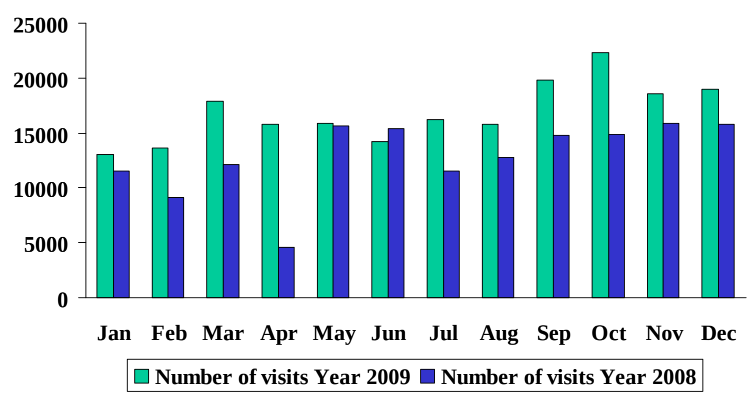


Figure 37a. Visits to the SoFT web site, January to December 2008 and 2009,

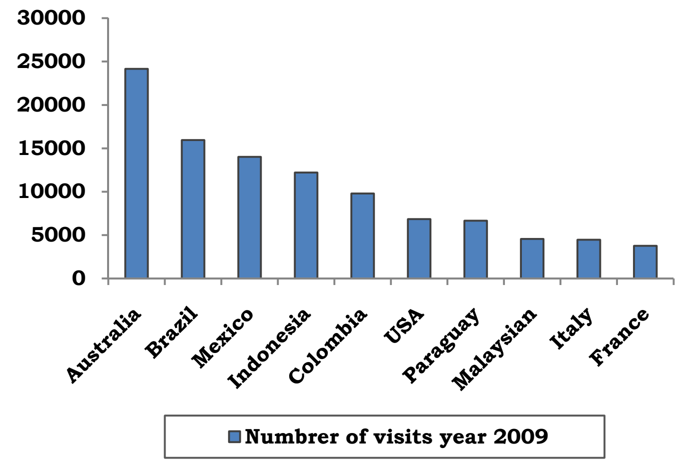


Figure 37b. Number of visits to the SoFT web site of the country more frequently between January and December 2009.

3.10 Agreement with CENIPALMA

Contributors: E. M. Garzón, D. L. Molina (CENIPALMA), M. Peters, L. H. Franco (CIAT)

Rationale

There is an increased interest in oil palm production in Colombia, partly due to the intensification of use as biofuel. As part of an agreement with CENIPALMA, the Colombian research institution responsible for palm tree research, in an effort to make production environmentally more friendly and economically more productive, a range of forage soil covers are evaluated.

Materials and Methods

In 2009 three trials were established in oil palm plantations in three zones of Colombia used for oil palm production: Magdalena Medio (Barrancabermeja), Costa Atlántica (Fundación) and the Llanos. An additional site will be established in the Pacific region (Tumaco), where wheather conditions impeded establishment in 2009.

Soil covers are planted under and between plantations to control erosion and protect the native fauna. 14 herbaceous legumes were established:

Canavalia brasiliensis CIAT 17009, CIAT 17462, *Canavalia* sp. CIAT 20303, *Pueraria phaseoloides* CIAT 7182, *Desmodium heterocarpon* supsp. ovalifolium CIAT 13651 cv Maquenque, , *Chamaecrista rotundifolia* CIAT 8990, *Lablab purpureus* CIAT 22759, *Centrosema molle* CIAT 15160, , *Mucuna pruriens* CIAT 9349, *Tadehagi triquetrum* CIAT 21958, *Calopogonium mucunoides* CIAT 9450, Control CENIPALMA (*Desmodium heterocarpon subsp. ovalifolium* CIAT 350)
The shrubby legumes . *Desmodium velutinum* CIAT 23996 and *Dendrolobium triangulare* CIAT 23935 were added

For the shrub legumes at borders and between fields the following species were established *Cratylia argentea* cv. Veranera, *Flemingia macrophylla* CIAT 21241, 17407, *Desmodium velutinum* CIAT 13218, *Cajanus cajan* CIAT 18701 and *Dendrolobium triangulare* CIAT 13710.

In addition to the trials, various training events were held with CENIPALMA technicians involved in the trials, with subjects such as establishment, agronomic evaluation, and artisanal seed production. To extend findings and knowledge additional presentation and additional training were carried out with institutions such as Universidad de Sucre and for technicians and farmers in collaboration with the Universidad de Caldas, ASEVEZ (a Producers Association) and Solla (a private feed enterprise).

Annex

List of publications 2009

Articles in refereed journals

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Calles, T. and R. Schultze-Kraft 2009. Una nueva especie venezolana de *Stylosanthes* (Leguminosae: Papilionoideae: Dalbergieae). Acta Botanica Venezuelica 32(1): 153-157.

