AGBIO4:

Tropical Forages Program

ANNUAL REPORT
2010

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Tropical Forages Program

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

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AGBIO4: Tropical Forages Program

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Tropical Forages Program. AGBIO4. Annual Report 2010.
Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia 215 p.

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

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

Highlight

- One hundred eighty preselected 2009 hybrids were advanced to progeny test to identify true apomicts.

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

1.1.1 Generate open-pollinated (OP) progenies of several hundred preselected BR09 plants and conduct progeny trial to assess reproductive mode of the mother plants. Identify apomicts and begin assessing commercial potential

Highlight

- Of 180 selections advanced, 168 (93.3%) were identified as apomictic, demonstrating the effectiveness of screening the seedling hybrid population generated in 2009 on a molecular marker of apomixis.

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

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. These were evaluated in field trials during 2009 to identify promising individual plants.

Materials and Methods

A testcross population of 6,856 individuals was generated in early 2009. Following screening with a molecular marker of apomixis, 3,156 individuals were identified as putatively apomictic. Following observation in field trials during 2009, 524 hybrids were "pre-selected" on general agronomic merit. Inflorescences of these plants were bagged and OP seed recovered. Following heavy culling on seed set, progenies of 180 hybrids (and seven check entries) were established in the 2010 progeny trial, each entry in four replicates of 5-plant plots.

Results and Discussion

One hundred sixty-eight of the 180 test hybrids (93.3%) were classed as apomicts (or facultative apomicts).

Seed was harvested from 148 of the apomictic hybrids (and seven check entries) by bagging inflorescences. Seed set, on a weight:weight basis, was determined. Seed set estimates ranged from 0.02 to 0.33. The better hybrids had higher seed set than any of the commercial checks (cv. Marandu, 0.23; cv. Toledo, 0.13; cv. Piatã, 0.20; cv. Basilisk, 0.22; cv. Mulato II, 0.28). The hybrids, in general, were earlier to flower and set seed than any of the commercial checks.

Apomictic hybrids have been propagated to the greenhouse. They will be multiplied vegetatively for assessment for reaction to various biotic (spittlebugs, *Rhizoctonia* foliar blight [RFB]) and abiotic (flooding, aluminum) stresses. Forage quality (crude protein and in vitro digestibility) is being assessed on plant material sampled directly from the field progeny trial.

1.1.2 By the same progeny test, assess value of SCAR N14 in distinguishing between apomictic and sexual plants in hybrid population

Highlight

- The proportion of apomictic hybrids identified among the 180 progeny-tested was far in excess of the 50% expected for an unselected SX x AP hybrid population, demonstrating the effectiveness of our molecular marker of apomixis.

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

Rationale

Culling on an effective marker of apomixis applied to a sexual-by-apomictic seedling population should increase the proportion of apomicts from 50% expected in an unselected SX x AP hybrid population to something approaching 100%, depending on the tightness of linkage between the marker and the "apolocus".

Materials and Methods

A testcross population of 6,856 individuals was generated in early 2009. Leaf tissue was sampled from small seedlings and assessed for presence/absence of a SCAR marker derived from RAPD N14, identified in CIAT's BRU in 1995. One hundred eighty of the 3,156 hybrids showing the marker were selected from 2009 field trials and progeny-tested during 2010. Presumably, these 180 selections, with regards to reproductive mode, are a random sample of the population remaining following culling on N14.

Results and Discussion

Of the 180 hybrids that were progeny-tested in 2010, 168 (93.3%) were classified as apomicts. This far in excess of the 50% expected with an unselected SX x AP hybrid population, demonstrating the effectiveness of culling the original hybrid population on the molecular marker of apomixis. Whether this cull on the molecular marker was also efficient remains to be determined by a careful accounting of all benefits and costs.

1.1.3 Harvest first seed increase of promising apomictic progenies

Highlight

- Seed was harvested from 20 plants of each of 148 apomictic hybrids and seven check entries.

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

Rationale

Seed is the convenient vehicle to distribute new apomictic hybrid genotypes for advanced agronomic evaluation by our private sector research and development partners. The initial progeny test to assess reproductive mode and identify apomictic hybrids serves the double purpose of generating tens or hundreds of grams of seed for this purpose.

Materials and Methods

At flowering, reproductive tillers are tied into "living sheaves" and inflorescences bagged with light-weight mesh bags. Seeds fall in the bag as they ripen. Detached seed is collected from the bags. A "pre-processing" weight of crude seed is taken, followed by processing (density separation in a wind column) to eliminate empty spikelets. Full spikelets (i.e., "pure" seed) are then weighed.

Results and Discussion

Seed yields for 148 selected hybrids ranged from 20.9 to 894.7 grams (mean: 254.7) (from a maximum of 20 plants in four 5-plant plots).

Seed set and seed yield were highly correlated ($r = 0.82$). A severe cull -- at least 50% -- will be imposed based on seed production.

1.1.4 Reconstitute the synthetic sexual tetraploid breeding population from selected sexual (SX08) clones

Highlight

- Thirty-seven selected SX08 clones were recombined in an isolated crossing block to produce an improved version of the synthetic sexual tetraploid breeding population.

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

Rationale

The rationale for recurrent selection in a sexual breeding population is that each cycle will improve the population's genetics, i.e., it's potential to produce superior apomictic hybrids on crossing with one or more appropriate apomictic pollen parents.

Materials and Methods

Thirty-seven SX08 clones were finally selected for recombination, based mainly on the performance of testcross progenies, but also on their *per se* reaction to spittlebugs. These were propagated four (or three) times each and a 144-plant crossing block was set up in 8-in pots, in an isolated field location. OP seed was hand-harvested as it matured from individual plants. Seed is currently (11 November 2010) being processed.

Results and Discussion

Although there were some differences among the 37 clones in their earliness to flower, all plants eventually did flower and seed was harvested. A rough estimate of seed fill will be obtained. The progenies of particular clones may be culled if consistently low fertility is detected. We only need to generate sufficient seed to produce 700-800 seedlings in early 2011.

1.2 *Brachiaria* breeding: Spittlebug resistance

Highlight

- A total of 92 *Brachiaria* genotypes have been screened for their reaction to two life stages (nymphs and adults) of four spittlebug species each so far in 2010. This represents a total of 2,856 experimental units (not counting check entries).

1.2.1 Screen 84 SX08 clones for reaction to nymphs and adults of three spittlebug species and to RFB; cull prior to recombination to form SX11

Highlight

- Eighty-four SX08 selections were assessed for their reactions to two life stages of each of four spittlebug species.

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

Rationale

An assumption of selection on testcross performance is that the merit of a genotype can best be assessed by the performance on its progeny. However, in order to maintain or increase the high levels of spittlebug resistance already achieved in our sexual breeding population, prudence dictates *per se* evaluation of selected sexual clones to allow culling of any susceptible ones.

Materials and Methods

SX08 clones were culled from an original 708 to 175 based on *per se* seed set and number of testcross progenies obtained. The respective 175 testcross families were included in the 2009 field trials. Based on testcross performance, an additional 91 SX08 clones were culled, leaving 84. These were assessed, in replicated greenhouse tests, for reaction to spittlebug nymphs and adults.

Results and Discussion

Most of the sexual SX08 clones showed good resistance to spittlebug nymphs, though a few were identified for culling on this trait. The results for spittlebug adults were markedly different, with susceptibility being quite common, a not very surprising result given the lack of correlation between reaction to spittlebug nymphs or adults (Cardona et al. 2010) and that no attention whatsoever had been given to tolerance to spittlebug adult feeding prior to this selection cycle. An attempt was made to retain the few clones that showed somewhat better tolerance to adult feeding, more or less consistently across insect species.

1.2.2 Continue screening *B. humidicola* "base germplasm" (13 hybrids, plus 19 accessions) for reaction to nymphs and adults

Highlight

- Large differences in reaction to spittlebugs were found in a small "base germplasm" set of *B. humidicola*.

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

Rationale

An important objective in any *B. humidicola* breeding strategy will be resistance to spittlebugs. Hence, an assessment of the genetic variation in our "base germplasm" set will indicate the potential for achieving this breeding objective.

Materials and Methods

Standard methods for spittlebug evaluations were employed.

Results and Discussion

Consistent differences among *B. humidicola* genotypes were observed for reaction to spittlebug nymphs and adults. In general, ranking of genotypes was similar among spittlebug species for each life stage. Much less consistency was observed for rankings of resistance between life stages (nymphs or adults). The single sexually-reproducing *B. humidicola* germplasm accession (CIAT 26146), which was the female parent of all the original hybrids, was among the most susceptible of the set of genotypes.

1.2.3 Screen second-cycle, hybrid-derived B. humidicola selections (See sections 1.5.2, and 1.5.3)

Highlight

- Moderate levels of resistance to spittlebugs was detected in sets of sexual or apomictic, hybrid-derived *B. humidicola* genotypes without prior history of selection for spittlebug resistance.

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

Rationale

Larger and genetically more broad-based sets of hybrid-derived *B. humidicola* genotypes are beginning to be characterized as to reproductive mode (See sections 1.7.2, and 1.7.3) and advanced, either to an OP crossing block (sexual genotypes) or initial seed multiplication for further testing. Reaction to spittlebugs will be an important criterion of selection for both sexual and apomictic selections.

Materials and Methods

An initial *B. humidicola* progeny trial (See sections 1.7.2, and 1.7.3) yielded a set of 18 putative sexual clones and 74 promising apomicts. These were propagated vegatatively and are being assessed for reaction to spittlebug nymphs and adults.

Results and Discussion

These evaluations are currently (09 November 2010) underway.

1.2.4 Begin screening BR09 selections for reaction to spittlebugs

Highlight

- Following a cull on seed set/seed yield, we will be left with approx. 50-70 BR09 selections still of possible interest for commercial release. These will need to be characterized for various traits, including reaction to spittlebug nymphs and adults.

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

Rationale

Promising BR09 apomictic hybrids need to be screened for reaction to common biotic and abiotic stresses, including spittlebugs.

Materials and Methods

Standard screening methodologies will be employed. These evaluations will commence early in 2011.

Results and Discussion

No results to date (09 November 2010).

1.3 *Brachiaria* breeding: *Rhizoctonia* foliar blight (RFB) resistance

Highlight

- Improved screening methodology continues to give consistent and reliable results.

Contributors: E. Álvarez; X. Bonilla; G. Sotelo; A. Betancourt; F. Pizarro; J.W. Miles (CIAT)

Rationale

RFB can cause large losses of forage under weather conditions favorable to disease development (high humidity and rainfall) on susceptible host genotypes. The most effective and viable control strategy will be based on host-plant resistance.

1.3.1 Screen 84 SX08 clones for reaction to RFB; cull prior to recombination to form SX11

Highlight

- Most of our hybrid-derived *B. ruziziensis*/*B. decumbens*/*B. brizantha* materials, including both sexual and apomictic genotypes, are very susceptible to RFB. Variation among SX08 genotypes in reaction to RFB was detected, though only a few clones were marginally better than the majority.

Contributors: Álvarez, E.; Bonilla, X.; Sotelo, G.; Betancourt, A.; Pizarro, F.; Miles, J.W. (CIAT)

Rationale

Owing to the lack until recently of a reliable screening methodology, we were unable to assess host-plant reaction to RFB. Recent methodological advances have opened new opportunities to deal genetically with this important disease.

Materials and Methods

Standard methodology was used, with individual propagules grown in small PVC tubes and the above-ground portion of each plant enclosed in a plastic drinking water bottle. Following artificial inoculation with mycelium-infected agar disks, disease severity was scored on a 1-5 visual scale.

Results and Discussion

The most RFB-resistant check accession (*B. brizantha* CIAT 16320) received a mean score of 1.87 (on the 1-5 visual scale. None of the 84 SX08 entries showed equal resistance, but five entries had mean scores less than 3.0, compared with an overall average of the sexual clones of 3.55.

1.3.2 Evaluate recombined, OP progeny of sexual parental clones selected on *Rhizoctonia* resistance or on waterlogging tolerance

Highlight

- A small parallel selection exercise will seek to produce sexual genotypes with high levels of tolerance to both waterlogging and to RFB by selecting only on these two criteria.

Contributors: Rao, I.M.; Rincón, J.; Cardoso, J.A.; Álvarez, E.; Bonilla, X.; Sotelo, G.; Betancourt, A.; Pizarro, F.; Miles, J.W. (CIAT)

Rationale

Owing to our previous inability reliably to assess host plant reaction to waterlogging and RFB, nearly all of our hybrid-derived germplasm is highly susceptible to these two stresses. Apparent genetic differences can be detected among tetraploid sexual genotypes. Intense selection focused only on these two criteria should quickly lead to improved resistance or tolerance, which can subsequently be introgressed into our main sexual breeding population.

Separate sexual populations were initiated for RFB or for waterlogging. These were subsequently merged into a single, sexually-reproducing population selected simultaneously on both criteria.

Materials and Methods

Two hundred thirty-three SX05 genotypes were screened for tolerance to waterlogging in 2006. Only six genotypes were selected and recombined in 2008. These produced over 500 OP progenies, which were screened for waterlogging tolerance early in 2009. Twenty genotypes selected and recombined in 2009.

In 2008, 81 putatively sexual clones derived from crosses made several years earlier with the highly RFB-resistant *B. brizantha* CIAT 16320 were assessed for RFB-reaction in early 2009. The 12 least susceptible genotypes were identified. These were progeny-tested to assure that all were fully sexual. Three of the 12 showed more or less apomictic reproduction and were discarded. Nine clones were recombined in 2009.

In 2010, the two populations were merged. OP progenies of the two 2009 crossing blocks were assessed for reaction to both waterlogging and RFB. Twenty clones were selected for recombination during 2010, based simultaneously on the two criteria by a simple, rank-sum criterion. An isolated crossing block was set up recently and is only just beginning to flower (11 November 2010).

Results and Discussion

It appears that useful genetic variation for both criteria exist in the germplasm under selection. However, the final outcome of this exercise will only become evident following several selection cycles. It seems that we can comfortably complete a full selection/recombination cycle within a single calendar year.

1.3.3 Assess viability of improving RFB resistance by selection. - Select best individuals and recombine

Highlight

- A parallel selection program was initiated focusing exclusively on resistance to RFB.

Contributors: Álvarez, E.; Bonilla, X.; Sotelo, G.; Betancourt, A.; Pizarro, F.; Miles, J.W. (CIAT)

Rationale

RFB is an important production limitation on *Brachiaria* pastures under humid conditions. Nearly all of our hybrid-derived germplasm (*B. ruziziensis*/*B. decumbens*/*B. brizantha*) is highly susceptible. Given the variation in reaction observed to date, focused selection should quickly lead to much greater levels of resistance, which can then be introgressed into our mainstream breeding population.

Materials and Methods

Thirteen clones were selected strictly on reaction to RFB from the recombined progenies of the 2009 RFB crossing block (see section 1.3.2). These were vegetatively propagated and are in an isolated crossing block at present (10 November 2010).

Results and Discussion

Initial results and the future potential of this very focused selection project ought to become evident when the progeny of the recently-established crossing block are assessed for RFB reaction in 2011.

1.3.4 Begin screening BR09 selections for reaction to RFB

Highlight

- Following a cull on seed set/seed yield, we will be left with approx. 50-70 BR09 selections still of possible interest for commercial release. These will need to be characterized for various traits, including RFB.

Contributors: Álvarez, E.; Bonilla, X.; Sotelo, G.; Betancourt, A.; Pizarro, F.; Miles, J.W. (CIAT)

Rationale

New apomictic *Brachiaria* hybrids under consideration for commercial release will require characterization for their reaction to RFB.

Materials and Methods

This screening will not commence until early 2011.

Results and Discussion

There are not results to report to date (10 November 2010).

1.4 *Brachiaria* breeding: Waterlogging tolerance

Highlight

- Improved screening methodology allows rapid and reliable assessment of tolerance to waterlogging. Large differences in tolerance are observed even among our "*ruziziensis/decumbens/brizantha*" breeding germplasm

Contributors: Rao, I.M.; Rincón, J.; Cardoso, J.A.; Betancourt, A.; Pizarro, F.; Miles, J.W. (CIAT)

Rationale

Several of the currently important commercial cultivars of *Brachiaria brizantha* do not tolerate prolonged flooding. Observed within-species difference in tolerance (e.g., cv. Toledo is much more tolerant than cv. Marandu) suggest that rigorous selection in our sexual breeding population could effect an improvement in this trait.

1.4.1 Screen SX08 clones for reaction to waterlogging; cull prior to recombination to form SX11

Highlight

- Large differences in tolerance to waterlogging were observed among 84 SX08 genotypes.

Contributors: Rao, I.M.; Rincón, J.; Cardoso, J.A.; Betancourt, A.; Pizarro, F. (CIAT)

Rationale

The ability of pasture plants to withstand prolonged flooding is useful in many parts of the Tropics. Efficient screening methodology has been developed.

Materials and Methods

Eighty-four SX08 genotypes (from our synthetic sexual breeding population) were propagated and established in plastic pots. When plants were well established, flooding conditions were imposed. Genotype response was assessed on several traits: Green leaf biomass; green leaf area; total chlorophyll content; visual score of plant condition.

Results and Discussion

Green leaf biomass of the 84 sexual clones ranged from 0.57 to 4.34 gm/plant. The best sexual clones performed better -- i.e., produced greater green leaf biomass under flooded conditions -- than the two *B. brizantha* commercial cultivar checks.

Literature cited:

Cardona, C., J.W. Miles, E. Zúñiga, and G. Sotelo. 2010. Independence of resistance in *Brachiaria* spp. to nymphs or to adult spittlebugs (Hemiptera: Cercopidae): implications for breeding for resistance. J. Econ. Entomol. 103(5): 1860-1865.

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

Highlight

- Two hundred sixty hybrid-derived individual plants representing a broad diversity of *B. humidicola* 2n=36 germplasm were progeny-tested. Both sexual and apomictic individuals were tentatively identified based on the relative uniformity of their OP progenies.

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

Rationale

We are attempting to synthesize a fully sexual, broad based breeding population from the genetic diversity represented in CIAT's collection of 2n=36 *B. humidicola* accessions (See previous Annual Reports).

Materials and Methods

OP seed was harvested from individual plants in the segregating progenies of a 2008 progeny trial. At least some proportion of these plants ought to be sexual, which will be identified by the morphological segregation among individual siblings within their progenies.

Results and Discussion

Plants identified as sexual will be propagated to one or more isolated crossing blocks for recombination.

1.5.1 Establish field progeny trial of 400 hybrid mother plants

Highlight

- A total of 260 hybrid-derived clones were progeny-tested. Both sexual and apomictic clones were tentatively identified

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

Rationale

A fully sexual, broad-based *B. humidicola* breeding population will be useful in future breeding work with this species.

Materials and Methods

Seed was germinated in two sets of progenies in 2010. Progenies of single plants were transplanted to the field in 5-plant plots with from one to four replications. The reproductive mode of mother plants was inferred by the relative uniformity or segregation among siblings within progenies. Two sets, of 146 or 114 progenies, were established in sequential field trials during 2010.

Results and Discussion

The progeny trial was established, by transplanting seedling to field plots, in two phases. The first phase trial has been terminated; the second phase is still under observation, but will be terminated before year's end.

1.5.2 Identify sexual mother plants and recombine to form tetraploid sexual *B. humidicola* breeding population

Highlight

- A total of 49 apparently sexually-reproducing, hybrid-derived clones have been identified.

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

Rationale

A fully sexual, broad-based *B. humidicola* breeding population will be useful in future breeding work with this species.

Materials and Methods

OP seed from a total of 260 hybrid-derived clones in a 2008 progeny trial conducted at CIAT-Quilichao was germinated in two sets (of 146 or 114 progenies) to produce progeny seedlings. These were transplanted to two field trials conducted sequentially at CIAT-Palmira. The relative uniformity or segregation among siblings within progenies was visually assessed to score the respective mother clones of the progenies as sexual (segregating) or apomictic (uniform). Some progenies appeared to be facultative apomicts; others were impossible to classify owing to too few individual siblings obtained.

Results and Discussion

A total of 49 apparently sexually-reproducing, hybrid-derived clones have been identified.

Only 18 putatively sexually-derived progenies were identified in the first set of 146 progenies. This is far fewer than the expected 50% based on an assumption of single factor inheritance of reproductive mode as reported for this germplasm by Zorzatto et al. (2010). However, Zorzatto et al. were working with a single, bi-parental hybrid population and this may explain the divergent results. It is still unclear why this 2n=36 *B. humidicola* germplasm is apparently behaving differently from other apomictic tropical forage grasses, where reproductive mode appears to be conditioned by a single, dominant Mendelian factor (see e.g., Miles 2007).

Thirty-one clones in the second phase of this progeny trial have, to date (10 November 2010), very tentatively been classified as sexual. If the classification to date is accurate, this is a higher proportion of sexuals than were found in the set of first phase progenies (~12.3% vs,
~27.2%).

The 18 clones identified in the first phase of the progeny trial have already been propagated and an isolated crossing block, established, in mid-June 2010. A second crossing block including the putative sexual clones identified in the second phase of the progeny trial can be established, probably before year's end.
When OP seed has been harvested from these two crossing blocks, the clones included will have to be progeny-tested once again to confirm that they are behaving as true sexuals. Then, a definitive selection of sexual clones can be recombined to synthesize the desired broad-based, sexually-reproducing *B. humidicola* breeding population.

The second phase of this progeny test is still on-going (10 November 2010), but it should be possible to conclude by year's end.

1.5.3 Identify strongly apomictic mother plants and begin to evaluate for possible commercial release

Highlight

- Seventy-four apparently apomictic, hybrid-derived clones with desirable agronomic attributes have been propagated vegetatively to establish small plots at CIAT-Popayán for further observation and initial seed increase.

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

Rationale

Many novel apomictic *B. humidicola* genotypes have been generated in the process of developing a broad-based sexual breeding population. Some of these may have commercial potential.

Materials and Methods

Progeny trials (See Sections 1.7.1 and 1.7.2) have allowed identification of apomictic clones as well as sexual ones. From the first phase of the progeny trial, 74 apparently apomictic clones have been propagated to establish un-replicated small plots (approx. 2 x 2 m) at CIAT-Popayán for further observation and initial seed increase for possible further agronomic testing.

Results and Discussion

A diversity of growth habits is evident among the 74 genotypes advanced. Whether these are advanced further will depend on seed setting behavior and reaction to spittlebugs.

Literature cited:

Miles, J.W. 2007. Apomixis for cultivar development in tropical forage grasses. Crop Sci. 47(S3):S238-S249.

Zorzatto, C., L. Chiari, G. de Araujo Bitencourt, C. B. do Valle, G. O. de Campos Leguizamon, I . Schuster, M. S. Pagliarini. 2010. Identification of a molecular marker linked to apomixis in Brachiaria humidicola (Poaceae). Plant Breeding First published online 04 March 2010. DOI: 10.1111/j.1439-0523.2010.01763.x

1.6 Identify sexual and apomictic *Brachiaria* hybrids with resistance/tolerance to major biotic and abiotic constraints and with high forage quality attributes

Highlights

- Field evaluation of 18 *Brachiaria* genotypes identified a group of four apomictic *Brachiaria* hybrids (BR02NO/1752, BR04NO/2069, BR06NO/2020, BR02NO/1372) and one sexual hybrid (SX03NO/0881) as superior performers during dry season and two cultivars (*B. brizantha* CIAT 6294 and *B. decumbens* CIAT 606) and 5 hybrids (BR04NO/2069, BR06NO/1932, BR05NO/0334, BR06NO/0204 and BR02NO/1752) as superior performers during rainy season under low fertility acid soil conditions in Quilichao, Colombia.

- Field evaluation of 11 *Brachiaria* genotypes identified a group of three *Brachiaria* hybrids (CIAT 36087=cv Mulato II, BR02NO/1794 and BR02NO/1752), and one cultivar (*B. brizantha* CIAT 6294= cv Marandú) as superior performers during both rainy and dry seasons under low fertility acid soil conditions of a farm near Puerto López in the Llanos region of Colombia.
- Greenhouse evaluation for drought resistance of 84 hybrids from the sexual series (SX08) along with 10 checks identified five sexual hybrids (SX08/0282, SX08/0716, SX08/0641, SX08/ 0103 and SX08/0748) as outstanding in their green leaf biomass production under drought stress.
- Evaluation of 66 germplasm accessions of *B. humidicola* along with 7 checks for their tolerance to waterlogging stress identified four *Brachiaria humidicola* (CIAT 16873, CIAT 6133, CIAT 26371 and CIAT 6707) germplasm accessions that were superior to the other genotypes in their tolerance to waterlogging. Three plant attributes (green leaf biomass, leaf chlorophyll content and green leaf biomass proportion to total leaf biomass) were identified as selection criteria for evaluating waterlogging tolerance in *Brachiaria*.
- Evaluation of 84 sexual hybrids of *Brachiaria* from SX08 series along with 9 checks for their tolerance to waterlogging identified four sexual hybrids (SX08NO/320, SX08NO/849, SX08NO/900 and SX08NO/466) as superior than the other sexual hybrids in their tolerance to waterlogging based on green leaf biomass proportion to total leaf biomass. Visual evaluation can be used to eliminate large number of hybrids from a breeding population.
- Evaluation of 209 sexual hybrids of *Brachiaria* from INRZ10NO series along with 9 checks for their tolerance to waterlogging identified four sexual hybrids (INRZ10NO/116, INRZ10NO/16, INRZ10NO/55 and INRZ10NO/40) as superior than the other sexual hybrids based on green leaf biomass proportion to total leaf biomass.
- Studies conducted to characterize aerenchyma formation as a mechanism of waterlogging tolerance in *Brachiaria humidicola* accessions indicated that aerenchyma is formed constitutively in *B. humidicola*. The capacity to increase the proportional area of aerenchyma together with the reduction in the relative proportion of stele under waterlogged conditions could be of adaptive advantage at the onset as well as during waterlogged conditions

1.6.1 Identify sexual and apomictic *Brachiaria* hybrids with resistance/tolerance to major abiotic constraints

1.6.1.1 Field evaluation of promising hybrids of *Brachiaria* in an Oxisol at Santander de Quilichao, Colombia

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

Rationale

Field evaluation of several *Brachiaria* hybrids under infertile acid soil conditions in the Llanos of Colombia has shown that low or high amounts of initial application of fertilizer, and application of maintenance fertilizer with half of the amounts of initial applications at 2 year intervals, improved the persistence of several hybrids. However this approach did not allow for distinguishing differences between moderately adapted cultivars (cv. Marandu) and the promising hybrids. Therefore a field experiment was established in May 2009 using 14 hybrids, 3 parents and 1check. The trial was established with low amounts of initial application of fertilizer with no maintenance fertilizer application.

The objective was to select hybrids that persist and produce green forage under acid infertile soil conditions. In August 2009, we tested the performance of these hybrids in the dry season at 3 months after establishment. The same group of genotypes was evaluated in January 2010 in the rainy season at 8 months after establishment.

Materials and Methods

A field trial was established at CIAT Quilichao station in May of 2009. Soil chemical characteristics showed low pH, low level of available phosphorus (P), moderate level of exchangeable potassium (K), low level of exchangeable calcium (Ca) and magnesium (Mg), and high level of exchangeable aluminum (Al) with high Al saturation up to 40 cm of soil depth (Table 1). Climatic conditions during the dry season and rainy season are shown in Figure 1. A field view of the trial during the dry season and rainy season is shown in Photo 1. The trial included three parents (*B. decumbens* CIAT 606, *B. brizantha* CIAT 6294 and *B.ruziziensis* 44-02) of the *Brachiaria* breeding program, 14 *Brachiaria* hybrids (BR02NO/1372; BR02NO/1752; BR04NO/2069; BR05NO/0334; BR05NO/0563; BR06NO/0012; BR06NO/0204; BR06NO/0531; BR06NO/1000; BR06NO/1454; BR06 NO/1932; BR06NO/1949; BR06NO/2020 and SX03NO/0881), and one CIAT check (CIAT 36087- Mulato II).

Table 1. Soil chemical characteristics (pH, available P (Bray II), exchangeable K, Ca, Mg, and Al and Al saturation) of a field site with an Oxisol in Santander de Quilichao, Colombia

Soil depth cm	pH	P ($\mu g\ g^{-1}$)	K	Ca	Mg	Al	Al saturation (%)
			---------------(cmol$_c$ kg^{-1})----------------------				
0-5	4.35	5.8	0.203	2.014	0.740	4.633	61.1
5-10	4.35	3.2	0.171	1.795	0.656	4.517	63.4
10-20	4.37	2.2	0.395	1.755	0.530	4.683	63.8
20-40	4.44	1.5	0.087	1.004	0.336	4.383	75.1

The trial was planted as a randomized block with 4 replications. Only a low level of initial fertilizer application was applied (kg/ha of 20P, 20K, 33Ca, 14 Mg, 10S) at the time of establishment. Maintenance fertilizer was not scheduled for application in order to identify genotypes that are better adapted to infertile acid soil conditions. The plot size was 4 m x 3 m (6 rows with a row-to-row spacing of 0.5 m and with a plant-to-plant spacing of 0.5 m). A number of plant attributes including forage yield, dry matter distribution, root biomass, root length, mean root diameter, specific root length, nutrient (N and P) uptake in living shoot biomass, chlorophyll content (SPAD chlorophyll meter reading), quantum yield of photosynthesis, and stomatal conductance were measured in the dry season at 3 months after establishment (August 2009) and at the end of rainy season at 8 months after establishment (January 2010). Root attributes were evaluated only using 9 selected genotypes.