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Herrero, M., P. K. Thornton, A. M. Notenbaert, S. Wood, S. Msangi, H. A. Freeman, D. Bossio, J. Dixon, M. Peters, J. van de Steeg, J. Lynam, P. Parthasarathy Rao, S. Macmillan, B. Gerard, J. McDermott, C. Seré, and M. Rosegrant. 2010. Smart investments in sustainable food production: revisiting mixed crop-livestock systems. Science 327, 822-825.

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Subbarao, G. V., K. Nakahara, M. P. Hurtado, H. Ono, D. E. Moreta, A. F. Salcedo, A. T. Yoshihashi, T. Ishikawa, M. Ishitani, M. Ohnishi-Kameyama, M. Yoshida, M. Rondon, I. M. Rao, C. E. Lascano, W. L. Berry and O. Ito. 2009. Evidence for biological nitrification inhibition in *Brachiaria* pastures. Proceedings of the National Academy of Sciences (USA) 106: 17302-17307.

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Rao, I. M. 2009. Essential plant nutrients and their functions. Working Document No. 209, CIAT, Cali, Colombia pp. 37.

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Martens, S. and J. F. Abello. (2009). A first screening of LAB strains as inoculants for tropical legume silages. In: Broderick, G. A., Adesogan, A. T., Bocher, L. W., Bolsen, K. K., Contreras-Govea, F. E.. Harrison, J. H. and Muck, R. E. (eds.) Proceedings of the XVth International Silage Conference, July 27-29. Madison, Wisconsin, USA. p. 269-270.
Martens, S., C.E. Lascano, P. Avila, L.H. Franco, B. Hincapie, M. Peters. 2009. Improving Milk Yield with *Canavalia brasiliensis*. In: Tielkes, E. (ed.) Tropentag 2009 International Research on Food Security, Natural Resource Management and Rural Development: Biophysical and socio-economic frame conditions for the sustainable management of natural resources. Book of Abstracts, p. 289. http://www.tropentag.de/

Sanabria, A. M., J. F. Abello and S. D. Martens. 2009. Protocol for total DNA extraction from tropical silages in preparation for 16S rRNA analysis for microbial community characterization. In: Broderick, G. A., Adesogan, A. T., Bocher, L. W., Bolsen, K. K., Contreras-Govea, F. E., Harrison, J. H. and Muck, R. E. (eds.) Proceedings of the XVth International Silage Conference, July 27-29. Madison, Wisconsin, USA. p. 457-458.

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Other Publications

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Douxchamps, S., E. Frossard, C. Binder, M. Kreuzer, M. Mena, A. Mosimann, I. M. Rao, A. Schmidt, R. Scholl, R. van der Hoek and A. Oberson. 2010. Realizing the benefits of cover crop legumes in smallholder crop-livestock systems in the hillsides of Central America – a case study with *Canavalia brasiliensis*. Poster paper presented at ISDA conference, Montpellier, France.

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Moreta, D. E., M. P. Hurtado, A. F. Salcedo, L. Chávez, M. Rondón, M. C. Duque, G. Subbarao, O. Ito, J. Miles, C. Lascano, I. Rao and M. Ishitani. 2009. Biological Nitrification Inhibition as a Novel Approach for Enhancing Nitrogen Use Efficiency in Crops. Poster paper presented at 7th ISRR Symposium ‘Root Research and Applications’(RootRAP), September 2-4, Vienna, Austria.

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Rincón, J., J. Polania, V. Hoyos, J. Ricaurte, R, García, J. Miles and I. M. Rao. 2009. Evaluación y selección de gramíneas tropicales con adaptación a sequía y exceso de agua. Paper presented at the International Seminar on Climate Change and Livestock Systems. March 24-25, 2009, CORPOICA, Bogota, Colombia.

Subbarao, G. V., T. Ishikawa, K. Nakahara, T. Watanabe, I. M. Rao, M. P. Hurtado, M. Rondon, D. Moreta, M. Ishitani and O. Ito. 2009. Biological Nitrification Inhibition (BNI) – A New Approach to Control Nitrification and N_2O emissions from Agricultural Systems?

Paper presented at the conference on the “Environmental Impacts of Carbon and Nitrogen Cycles in Terrestrial Ecosystems in East Asia", September 7-11, 2009, Nanjing, China.

Wagatsuma, T., A. Ishikawa, N. Ueki, M. S. H. Khan, I. M. Rao, P. Wenzl, M. Ishitani, H. Koyama, T. Toyomasu, M. Yamaguchi, S. Ishikawa and K. Tawaraya. 2009. Making aluminum tolerant-plants by modifying plasma membrane lipid layer of root-tip cells. Paper presented at the Annual Meeting of the Japanese Society for Soil Science and Plant Nutrition. September 15-17, 2009. Kyoto University, Japan.