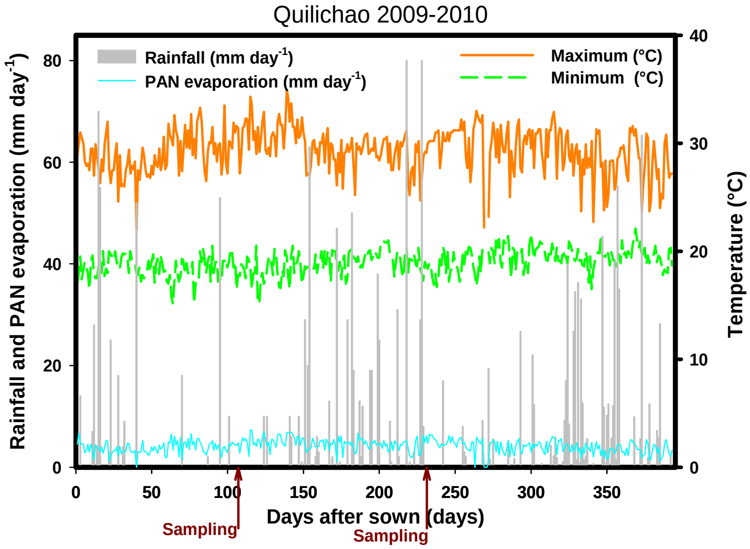


Figure 1. Climatic conditions at Santander de Quilichao, Colombia, during the evaluation of 18 genotypes of *Brachiaria* for adaptation to an Oxisol with low nutrient supply. The arrows indicate the sampling moments for dry (3 months after establishment) and rainy (8 months after establishment) seasons.

Photo 1. A field view of the trial during dry season (13 August 2009) and rainy season (5 January 2010) that included the evaluation of 18 genotypes of *Brachiaria* in an oxisol at Santander de Quilichao, Colombia.

Results and Discussion

After 3 months of establishment the apomictic hybrids BR02NO/1752, BR04NO/2069, BR06NO/2020, BR02NO/1372 and the sexual SX03NO/0881 showed greater amounts of living shoot biomass (Figure 2). As expected, canopy temperature was significantly lower in rainy season than during the dry season. The degree of leaf wilting symptoms were less during intensive dry period with *B.ruziziensis* 44-02 compared with BR06NO/0012 < BR05NO/0563 < BR06NO/1454 < BR06NO/0531= *B. brizantha* CIAT 6294 < BR02NO/1372. It is important to note that BR02NO/1372 and BR06 NO/1454 maintained higher living shoot biomass with low root biomass system. Two hybrids (BR06NO/0531 and BR06NO/0012) showed greater root system vigor that contributed to greater canopy temperature depression during the dry season (Figures 3 and 4). In contrast to these two hybrids, three hybrids (BR06NO/1454, SX03NO/0881 and BR02NO/1752) and one of the parents, *B. brizantha* CIAT 6294 also showed greater values of canopy temperature depression with less vigorous root system (Figures 3 and 4).

The overall root vigor was greater with BR06NO/0012 and BR06NO/0531 during both dry and rainy seasons with greater distribution of roots in the top soil layers (0-10 cm depth, Figure 3). As expected, the Al^{+3} sensitive sexual parent *B.ruziziensis* 44-02 showed limited root growth and distribution across the soil profile. But one of the sexual hybrids, SX03NO/0881 showed greater root growth under a highly Al saturated Oxisol.

As expected, during the rainy season, at 8 months of establishment of the experiment, a greater shoot and root biomass production was observed (Figures 2 y 3).

During rainy season two parents (*B. brizantha* CIAT 6294 and *B. decumbens* CIAT 606) were outstanding in shoot living biomass production followed by five hybrids, BR04NO/2069, BR06NO/1932, BR05NO/0334, BR06NO/0204 and BR02NO/1752 hybrids. BR06NO/0531and Mulato II hybrids showed greater root biomass and root length (Figure 3). Mulato II hybrid developed a thicker root system (based on mean root diameter values) and showed an increase in canopy temperature compared with the ambient temperature in the dry season while it showed some level of canopy temperature depression in the rainy season (Figure 4). The increase in canopy temperature exhibited by some genotypes is not common in most crop plants and indicates the ability of some genotypes to close stomata and reduce the evaporative demand. A thicker root system was observed in older plants during rainy season (0.549 mm of average root diameter) compared with rainy season (0.485 mm) probably due to a greater availability of photosynthates for root growth during the rainy season.

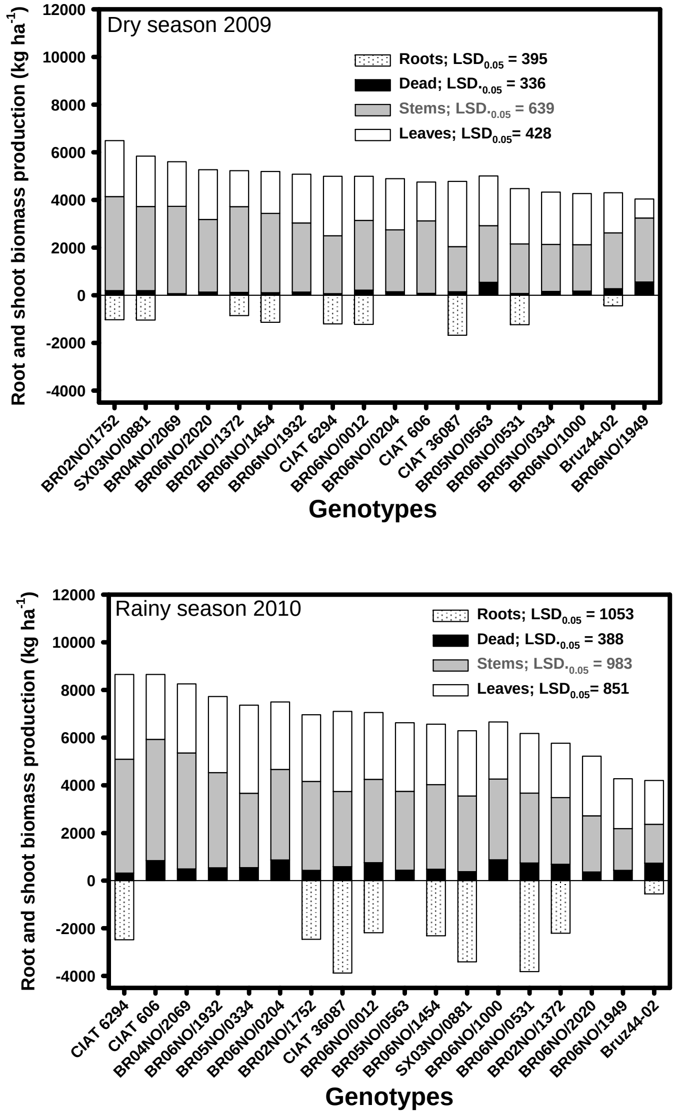


Figure 2. Genotypic variation in root and shoot biomass production (forage yield) and root biomass of 9 selected genotypes of *Brachiaria* out of 18 grown in an oxisol at Santander de Quilichao, Colombia. Plant attributes were measured at 3 and 8 months after establishment (August 2009 and January 2010). LSD values are at the 0.05 probability level.

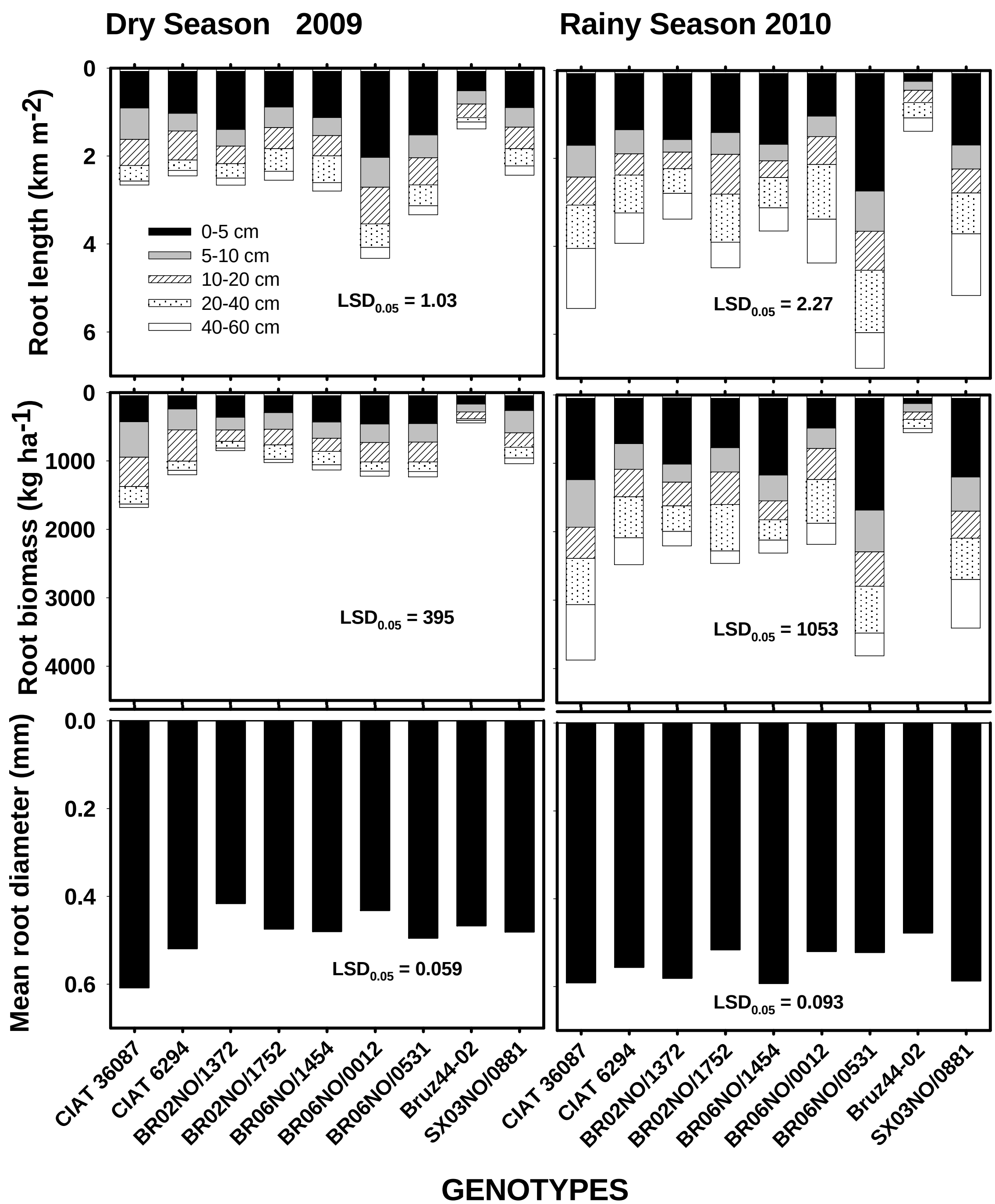


Figure 3. Genotypic variation in root length, root biomass production and mean root diameter of 9 selected genotypes of *Brachiaria* out of 18 grown in an oxisol at Santander de Quilichao, Colombia. Plant attributes were measured at 3 and 8 months after establishment (August 2009 and January 2010). LSD values are at the 0.05 probability level.

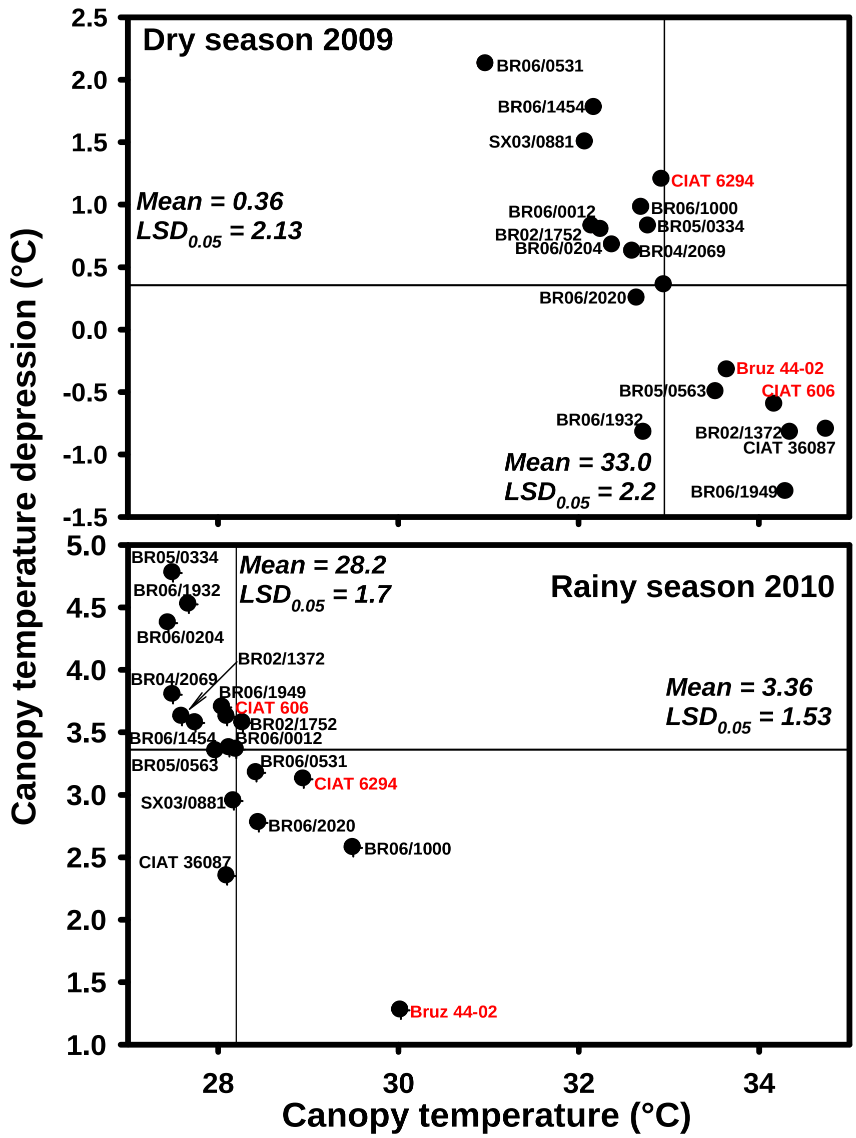


Figure 4. Genotypic variation in canopy temperature and canopy temperature depression of 18 genotypes *Brachiaria* grown in an oxisol at Santander de Quilichao, Colombia. Plant attributes were measured at 3 and 8 months after establishment (August 2009 and January 2010). LSD values are at the 0.05 probability level.