Capacity Building (Training)

BS Theses

Name	Status	University	Title
Aguirre B., Lina María	On-going	Universidad del Valle, Cali, Colombia	Mechanisms of resistance to adult feeding damage in *Brachiaria* spp.
Latorre, Michael	On-going	Universidad del Valle, Cali, Colombia	Morphological, pathogenic and molecular characterization of isolates of *Rhizoctonia* spp. obtained from *Brachiaria* spp. with foliar blight
Martinez M., Carlos Augusto	Completed	Universidad del Cauca, Popayán, Colombia	Evaluación fenológica y caracterización morfológica de *Tadehagi* spp.
Uehlinger, Noémi	On-going	ETH, Zurich	Realizing the benefits of cover crop legumes in smallholder crop-livestock systems of the hillsides of Central America
Valencia, Lina	On-going	Universidad de Caldas, Manizales Colombia	Characterization of *Xanthomonas* spp. isolates causing bacterial wilt on *Brachiaria*

MS Theses

Name	Status	University	Title
Ceron F., Claudia Lorena	On-going	Universidad Nacional de Colombia, Palmira, Colombia	Evaluación agronómica y valor nutricional de 8 accesiones de *Tadehagi* spp en suelos ácidos del Norte del Cauca
Mosimann, Anna	On-going	ETH, Zurich	Application of the Structured Mental Model Approach (SMMA) to analyze the sustainability of a new cultivation and livestock feeding method in Nicaragua
Torres Jaramillo, Julieta	Completed	Universidad Nacional de Colombia, Sede Palmira, Colombia	Tropical grain legumes as alternatives to soybean meal for small producers of monogastric animals in the tropics
Mutimura, Mupenzi	On going	University of KwaZulu-Natal/ Pietermaritzburg Campus/ South Africa	On-farm evaluation of *Brachiaria* grass options in Rwanda
Heinritz, Sonia	On-going	University of Hohenheim, Germany	Ensiling suitability of high protein tropical forage and their digestibility in pigs

PhD Theses

Name	Status	University	Title
Cardoso Arango, Juan Andrés	On-going	Universidad de Granada, Spain	Abiotic stress adaptation in forage grasses and legumes
Castro, Aracely	On-going	Universidad Nacional de Colombia, Palmira, Colombia	Nutrient dynamics in the Quesungual slash and mulch agroforestry system
Douxchamps, Sabine	On going	ETH-Zurich, Switzerland	Effect of *Canavalia brasiliensis* on the nitrogen supply to the traditional maize-bean system in Nicaragua
Ipaz, Sandro	On-going	Universidad Nacional de Colombia, Palmira, Colombia	Diagnóstico y caracterización del sellamiento y encostramiento en molisoles y vertisoles bajo sistemas de producción tradicional y agricultura agrosostenible en el Valle del Cauca
Louw-Gaume, Annabé	Completed	ETH-Zurich, Switzerland	Adaptation of *Brachiaria* grasses to low P soils
Noguera, Diana Cristina	On-going	Université Paris VI Pierre et Marie Curie	Interacciones de la tierra y las lombrices y análisis de sus efectos sobre el crecimiento y la fisiología de las plantas
Reiber, Christoph	On going	University of Hohenheim, Germany	Encouraging adoption of research-based offerings with contrasting extension approaches
Burkart, Stefan	On going	University of Hohenheim, Germany	Performance and reputation analysis of organizations: Measuring stakeholder perceptions and priorities to improve value chains of forages, chickens and pigs in Nicaragua and Colombia

List of Donors

Australia - ACIAR

Forage legumes for supplementing village pigs in Lao PDR. 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. Use of legumes in low input systems (ULLIS), KEF Commission for Development Studies at the Austrian Academy of Sciences. (NARS: INTA; University UNA, ARI: BOKU)

Africa - IWMI

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

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

Brasil, EMBRAPA –CGIAR

Soil quality monitoring system

Colombia – CORPOICA – Nicaragua - INTA

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

Colombia – MADR – IICA -FEDEGAN

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

Colombia - 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.

Germany - BMZ

Demand-Driven Use of Forages in Fragile, Long Dry Season Environments of Central America to Improve Livelihoods of Smallholders.

PostDoc proposal Understanding and Catalyzing Learning Selection processes, BMZ, (NARS: DICTA; ARI: University of Hohenheim, CG: ILRI).

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

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

Germany – CIM

Forage Conservation and Feed Systems for Monogastrics

Germany - Volkswagen Foundation

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

Italy - FAO

Translation of Soft into Spanish

Italy - IFAD

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

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

Brachiaria Improvement Program

Netherlands - CFC

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

Switzerland ZIL - ETH

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**.

United States - North Carolina State University

Adoption of the Nutrient Management Support System (NuMass) Software Throughout Latin America.

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