Shoot P uptake in living biomass was greater in rainy season than in dry season. The opposite happened with shoot N uptake (Figure 5). A more extensive root system could explain the greater P uptake in rainy season while greater mineralization and leaching of N might have contributed to less N uptake in rainy season. Greater N and P uptake was observed with two hybrids (BR06NO/2020, BR06NO/0204) and N uptake in *B.ruziziensis* 44-02 parent in dry season. This sexual parent had the lowest amount of P uptake in shoot biomass in dry and rainy seasons, probably due to its more limited root system that limited the acquisition of a less mobile nutrient such as P (Table 1). Greater values of shoot N and P uptake were observed with *B. decumbens* CIAT 606 and *B. brizantha* CIAT 6294, followed by BR05NO/0334 hybrid in rainy season.

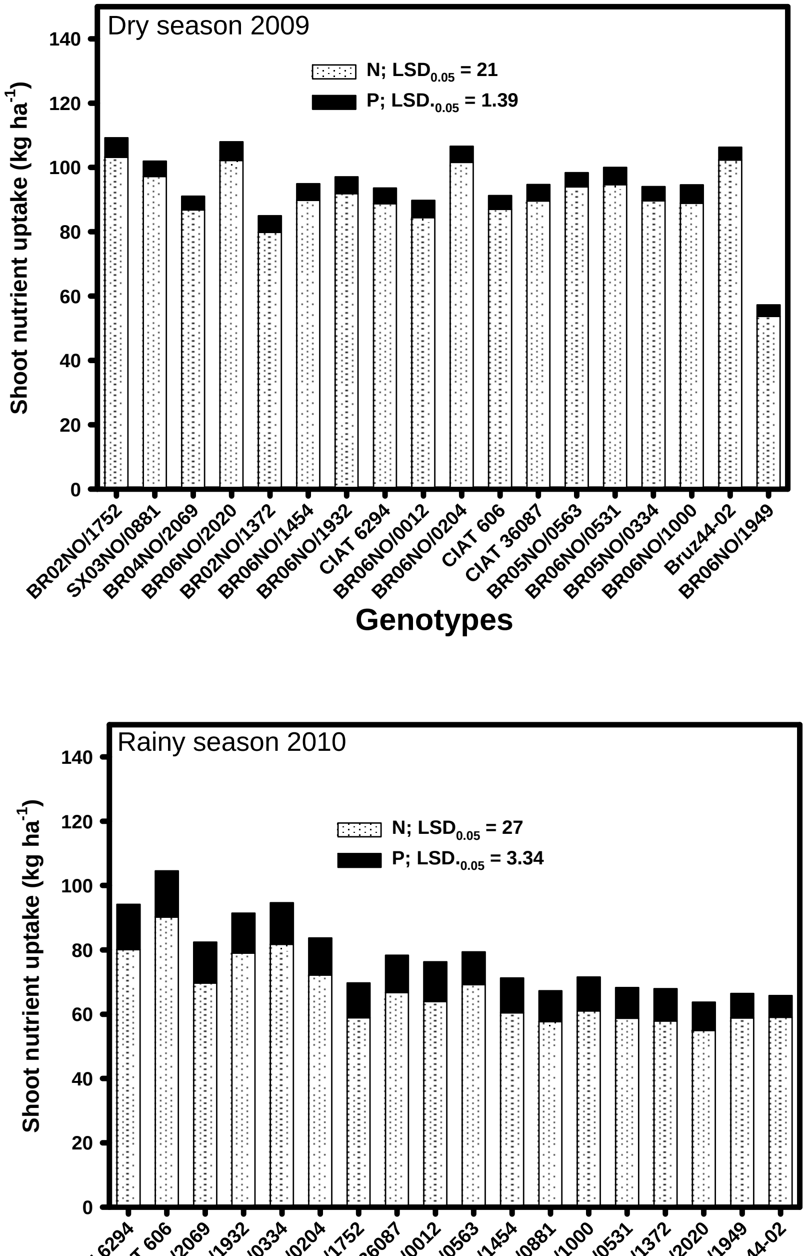


Figure 5. Genotypic variation in nitrogen (N) and phosphorus (P) uptake of 18 genotypes of *Brachiaria* grown in an oxisol at Santander de Quilichao, Colombia. Plant attributes were measured at 3 months after establishment (August 2009). LSD values are at the 0.05 probability level. NS = not significant.

Results on correlation coefficients indicated significant positive association between green forage yield (living shoot biomass) and a number of plant attributes including leaf biomass, stem biomass, shoot N uptake and shoot P uptake in both dry and rainy seasons (Table 2). Root biomass and root length was significantly related to green forage yield only in rainy season (r=0.34 and 0.36) but other root attributes such as mean root diameter or specific root length showed no significant relationship. Canopy temperature depression showed positive association with green forage yield in both dry and rainy seasons indicating the importance of canopy cooling for improving photosynthate production. Significant negative relationship was found between green forage yield and other plant attributes such as stem N and leaf TNC (Table 2). A negative relationship was observed between green forage yield and animal consumption and this could be related to forage quality characteristics. A group of four *Brachiaria* hybrids (BR06NO/1000, BRO6NO/0204, BR06NO/0531 and BR05NO/0334) were identified as more consumed by cows in both dry and rainy seasons (Figure 6).

Table 2. Correlation coefficients (r) between green forage yield (t/ha) and other shoot attributes of *Brachiaria* genotypes grown with low initial fertilizer application in an Oxisol of Santander de Quilichao, Colombia

Shoot traits	Dry season 2009	Rainy season 2010
Total (live + dead) shoot biomass (kg ha^{-1})	0.96 ***	0.97 ***
Dead shoot biomass (kg ha^{-1})	-0.22	-0.07*
Leaf biomass (kg ha^{-1})	0.55 ***	0.82 ***
Stem biomass (kg ha^{-1})	0.83 ***	0.93 ***
Root biomass (kg ha^{-1})	0.11	0.34 *
Root length (km m^{-2})	0.06	0.36 *
Mean root diameter (mm)	-0.06	0.16
Specific root length (m g^{-1})	-0.10	-0.25
Canopy temperature (°C)	-0.21	-0.22 *
Canopy temperature depression (°C)	0.25 *	0.25 *
Leaf N content (%)	-0.15	-0.02
Leaf P content (%)	-0.35 **	-0.09
Leaf ash content (%)	0.08	-0.38 **
Leaf TNC content (mg g^{-1})	-0.28 *	-0.37 **
Stem N content (%)	-0.35 **	-0.42 ***
Stem P content (%)	-0.13	-0.32 **
Stem ash content (mg g^{-1})	-0.11	-0.22
Stem TNC content (mg g^{-1})	-0.07	-0.10
Shoot N uptake (kg ha^{-1})	0.62 ***	0.78 ***
Shoot P uptake (kg ha^{-1})	0.61 ***	0.90 ***
Animal intake of green forage (scale 1-9)	-0.19	-0.22 *

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

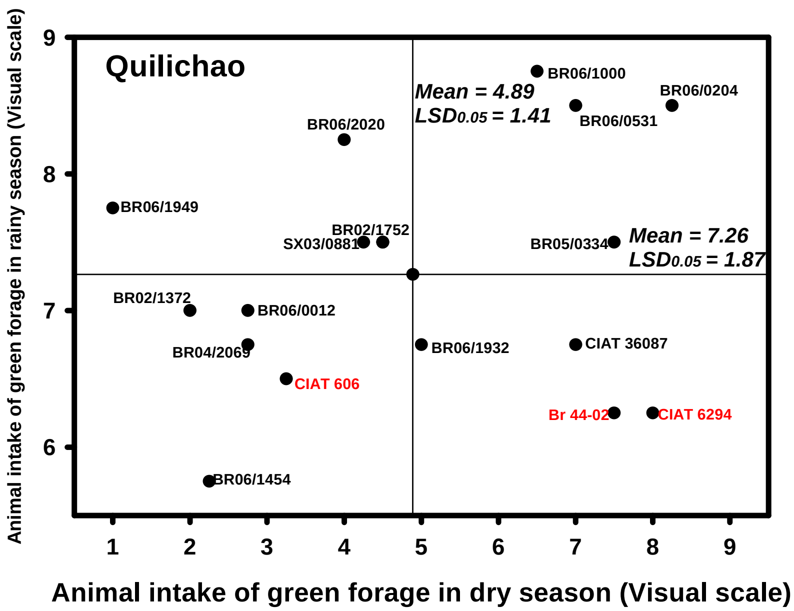


Figure 6. Differences in animal intake of green forage based on a visual scale (1 is low and 9 is high) for 18 genotypes of *Brachiaria* grown in an oxisol at Santander de Quilichao, Colombia. Plots were subjected to mob grazing of cows at 3 (dry season) and 8 (end of rainy season) months after establishment (August 2009 and January 2010, respectively). LSD values are at the 0.05 probability level.

Conclusions

We identified a group of four apomictic *Brachiaria* hybrids (BR02NO/1752, BR04NO/2069, BR06NO/2020, BR02NO/1372) and one sexual hybrid (SX03NO/0881) as superior performers during dry season and two cultivars (*B. brizantha* CIAT 6294 and *B. decumbens* CIAT 606) and 5 hybrids (BR04NO/2069, BR06NO/1932, BR05NO/0334, BR06NO/0204 and BR02NO/1752) as superior performers during rainy season under low fertility acid soil conditions. Among the genotypes tested, the hybrid BR02NO/1752 performed better under both dry and rainy season conditions. The forage on offer was more consumed by animals for a group of four *Brachiaria* hybrids (BR06NO/1000, BRO6NO/0204, BR06NO/0531 and BR05NO/0334) in both dry and rainy seasons. A negative association between shoot biomass production and animal consumption in dry and rainy seasons could be related to forage quality characteristics.

1.6.2 Phenotypic differences in drought resistance of 94 *Brachiaria* genotypes

Contributors: Polanía, J.; Miles, J.; Rao, I.M. (CIAT)

Rationale

In 2009, 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. In 2010, we evaluated 84 hybrids from the sexual series (SX08) along with 10 checks for phenotypic differences in drought resistance.

Material and Methods

A greenhouse experiment using pots was conducted at CIAT Palmira to determine differences in resistance to drought among 94 *Brachiaria* genotypes (84 hybrids from SX08 series and 10 checks: CIAT 606, CIAT 679, B. ruz 44-02, CIAT 6133, CIAT 6294, CIAT 26110, CIAT 36061, CIAT 36087, BR02/1372 and BR02/1752). 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 (Oxisol) 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. Progressive soil drying treatment was imposed by withholding water supply to simulate terminal drought stress. At the time to induce 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 30 ^{o}C and 19^{o}C, respectively. Significant genotypic differences were observed in green leaf biomass production under terminal drought stress conditions. Five genotypes (SX08/0282, SX08/0716, SX08/0641, SX08/ 0103 and SX08/0748) were found to be outstanding in their green leaf biomass production. Four genotypes (SX08/1027, SX08/0505, CIAT/679 and SX08/1025) were found to be inferior in their green leaf biomass production (Figure 7). Significant genotypic differences were observed in green leaf biomass proportion (green leaf biomass/total leaf biomass x 100). Six genotypes (CIAT/606, CIAT/26110, SX08/0885, SX08/0955, SX08/ 0183 and CIAT/6133) showed higher green leaf biomass proportion than the other genotypes tested. The genotype SX08/ 0183 was outstanding in its green leaf biomass production and also showed higher value of green leaf biomass proportion.

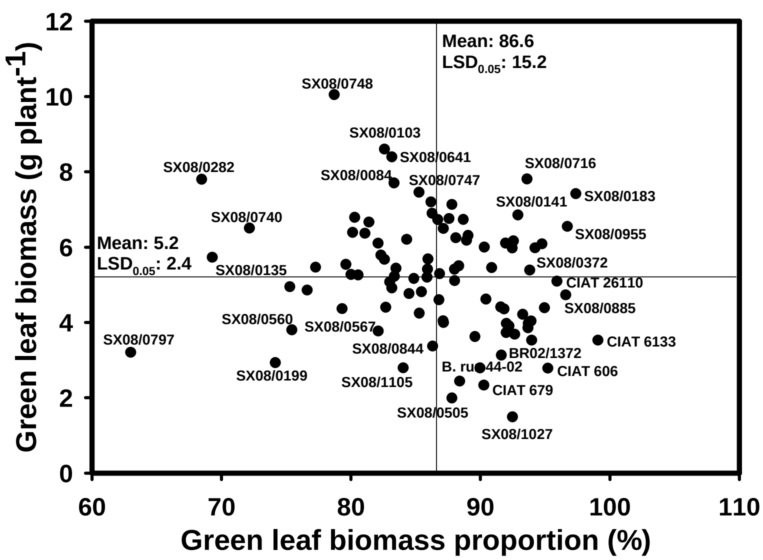


Figure 7. Identification of genotypes with higher green leaf production with higher green leaf biomass proportion (green leaf biomass/total leaf biomass) when grown under terminal drought stress at CIAT, Palmira. Genotypes with greater values of green leaf biomass and green leaf biomass proportion were identified in the upper, right hand quadrant.

1.6.3 Evaluation of *Brachiaria humidicola* germplasm accessions for tolerance to waterlogging

Contributors: J. Rincón, J.A. Cardoso, 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. Among the Brachiaria species, *B. humidicola* is relatively more tolerant to waterlogging conditions. But the extent of genotypic variation for tolerance to waterlogging among the germplasm accessions of *B. humidicola* is unknown. Thus the main objective of this work was to screen 66 germplasm accessions of *B. humidicola* along with 7 checks for their tolerance to waterlogging stress.

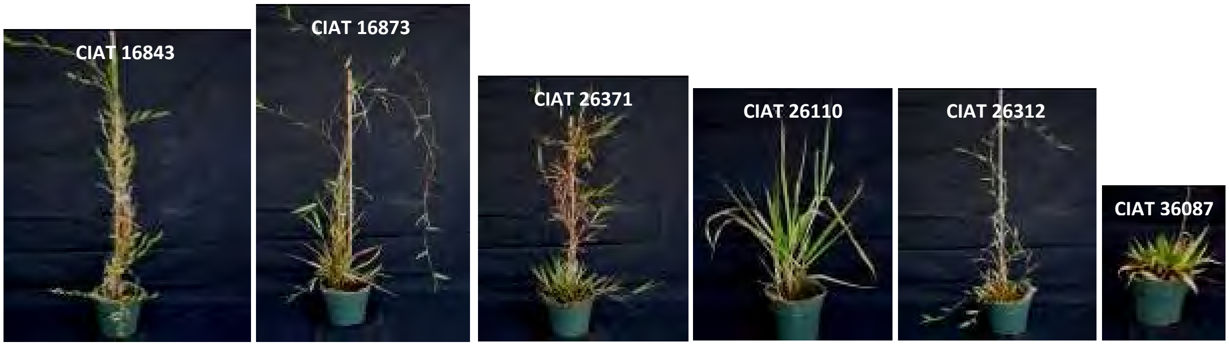
Materials and methods

One trial was conducted outside in the Forages patio area of CIAT Palmira during January 2010 to determine differences in tolerance to waterlogging among 73 *Brachiaria* genotypes (66 germplasm accessions of *B. humidicola with* 7 checks: BR04/3207,BR05/1738, BR06/1000, *B. brizantha* CIAT 26110, *Brachiaria* hybrid cv. Mulato 2 CIAT 36087, *B. arrecta* CIAT 16843, Brachipara). The trial was planted as a randomized complete block arrangement with four replications. Each experimental unit 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. After two months of growth, soil was waterlogged with a 5 cm water lamina over the soil. Drainage of water was prevented using a plastic bag outside the pot and maintained in position by inserting the plastic covered pot into another pot of the same size. Leaf chlorophyll content (in SPAD chlorophyll meter reading, SCMR units) and photosynthetic efficiency in light adapted leaves (fv'/fm') were measured at weekly intervals for 4 weeks on a fully expanded young leaf marked at the initiation of waterlogging treatment. At the end of the 30 days of treatment, green leaf area (cm^2 pot^{-1}), green leaf biomass (g pot^{-1}), dead leaf biomass (g pot^{-1}), stem biomass (g pot^{-1}) were determined. Visual evaluation (1 = highly sensitive and 9 = highly tolerant) was made and green leaf biomass proportion was determined as % of total leaf biomass.

Results and discussion

The maximum temperature during the experimental period ranged from 24.5 to 35.3 °C while the minimum temperatures were 18.9 to 22.5 °C. The solar radiation was 4 to 23 MJ m^{-2} d^{-1}.

After 30 days of waterlogging treatment, significant differences in tolerance to waterlogging were observed among the genotypes tested (Photo 2). Four genotypes (CIAT 16873, CIAT 6133, CIAT 26371 and CIAT 6707) were found to be outstanding in their ability to withstand waterlogging stress since these genotypes maintained a higher proportion of green leaf biomass compared to total leaf biomass. The check genotype CIAT 36087 (Mulato 2) showed the lower green leaf biomass proportion to total leaf biomass (Figure 8). Two other checks (CIAT 26110 and Brachipara) showed an intermediate level of waterlogging tolerance (Figure 8).



Tolerant check | Tolerant genotype | Tolerant genotype | Intermediate check | Sensitive genotype | Sensitive check

Photo 2. Visual differences in waterlogging tolerance of tested genotypes compared with checks.

SCMR showed a significant positive correlation with green leaf biomass proportion to total leaf biomass (r^2= 0.42), thus indicating that this can be a useful trait that can be considered as a tool to evaluate differences of waterlogging tolerance among genotypes of *Brachiaria* (Figure 9). The genotype that showed the highest value of total shoot biomass after 30 days of waterlogging treatment was the tolerant check CIAT 16843 (*Brachiaria arrecta*) and the one with the lowest total shoot biomass was *Brachiaria humidicola* CIAT 26312 (Figure 10 and Table 3).

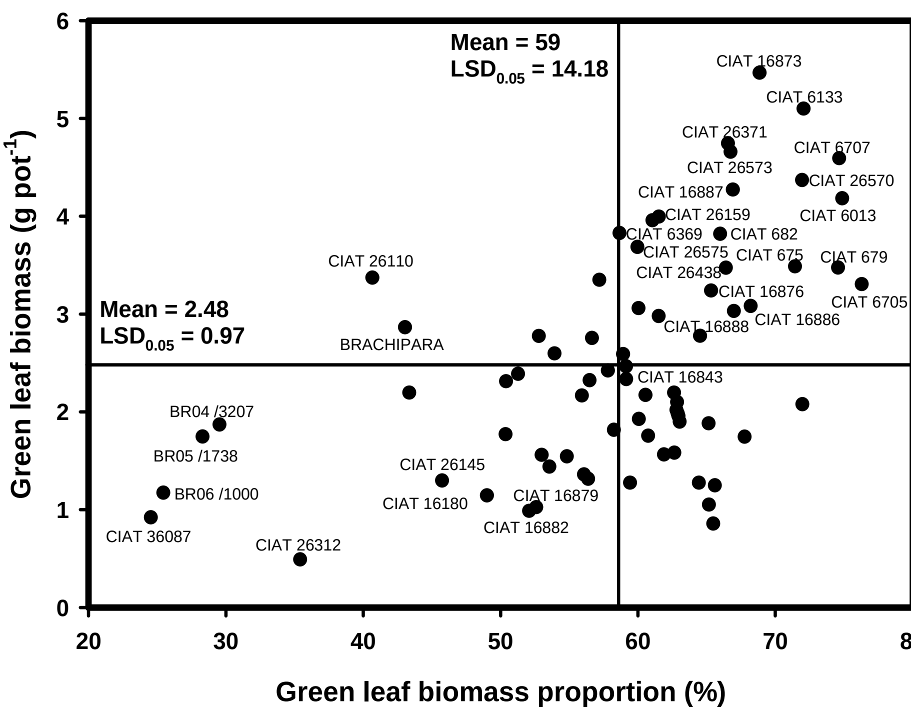


Figure 8. Relationship between green leaf biomass proportion to total leaf biomass and green leaf biomass for 66 *Brachiaria humidicola* germplasm accessions and 7 checks, grown under waterlogging conditions. *Brachiaria* genotypes that showed greater values of green leaf biomass and green leaf biomass proportion were identified in the upper, right hand quadrant.

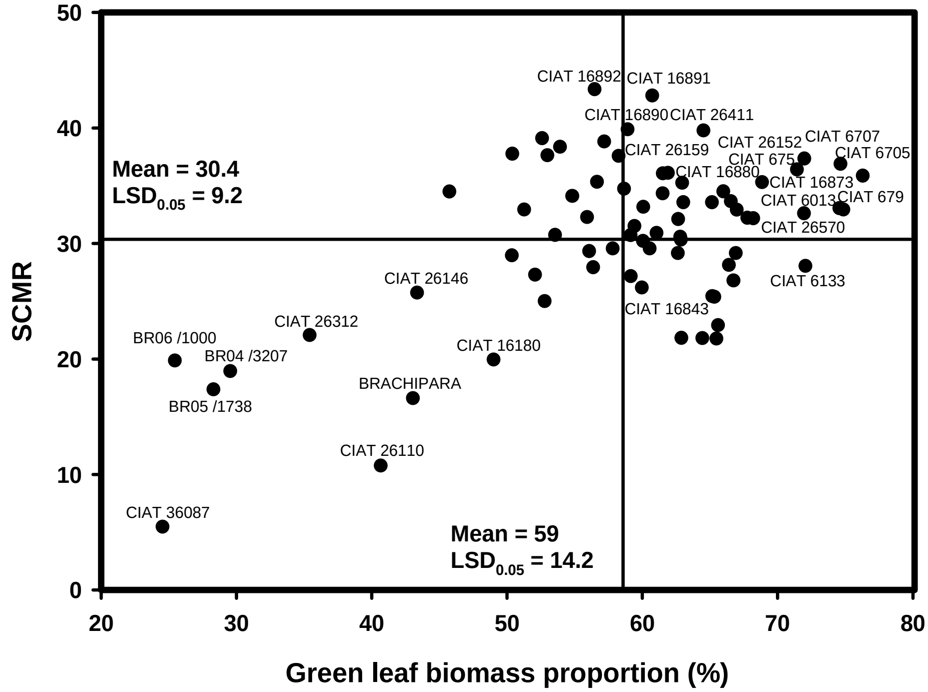


Figure 9. Relationship between green leaf biomass proportion to total leaf biomass and SCMR for 66 *Brachiaria humidicola* germplasm accessions and 7 checks grown under waterlogging conditions. *Brachiaria* genotypes that showed greater values of leaf chlorophyll content and green leaf biomass proportion were identified in the upper, right hand quadrant.

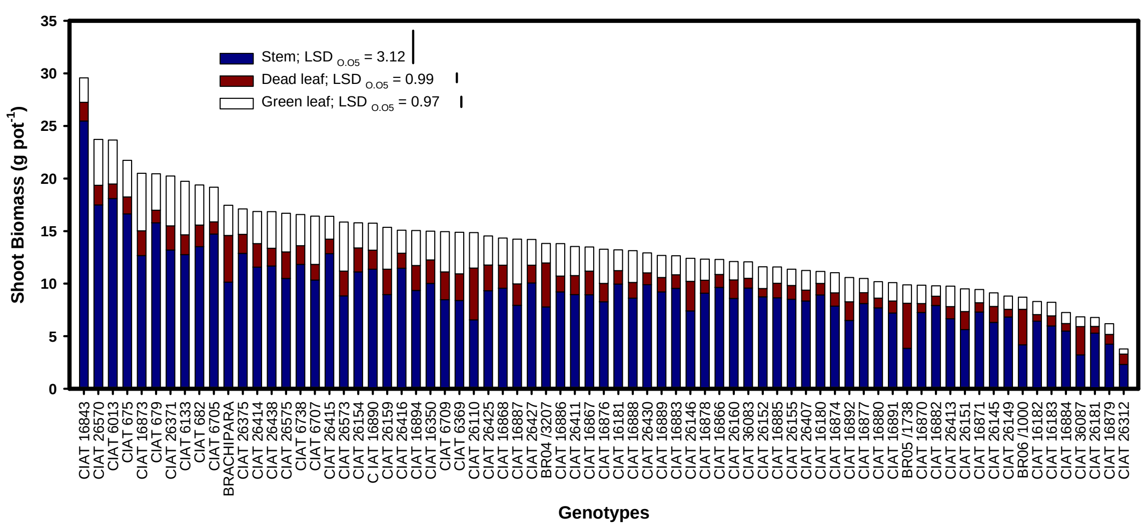


Figure 10. Influence of waterlogging treatment on genotypic variation in shoot biomass of 66 *Brachiaria humidicola* germplasm accessions and 7 checks. LSD values are at the 0.05 probability level.

Table 3. Green leaf biomass, leaf area, SCMR, dead leaf biomass, and green leaf biomass proportion to toal leaf biomass of 66 *Brachiaria humidicola* germplasm accessions and 7 checks after 30 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia

Genotype	Green leaf biomass (g pot^{-1})	Leaf area (cm^2 pot^{-1})	SCMR	Dead leaf biomass (g pot^{-1})	Green leaf biomass proportion (%)
Checks					
CIAT 16843	2.33	449	27.10	1.77	59
BRACHIPARA	2.86	475	16.54	4.44	43
CIAT 26110	3.37	355	10.69	4.92	41
BR04/ 3207	1.86	283	18.88	4.19	30
BR05/1738	1.74	266	17.30	4.30	28
BR06/ 1000	1.17	214	19.79	3.36	26
CIAT 36087	0.91	157	5.41	2.69	25
Accessions					
CIAT 6705	3.30	278	35.80	1.17	76
CIAT 6013	4.18	346	32.86	1.38	75
CIAT 6707	4.59	246	36.83	1.49	75
CIAT 679	3.47	402	32.98	1.19	75
CIAT 6133	5.09	516	27.98	1.89	72
CIAT 26152	2.07	218	37.28	0.79	72
CIAT 26570	4.36	452	32.54	1.87	72
CIAT 675	3.48	286	36.34	1.62	71
CIAT 16873	5.46	607	35.24	2.37	69
CIAT 16886	3.08	369	32.11	1.51	68
CIAT 16870	1.74	181	32.15	0.85	68
CIAT 16888	3.02	369	32.85	1.50	67
CIAT 16887	4.27	557	29.10	2.04	67
CIAT 26573	4.65	431	26.73	2.38	67
CIAT 26371	4.74	458	33.58	2.30	67
CIAT 26438	3.47	441	28.06	1.69	66
CIAT 682	3.81	426	34.44	2.06	66
CIAT 16182	1.24	187	22.85	0.63	66
CIAT 26181	0.85	94	21.69	0.64	66
CIAT 16876	3.23	296	25.31	1.75	65
CIAT 16884	1.04	93	25.36	0.71	65
CIAT 26407	1.88	208	33.49	1.04	65
CIAT 26411	2.77	301	39.71	1.81	65
CIAT 26149	1.27	162	21.74	0.73	64
CIAT 26430	1.89	231	33.49	1.13	63
CIAT 26413	1.95	216	35.18	1.16	63
CIAT 16181	1.98	210	21.75	1.28	63
CIAT 16889	2.09	263	30.26	1.38	63
CIAT 16878	2.01	254	30.51	1.23	63
CIAT 36083	1.58	190	32.04	0.93	63
CIAT 26416	2.19	257	29.09	1.43	63
CIAT 16880	1.56	142	36.04	0.94	62
CIAT 26159	3.99	456	35.99	2.41	62
CIAT 6738	2.97	332	34.26	1.78	62
CIAT 6369	3.95	621	30.84	2.54	61
CIAT 16891	1.75	191	42.74	1.14	61
CIAT 26415	2.17	249	29.49	1.39	61
CIAT 16874	1.92	156	33.10	1.26	60

Continues…

Table 3. Green leaf biomass, leaf area, SCMR, dead leaf biomass, and green leaf biomass proportion to toal leaf biomass of 66 *Brachiaria humidicola* germplasm accessions and 7 checks after 30 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia

Genotype	Green leaf biomass (g pot^{-1})	Leaf area (cm^2 pot^{-1})	SCMR	Dead leaf biomass (g pot^{-1})	Green leaf biomass proportion (%)
CIAT 26414	3.05	309	30.15	2.23	60
CIAT 26575	3.68	349	26.11	2.52	60
CIAT 16871	1.27	120	31.44	0.89	59
CIAT 26427	2.46	244	30.65	1.68	59
C IAT 16890	2.58	253	39.81	1.81	59
CIAT 6709	3.82	332	34.66	2.65	59
CIAT 16883	1.81	193	37.51	1.30	58
CIAT 26375	2.42	230	29.50	1.81	58
CIAT 16894	3.34	262	38.75	2.38	57
CIAT 16350	2.75	316	35.26	2.23	57
CIAT 16892	2.32	212	43.28	1.78	57
CIAT 16183	1.31	181	27.86	0.94	56
CIAT 16877	1.35	179	29.26	1.03	56
CIAT 26151	2.16	211	32.21	1.71	56
CIAT 26155	1.54	234	34.04	1.32	55
CIAT 16868	2.59	183	38.30	2.19	54
CIAT 16866	1.43	149	30.66	1.23	54
CIAT 16885	1.55	169	37.56	1.38	53
CIAT 26425	2.77	338	24.94	2.45	53
CIAT 16879	1.02	102	39.04	0.93	53
CIAT 16882	0.98	92	27.23	0.87	52
CIAT 26154	2.38	356	32.86	2.27	51
CIAT 16867	2.31	211	37.69	2.24	50
CIAT 26160	1.76	209	28.90	1.76	50
CIAT 16180	1.14	100	19.88	1.10	49
CIAT 26145	1.29	134	34.43	1.53	46
CIAT 26146	2.19	252	25.66	2.82	43
CIAT 26312	0.48	53	22.00	1.00	35
Mean	**2.48**	**272**	**30.37**	**1.77**	**59**
$LSD_{0.05}$	**0.97**	**127.80**	**9.20**	**0.99**	**14.18**

Correlations among plant attributes indicated that green leaf biomass proportion to total leaf biomass was positively associated with green leaf biomass, SCMR and leaf area while it was negatively associated with dead leaf biomass (Table 4). Green leaf area was positively associated with dead leaf biomass indicating the importance of remobilization of photosynthates to allow leaf expansion in tolerant genotypes.

Table 4. Correlation matrix (r) among shoot traits of 73 *Brachiaria* genotypes after 30 days of waterlogging in an Oxisoil from Santander de Quilichao, Colombia

	Green leaf biomass	**Leaf area**	**SCMR**	**Dead leaf biomass**	**Green leaf biomass proportion**
Green leaf biomass	1				
Leaf area	0.81***	1			
SCMR	0.20***	0.07 NS	1		
Dead leaf biomass	0.30***	0.39***	-0.27***	1	
Green leaf biomass proportion	0.45***	0.27***	0.42***	-0.60***	1

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

Conclusions

We identified four *Brachiaria humidicola* (CIAT 16873, CIAT 6133, CIAT 26371 and CIAT 6707) germplasm accessions that were superior to the other genotypes in their level of tolerance to waterlogging. Green leaf biomass, SCMR and green leaf biomass proportion to total leaf biomass are the three plant attributes that can be used as selection criteria for evaluating waterlogging tolerance in *Brachiaria*.

1.6.4 Genotypic variation in waterlogging tolerance of 93 *Brachiaria* genotypes

Contributors: Rincón, J.; Cardoso, J.A.; Miles, J.W.; Rao, I.M. (CIAT)

Rationale

In 2009, we evaluated 500 *Brachiaria* hybrids from the IN08 population and identified one hybrid, IN08/313, as outstanding in terms of waterlogging tolerance based on green leaf biomass production. Green leaf biomass proportion to total leaf biomass was identified as a useful selection index to evaluate waterlogging tolerance. In 2010, we evaluated 84 sexual hybrids of *Brachiaria* from SX08 series along with 9 checks for their tolerance to waterlogging. The 84 hybrid-derived, sexual clones (Series SX08) were selected from an original SX08 population of 1,120 clones generated in 2008, through a series of culls based on: 1) seedling vigor prior to transplantation to a field crossing block; 2) flowering, seed production, and seed set of individuals in the field crossing block; 3) germination of testcross (hybrid) seed and number of testcross progenies obtained; and 4) performance of testcross progenies in field trials.

Material and Methods

One trial was conducted outside in the Forages patio area of CIAT Palmira during April 2010 to determine differences in tolerance to waterlogging among 93 *Brachiaria* genotypes (84 hybrids from SX08NO series; 9 checks - *B. decumbens* CIAT 606; *B. ruziziensis* 44-02; *B. brizantha* CIAT 6294; *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; CIAT 16843). The trial was planted as a randomized complete block arrangement whit three replications. Each experimental unit 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 20 days. Leaf chlorophyll content (in SPAD chlorophyll meter reading, SCMR units) and leaf photosynthetic efficiency (fv'/fm') were measured at weekly intervals for 3 weeks on a full expanded young leaf marked at the initiation of waterlogging treatment. At the end of the 20 days of treatment, green leaf area (cm^2 pot^{-1}), green leaf biomass (g pot^{-1}), dead leaf biomass (g pot^{-1}), stem biomass (g pot^{-1}) were determined. Visual evaluation (1 = highly sensitive and 9 = highly tolerant) was made and green leaf biomass proportion was determined as % of total leaf biomass.

Results and discussion

The maximum temperature during the experimental period ranged from 26ºC to 34.6ºC while the minimum temperature ranged from 17 ºC to 25.1 ºC. The solar radiation ranged from 4.1 to 22.0 MJ m^{-2} d^{-1}. Significant phenotypic variability among hybrids from SX08NO series in green leaf biomass proportion to total leaf biomass was observed after 20 days of waterlogging treatment (Table 5; Photo 3). The checks *B. humidicola* CIAT 6133 and *B. brizantha* CIAT 26110 were superior in their level of tolerance to waterlogging. Among checks, B. ruz 44-02 was sensitive to waterlogging (Table 5).

Table 5. Green leaf biomass, green leaf area, SCMR, dead leaf biomass, visual evaluation and green leaf biomass proportion to total leaf biomass of 93 *Brachiaria* genotypes after 20 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia

Genotype	Green leaf biomass (g pot^{-1})	Green leaf area (cm^2 pot^{-1})	SCMR	Dead leaf biomass (g pot^{-1})	Visual evaluation (1-9)	Green leaf biomass proportion (%)
Checks						
CIAT 6133	2.09	198	40.72	0.22	8	91
CIAT 26110	3.96	347	21.50	0.50	7	89
CIAT 16843	1.95	367	33.72	0.34	7	85
CIAT 6294	3.86	393	36.23	0.80	6	83
CIAT 606	2.80	353	27.52	0.53	7	83
CIAT 679	1.43	191	42.37	0.34	8	79
CIAT 36087	4.19	515	32.72	1.19	7	77
CIAT 36061	2.72	307	23.48	1.84	6	60
Br44-02	2.31	219	28.20	2.11	6	51
Hybrids						
SX08NO/0320	4.34	537	25.97	0.60	7	88
SX08NO/0849	3.97	499	20.10	1.06	6	77
SX08NO/0900	2.98	299	21.67	1.03	6	75
SX08NO/0466	2.21	270	29.32	0.92	6	74
SX08NO/0495	3.24	434	22.80	1.16	6	74
SX08NO/0567	2.81	410	21.58	1.00	6	73
SX08NO/0293	3.45	514	9.83	1.27	6	72
SX08NO/ 0182	2.87	386	21.63	1.30	6	71
SX08NO/0314	2.85	338	20.43	1.23	6	70

Continues…

Table 5. Green leaf biomass, green leaf area, SCMR, dead leaf biomass, visual evaluation and green leaf biomass proportion to total leaf biomass of 93 *Brachiaria* genotypes after 20 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia

Genotype	Green leaf biomass (g pot^{-1})	Green leaf area (cm^2 pot^{-1})	SCMR	Dead leaf biomass (g pot^{-1})	Visual evaluation (1-9)	Green leaf biomass proportion (%)
SX08NO/0614	1.61	234	25.50	0.78	6	70
SX08NO/ 0183	3.23	358	25.97	1.40	6	70
SX08NO/0292	2.70	340	12.43	1.17	6	69
SX08NO/0295	3.17	355	26.15	1.41	6	69
SX08NO/ 0064	2.66	316	20.78	1.24	6	69
SX08NO/0505	2.98	371	25.42	1.35	6	68
SX08NO/0548	3.12	374	14.32	1.45	6	68
SX08NO/0797	2.48	311	21.42	1.17	6	68
SX08NO/0950	2.12	213	8.33	1.08	5	67
SX08NO/0783	2.54	381	13.43	1.26	6	66
SX08NO/0564	2.90	367	19.13	1.52	5	66
SX08NO/ 0141	3.22	336	23.47	1.66	6	66
SX08NO/ 0084	2.72	359	11.20	1.38	5	66
SX08NO/0940	2.32	304	22.95	1.25	5	66
SX08NO/0319	2.47	291	16.33	1.38	5	64
SX08NO/0885	2.72	344	18.37	1.51	6	64
SX08NO/0868	2.46	352	8.68	1.43	5	63
SX08NO/0641	2.16	282	21.77	1.19	5	63
SX08NO/ 0249	2.39	299	17.28	1.42	6	63
SX08NO/ 0103	2.84	359	16.30	1.75	5	62
SX08NO/0378	2.70	337	15.02	1.69	5	62
SX08NO/1025	1.85	280	12.20	1.15	6	61
SX08NO/0867	2.59	362	14.05	1.63	5	61
SX08NO/ 0254	2.32	312	18.93	1.54	5	60
SX08NO/0861	2.15	327	3.08	1.48	6	59
SX08NO/0425	2.34	283	28.23	1.68	6	59
SX08NO/0522	1.71	190	18.93	1.28	5	58
SX08NO/0779	1.17	203	3.92	0.85	4	58
SX08NO/0547	1.02	137	6.57	0.93	5	58
SX08NO/ 0172	2.86	315	20.40	2.08	5	57
SX08NO/0492	2.18	296	23.95	1.63	6	57
SX08NO/0413	1.98	216	28.75	1.37	5	57
SX08NO/0539	1.94	302	15.23	1.52	6	57
SX08NO/0740	2.08	302	15.33	1.40	6	56
SX08NO/0588	2.36	369	8.90	1.88	6	56
SX08NO/0850	2.87	415	15.27	2.33	6	55

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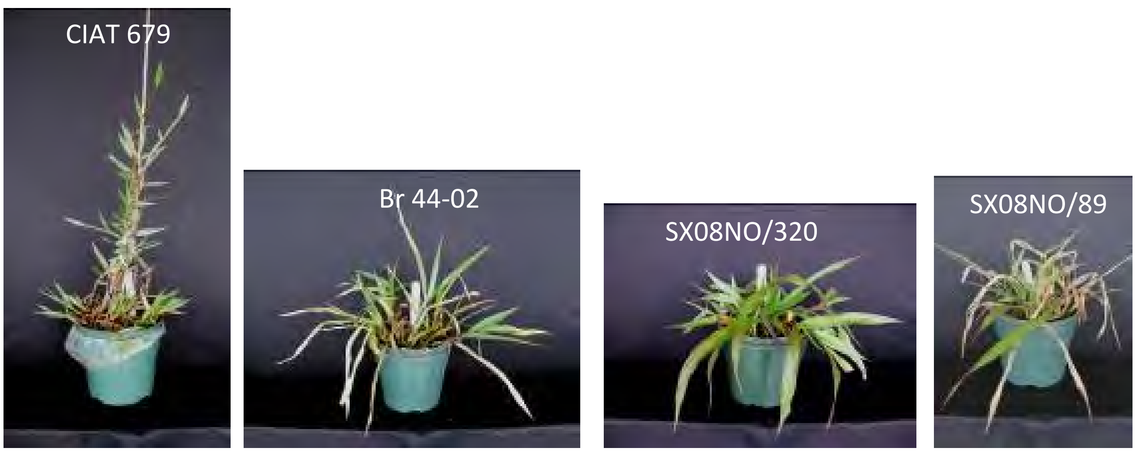
Table 5. Green leaf biomass, green leaf area, SCMR, dead leaf biomass, visual evaluation and green leaf biomass proportion to total leaf biomass of 93 *Brachiaria* genotypes after 20 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia

Genotype	Green leaf biomass (g pot^{-1})	Green leaf area (cm^2 pot^{-1})	SCMR	Dead leaf biomass (g pot^{-1})	Visual evaluation (1-9)	Green leaf biomass proportion (%)
SX08NO/0769	1.08	145	20.00	0.89	5	55
SX08NO/0523	1.84	249	27.12	1.52	5	54
SX08NO/1027	1.57	250	6.78	1.26	5	54
SX08NO/ 0105	2.07	294	3.20	1.41	5	54
SX08NO/0844	1.84	267	1.43	1.63	5	53
SX08NO/0747	1.85	295	13.40	1.58	5	53
SX08NO/ 0133	2.40	329	15.62	2.12	5	53
SX08NO/ 0135	2.80	376	13.33	2.48	6	53
SX08NO/0952	1.48	187	13.73	1.27	5	53
SX08NO/0954	1.40	164	8.48	1.18	5	53
SX08NO/0318	1.97	229	6.62	1.83	4	52
SX08NO/0955	1.48	186	4.85	1.18	5	51
SX08NO/ 0109	1.67	295	3.78	1.64	4	51
SX08NO/0847	2.08	315	22.33	2.05	5	51
SX08NO/0411	1.76	255	11.92	1.76	5	51
SX08NO/1105	2.07	299	18.97	1.99	6	50
SX08NO/0697	1.55	230	4.52	1.71	5	48
SX08NO/0560	1.71	294	8.92	1.86	5	47
SX08NO/0716	1.58	238	11.42	1.72	5	47
SX08NO/1090	1.25	199	7.92	1.50	4	46
SX08NO/0767	1.29	169	20.32	1.58	5	45
SX08NO/0372	1.80	177	16.02	2.25	4	45
SX08NO/0748	1.49	202	6.82	1.88	4	44
SX08NO/0558	1.22	193	14.78	1.52	5	44
SX08NO/0337	1.00	136	18.58	1.15	4	42
SX08NO/0958	1.45	177	5.55	1.24	4	41
SX08NO/0938	0.96	133	1.77	1.20	4	40
SX08NO/ 0199	0.94	127	5.55	1.49	4	40
SX08NO/0751	1.40	220	7.50	2.06	4	40
SX08NO/0282	1.52	210	14.65	2.39	4	38
SX08NO/1118	1.60	234	11.25	2.41	4	38
SX08NO/0653	0.93	97	10.05	1.66	4	37
SX08NO/ 0118	1.33	169	21.82	2.35	4	36
SX08NO/ 0089	0.81	132	10.27	1.52	4	34
SX08NO/0472	0.64	75	11.23	1.23	4	32
SX08NO/0613	0.73	94	12.77	1.47	4	32

Continues…

Table 5. Green leaf biomass, green leaf area, SCMR, dead leaf biomass, visual evaluation and green leaf biomass proportion to total leaf biomass of 93 *Brachiaria* genotypes after 20 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia

Genotype	Green leaf biomass (g pot^{-1})	Green leaf area (cm^2 pot^{-1})	SCMR	Dead leaf biomass (g pot^{-1})	Visual evaluation (1-9)	Green leaf biomass proportion (%)
SX08NO/0593	0.83	114	21.50	1.81	4	32
SX08NO/0776	0.57	76	17.93	1.29	4	29
SX08NO/0956	0.91	115	1.75	2.37	4	27
Mean	**2.13**	**277**	**16.69**	**1.44**	**5**	**58**
$LSD_{0.05}$	**1.07**	**149.10**	**12.53**	**0.76**	**1.31**	**19.94**



Tolerant check | **Sensitive check** | **Tolerant hybrid** | **Susceptible hybrid**

Photo 3. Visual differences in waterlogging tolerance of tested genotypes compared with checks.

Among the SX08NO series, 4 hybrids (SX08NO/320, SX08NO/849, SX08NO/900 and SX08NO/466) were superior in their production green leaf biomass proportion to total leaf biomass than the others hybrids. Four hybrids (SX08NO/956, SX08NO/776, SX08NO/593 and SX08NO/613) were found to be lower in their level of waterlogging tolerance (Table 5; Figure 11).

Correlations among plant attributes indicated that green leaf biomass proportion to total leaf biomass was positively associated with green leaf biomass, leaf area, SCMR and photosynthetic efficiency while it was negatively associated with dead leaf biomass (Table 6; Figures 12, 13 and 14). It is important to note that the green leaf biomass proportion to total leaf biomass showed highly significant positive association with visual evaluation of genotypes. This indicates that visual evaluation may be used as selection criteria to eliminate a large proportion of hybrids when large scale phenotyping is needed to support the ongoing *Brachiaria* breeding program.

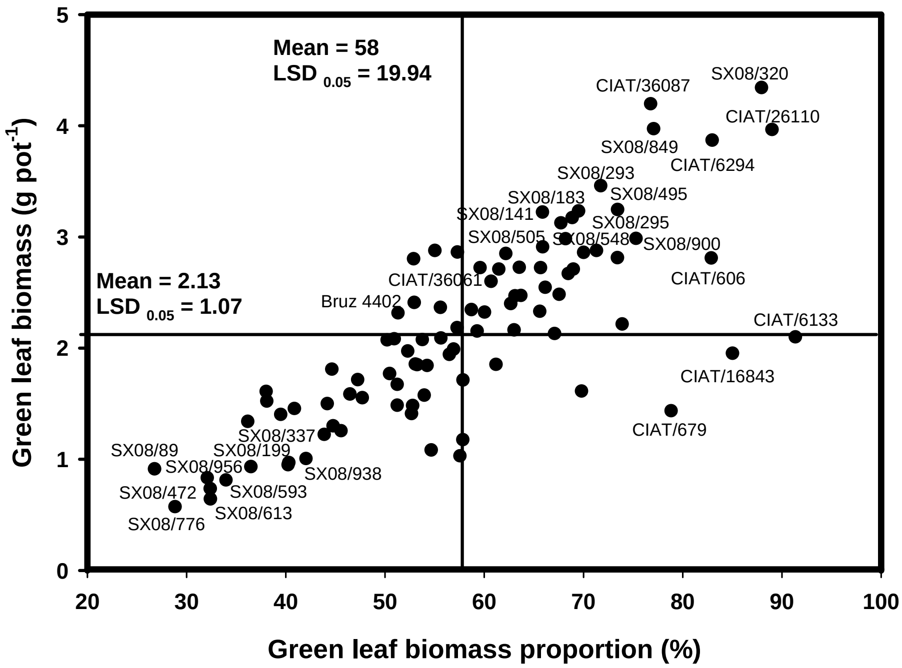


Figure 11. Relationship between green leaf biomass and green leaf biomass proportion to total leaf biomass of 93 *Brachiaria* genotypes after 20 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia.

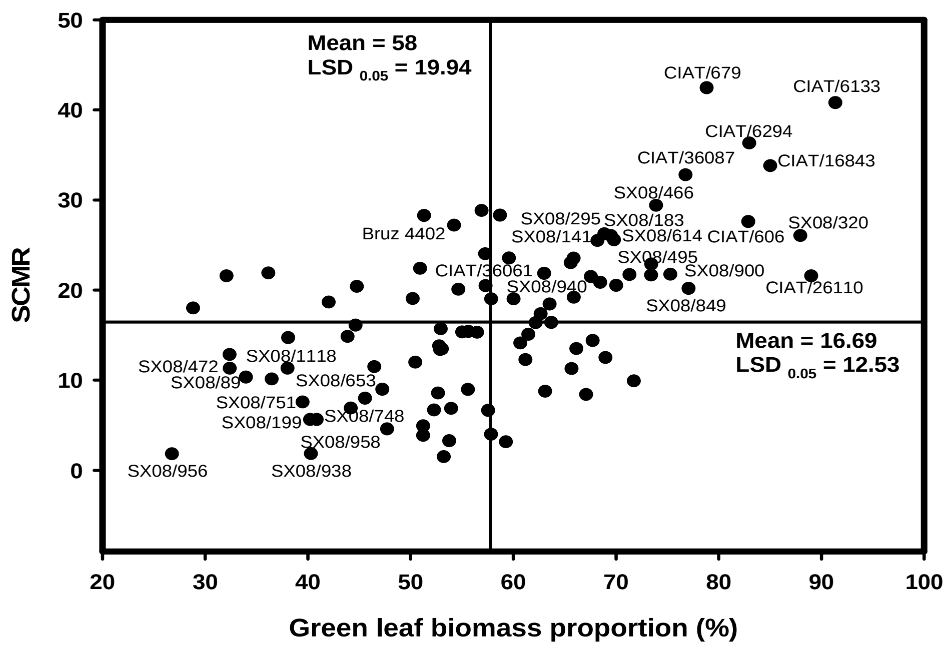


Figure 12. Relationship between SCMR and green leaf biomass proportion to total leaf biomass of 93 *Brachiaria* genotypes after 20 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia.

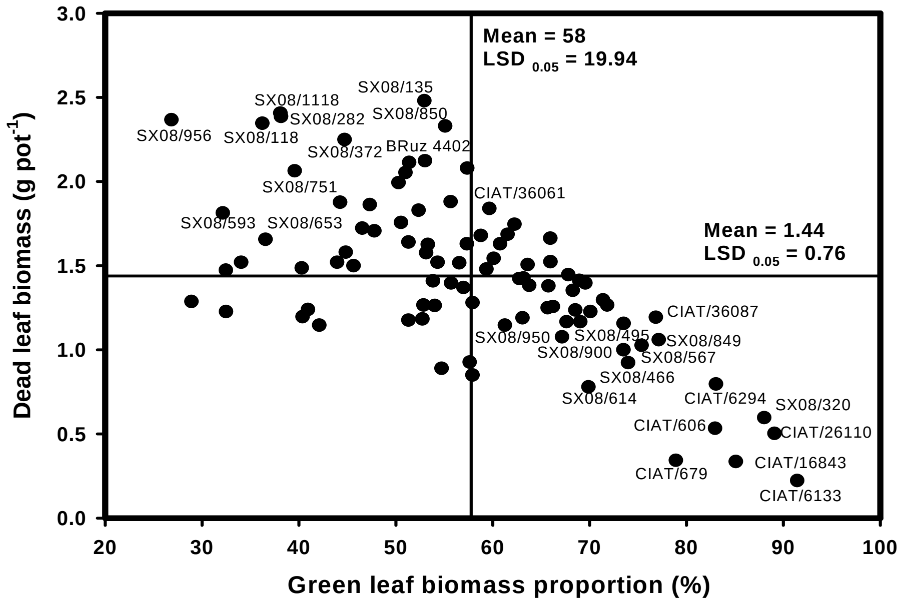


Figure 13. Relationship between dead leaf biomass and green leaf biomass proportion to total leaf biomass of 93 *Brachiaria* genotypes after 20 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia.

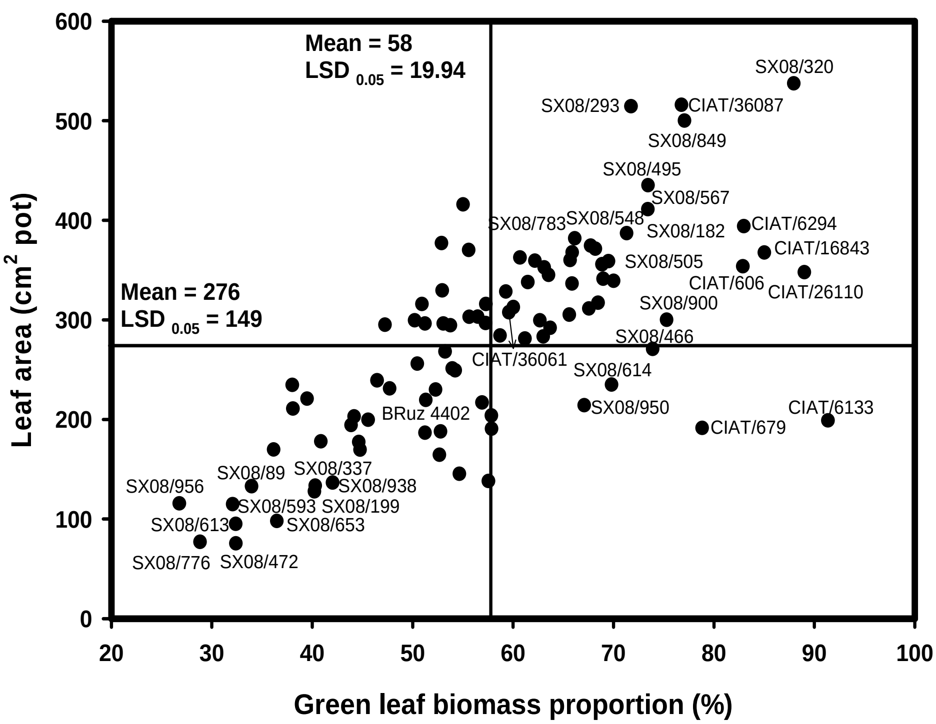


Figure 14. Relationship between leaf area and green leaf biomass proportion to total leaf biomass of 93 *Brachiaria* genotypes after 20 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia.

Table 6. Correlation matrix (r) among shoot traits of 93*Brachiaria* genotypes after 20 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia

	Green leaf biomass	Leaf area	SCMR	Photosynthetic efficiency	Dead leaf biomass	Green leaf biomass proportion	Visual evaluation
Green leaf biomass	1						
Leaf area	0.89***	1					
SCMR	0.39***	0.28***	1				
Photosynthetic efficiency	0.20***	0.14*	0.65***	1			
Dead leaf biomass	-0.18**	-0.14*	-0.33***	-0.34***	1		
Green leaf biomass proportion	0.77***	0.70***	0.51***	0.41***	-0.66***	1	
Visual evaluation	0.61***	0.56***	0.56***	0.44***	-0.46***	0.80***	1

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

Conclusions

We identified four hybrids of SX08NO series (SX08NO/320, SX08NO/849, SX08NO/900 and SX08NO/466) that were superior to the other hybrids in their level of tolerance to waterlogging. We also found four hybrids (SX08NO/956, SX08NO/776, SX08NO/593 and SX08NO/613) that were lower in their level of waterlogging tolerance. Visual evaluation can be used to eliminate large number of hybrids from a breeding population.

1.6.5 Genotypic variation in waterlogging tolerance of 217 *Brachiaria* genotypes

Contributors: Jimenez, J.; Rincón, J.; Cardoso, J.A; Miles, J.W.; Rao, I.M. (CIAT)

Rationale

In 2009, we evaluated 500 *Brachiaria* hybrids from the IN08 population that was specifically developed for improving waterlogging tolerance and identified one hybrid, IN08/313, as outstanding in terms of waterlogging tolerance based on green leaf biomass proportion to total leaf biomass. Green leaf biomass proportion to total leaf biomass was identified as a useful selection index to evaluate waterlogging tolerance. In 2010, we evaluated 209 sexual hybrids of *Brachiaria* from INRZ10NO series along with 9 checks for their tolerance to waterlogging. INRZ10NO series of sexual hybrids were developed to combine waterlogging tolerance with *Rhizoctonia* foliar blight resistance in *Brachiaria*. The INRZ10 clones are derived originally from five sexual clones selected from 37 SX05 clones on their tolerance to waterlogging. These original five clones were recombined. The resulting population was maintained as a separate breeding population and was subjected to an additional cycle of selection and recombination to give rise to a population designated IN08. This population was merged with another population selected on *Rhizoctonia* resistance with the objective eventually of producing sexual germplasm with combined tolerance to waterlogging conditions and *Rhizoctonia* foliar blight.

Material and Methods

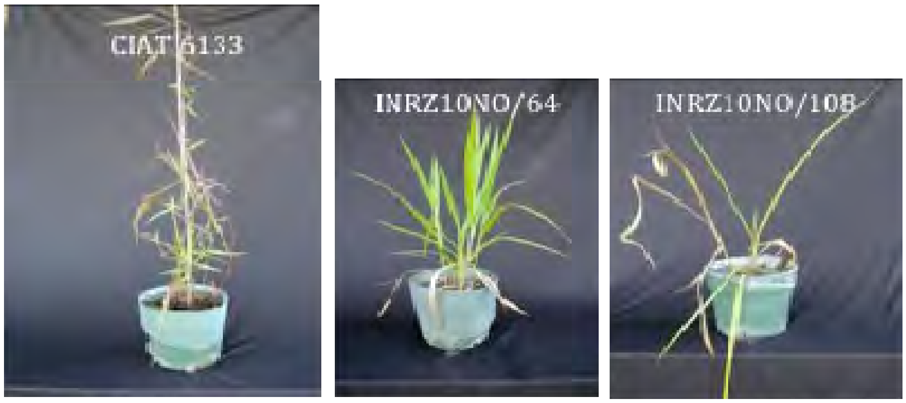
One trial was conducted at the Forages patio area of CIAT Palmira from July 16th to August 6th 2010 to determine differences in tolerance to waterlogging among 217 *Brachiaria* genotypes (209 sexual hybrids from INRZ10NO series; 8 checks - *B. decumbens* CIAT 606; *B. ruziziensis* Br 44-02; *B. brizantha* CIAT 6294; *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 planted with two replications. Each experimental unit consisted of one pot filled with 1.25 kg of topsoil (0-20 cm) from Santander de Quilichao (Oxisol) and sown with one vegetative propagule (stem cutting). 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 applying excessive amount of water to the soil (~ 3 cm over soil surface) for 21 days.

Leaf chlorophyll content (in SPAD chlorophyll meter reading, SCMR units) and leaf photosynthetic efficiency (fv'/fm') were measured at weekly intervals for 3 weeks on two fully expanded young leaves marked at the initiation of the waterlogging treatment. After 21 days of treatment, green leaf area (cm^2 plant^{-1}), green leaf biomass (g plant^{-1}), dead leaf biomass (g plant^{-1}), and stem biomass (g plant^{-1}) were determined. Visual evaluation (1 = highly sensitive and 9 = highly tolerant) was made and green leaf biomass proportion was calculated as percentage (%) of green leaf biomass to total leaf biomass.

Results and discussion

The maximum temperature during the experimental period ranged from 26ºC to 33ªC while the minimum temperature ranged from 18ºC to 21ºC. The solar radiation ranged from 9.2 to 21.0 MJ m^{-2} d^{-1}. Waterlogging for 21 days resulted in senescence and death of a significant proportion of shoot biomass for most of the tested sexual hybrids. Most of the tested hybrids developed adventitious roots above the soil (data not shown).

The checks *B. humidicola* CIAT 6133 and *B. humidicola* CIAT 679 were superior in their level of tolerance to waterlogging, and showed a green leaf biomass proportion of 95% and 93%, respectively (Table 7; Photo 4; Figure 15). Among the checks, B. ruz 44-02 was the most sensitive to waterlogging (Table 7). Four sexual hybrids (INRZ10NO/116, INRZ10NO/16, INRZ10NO/55 and INRZ10NO/40) were found to be outstanding in green leaf biomass proportion to total leaf biomass. Four hybrids (INRZ10NO/70, INRZ10NO/349, INRZ10NO/111 and INRZ10NO/33) were almost dead after 21 days of waterlogging (Table 7; Figures 16 and 17).



Tolerant check **Tolerant hybrid** **Sensitive hybrid**

Photo 4. Visual differences in waterlogging tolerance of two contrasting hybrids compared with the tolerant check.

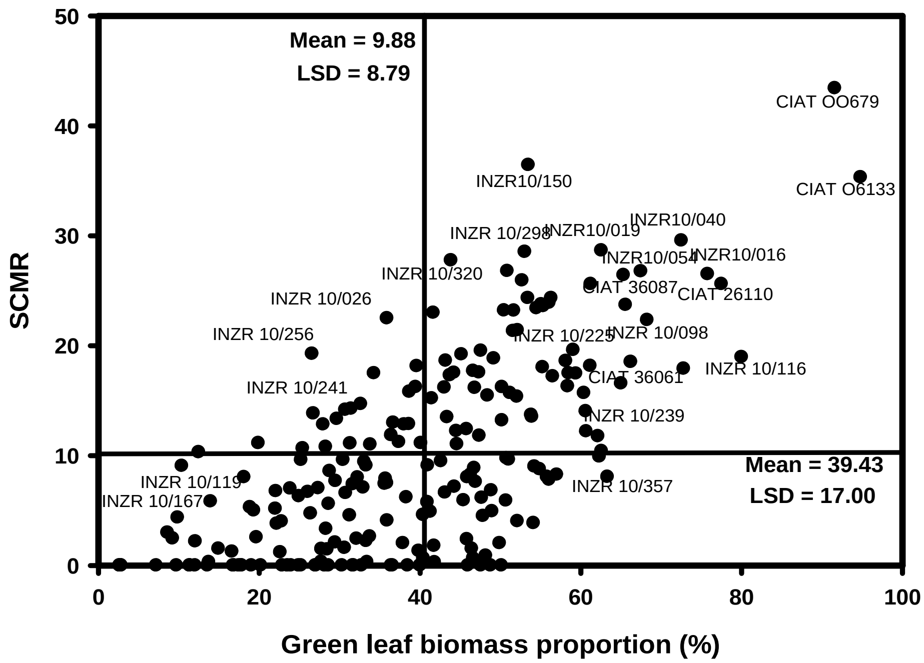


Figure 15. Relationship between green leaf biomass proportion (%) and SCMR of 217 *Brachiaria* genotypes after 21 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia.

Table 7. Green leaf biomass, green leaf area, SCMR, dead leaf biomass, visual evaluation and green leaf biomass proportion to total leaf biomass of 217 *Brachiaria* genotypes after 21 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia

Genotype	Green leaf biomass (g plant^{-1})	Green leaf area (cm^2 plant^{-1})	SPAD chlorophyll meter reading (SCMR)	Dead leaf biomass (g plant^{-1})	Visual Evaluation (1-9)	Green leaf biomass proportion (%)
Checks						
CIAT 6133	2.54	131.7	35.31	0.13	9	95
CIAT 679	2.96	183.4	43.41	0.29	9	92
CIAT 26110	3.93	242.6	25.59	1.16	6	78
CIAT 36061	2.88	312.5	18.51	1.43	5	66
CIAT 36087	2.24	200.1	26.41	1.19	6	65
CIAT 606	1.14	124.3	18.63	1.52	4	43
CIAT 6294	1.29	121.7	16.18	1.80	4	43
Br4X 44-02	0.71	42.7	0.30	1.51	4	33
Hybrids						
INRZ10NO/116	3.40	132.7	18.95	0.87	5	80
INRZ10NO/016	1.90	197.1	26.50	0.67	6	76
INRZ10NO/055	3.44	231.8	17.90	1.28	6	73
INRZ10NO/040	2.67	175.4	29.55	0.94	6	73
INRZ10NO/098	2.34	205.8	22.33	1.12	5	68
INRZ10NO/054	3.49	274.2	26.75	1.67	6	68
INRZ10NO/101	2.17	137.7	23.70	1.21	5	66
INRZ10NO/191	1.98	176.8	16.55	1.06	5	65
INRZ10NO/357	2.78	394.0	8.05	1.61	5	63
INRZ10NO/001	2.53	150.6	10.40	1.51	4	63
INRZ10NO/019	2.21	172.6	28.65	1.39	5	63
INRZ10NO/347	1.52	151.6	9.90	0.89	5	62
INRZ10NO/356	2.67	291.4	11.75	1.62	4	62
INRZ10NO/218	1.66	134.7	25.60	1.04	5	61
INRZ10NO/153	2.08	219.3	18.15	1.21	5	61
INRZ10NO/095	2.00	124.1	12.20	1.37	5	61
INRZ10NO/239	1.76	222.9	14.03	1.15	5	61
INRZ10NO/199	2.12	184.1	15.68	1.33	6	60
INRZ10NO/018	3.13	238.2	17.45	2.15	4	59
INRZ10NO/225	1.21	148.5	19.60	0.80	5	59
INRZ10NO/244	1.54	158.5	17.48	1.00	4	59
INRZ10NO/304	1.43	146.7	16.30	1.00	5	58
INRZ10NO/099	2.74	221.9	18.60	2.07	6	58
INRZ10NO/097	2.54	147.3	8.25	2.01	5	57
INRZ10NO/353	2.51	206.7	17.20	1.87	5	57
INRZ10NO/158	2.00	172.3	24.33	1.56	5	56
INRZ10NO/266	1.47	129.7	23.90	1.14	4	56
INRZ10NO/352	1.65	166.0	7.80	1.28	5	56
INRZ10NO/125	1.71	112.5	8.05	1.33	5	56
INRZ10NO/110	2.64	217.7	23.58	2.14	4	55

Table 7. Green leaf biomass, green leaf area, SCMR, dead leaf biomass, visual evaluation and green leaf biomass proportion to total leaf biomass of 217 *Brachiaria* genotypes after 21 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia

Genotype	Green leaf biomass (g plant^{-1})	Green leaf area (cm^2 plant^{-1})	SPAD chlorophyll meter reading (SCMR)	Dead leaf biomass (g plant^{-1})	Visual Evaluation (1-9)	Green leaf biomass proportion (%)
INRZ10NO/351	1.56	135.6	18.03	1.21	5	55
INRZ10NO/064	2.46	242.1	23.75	2.01	5	55
INRZ10NO/130	1.74	121.8	8.75	1.45	4	55
INRZ10NO/121	2.46	165.0	23.40	2.07	4	55
INRZ10NO/211	2.08	155.8	9.00	1.75	3	54
INRZ10NO/135	1.53	143.5	3.85	1.29	4	54
INRZ10NO/193	2.12	251.4	13.53	1.72	4	54
INRZ10NO/003	2.20	162.2	13.70	1.89	4	54
INRZ10NO/150	1.63	188.7	36.43	1.38	5	54
INRZ10NO/057	1.69	90.7	24.33	1.48	5	53
INRZ10NO/298	1.51	109.7	28.53	1.33	4	53
INRZ10NO/208	1.77	149.5	25.93	1.59	5	53
INRZ10NO/190	1.27	83.9	21.40	1.16	5	52
INRZ10NO/288	1.22	134.1	4.03	1.15	4	52
INRZ10NO/139	1.72	170.4	15.35	1.65	4	52
INRZ10NO/179	1.32	117.7	23.18	1.23	4	52
INRZ10NO/295	1.91	145.7	21.33	1.79	4	52
INRZ10NO/007	1.46	98.8	15.68	1.48	4	51
INRZ10NO/080	1.50	113.0	9.63	1.40	5	51
INRZ10NO/058	1.79	120.4	26.78	1.66	4	51
INRZ10NO/265	1.33	117.8	9.75	1.24	4	51
INRZ10NO/338	1.42	147.5	5.90	1.35	4	51
INRZ10NO/283	1.65	197.6	23.20	1.64	4	51
INRZ10NO/238	1.41	105.7	13.20	1.46	5	50
INRZ10NO/316	1.28	143.5	16.23	1.22	4	50
INRZ10NO/156	1.42	124.8	0.00	1.37	3	50
INRZ10NO/092	1.50	77.4	2.03	1.55	4	50
INRZ10NO/330	1.13	117.8	18.83	1.17	6	49
INRZ10NO/051	1.94	118.2	4.93	1.80	4	49
INRZ10NO/284	1.48	116.1	6.83	1.51	4	49
INRZ10NO/273	1.13	107.1	0.00	1.19	5	49
INRZ10NO/335	1.41	138.1	15.45	1.49	4	48
INRZ10NO/248	1.53	135.7	0.88	1.67	4	48
INRZ10NO/004	0.95	92.4	4.50	0.94	3	48
INRZ10NO/105	1.68	133.8	6.15	1.87	4	48
INRZ10NO/170	1.34	140.8	0.00	1.52	4	48
INRZ10NO/315	1.35	150.1	19.53	1.46	4	48
INRZ10NO/308	1.24	146.5	11.80	1.36	4	47
INRZ10NO/084	1.76	124.5	17.55	1.90	4	47
INRZ10NO/182	1.27	129.3	7.60	1.23	4	47

Table 7. Green leaf biomass, green leaf area, SCMR, dead leaf biomass, visual evaluation and green leaf biomass proportion to total leaf biomass of 217 *Brachiaria* genotypes after 21 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia

Genotype	Green leaf biomass (g plant^{-1})	Green leaf area (cm^2 plant^{-1})	SPAD chlorophyll meter reading (SCMR)	Dead leaf biomass (g plant^{-1})	Visual Evaluation (1-9)	Green leaf biomass proportion (%)
INRZ10NO/287	1.30	109.4	16.15	1.47	4	47
INRZ10NO/186	1.60	136.3	8.85	1.82	4	47
INRZ10NO/198	1.46	145.2	0.65	1.60	4	47
INRZ10NO/258	1.58	162.9	17.70	1.82	4	47
INRZ10NO/346	1.36	190.9	1.53	1.57	4	46
INRZ10NO/093	1.51	126.2	8.25	1.73	4	46
INRZ10NO/251	1.37	156.1	0.00	1.61	4	46
INRZ10NO/166	1.40	141.0	8.03	1.71	4	46
INRZ10NO/201	1.32	178.4	2.38	1.55	4	46
INRZ10NO/331	1.66	148.4	12.40	2.03	5	46
INRZ10NO/087	1.63	114.6	5.93	1.89	5	45
INRZ10NO/268	1.50	117.2	19.20	1.83	5	45
INRZ10NO/012	1.37	116.5	11.03	1.61	4	45
INRZ10NO/203	1.57	157.0	12.23	1.96	4	45
INRZ10NO/029	1.48	122.2	7.15	1.80	4	44
INRZ10NO/329	1.21	121.9	17.53	1.59	4	44
INRZ10NO/320	0.86	95.1	27.75	1.05	5	44
INRZ10NO/286	1.31	96.7	17.30	1.70	4	44
INRZ10NO/096	1.73	174.6	13.48	2.20	4	43
INRZ10NO/355	1.23	109.9	6.63	1.49	4	43
INRZ10NO/305	1.02	100.9	9.48	1.37	3	43
INRZ10NO/089	1.24	78.2	0.28	1.64	4	42
INRZ10NO/188	1.34	121.5	1.78	1.87	4	42
INRZ10NO/112	1.42	100.1	22.98	2.39	5	42
INRZ10NO/311	1.37	118.4	15.20	2.07	4	41
INRZ10NO/134	0.86	79.7	4.88	0.96	3	41
INRZ10NO/319	1.12	92.2	9.10	1.58	4	41
INRZ10NO/271	1.21	139.8	5.75	1.71	4	41
INRZ10NO/343	0.91	142.7	0.65	1.40	3	40
INRZ10NO/229	1.81	168.7	4.60	2.68	5	40
INRZ10NO/132	1.39	147.7	11.13	2.15	4	40
INRZ10NO/197	1.17	131.3	0.00	1.75	4	40
INRZ10NO/078	0.92	82.9	1.33	1.11	5	40
INRZ10NO/015	1.43	116.1	18.13	2.11	4	40
INRZ10NO/163	0.98	138.9	16.23	1.41	4	39
INRZ10NO/243	1.20	135.1	15.80	1.84	4	39
INRZ10NO/230	1.05	107.5	12.85	1.66	5	39
INRZ10NO/332	1.39	132.4	0.00	2.24	4	38
INRZ10NO/011	1.15	121.4	6.20	1.41	4	38
INRZ10NO/207	1.01	118.9	12.83	1.74	3	38

Table 7. Green leaf biomass, green leaf area, SCMR, dead leaf biomass, visual evaluation and green leaf biomass proportion to total leaf biomass of 217 *Brachiaria* genotypes after 21 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia

Genotype	Green leaf biomass (g plant^{-1})	Green leaf area (cm^2 plant^{-1})	SPAD chlorophyll meter reading (SCMR)	Dead leaf biomass (g plant^{-1})	Visual Evaluation (1-9)	Green leaf biomass proportion (%)
INRZ10NO/056	1.75	150.3	2.03	3.19	4	38
INRZ10NO/302	1.00	79.2	11.23	1.60	4	37
INRZ10NO/196	1.01	112.4	12.98	1.74	4	37
INRZ10NO/213	1.09	118.7	0.00	2.13	4	37
INRZ10NO/010	1.04	108.7	11.85	2.12	5	36
INRZ10NO/242	0.98	112.9	0.00	1.77	4	36
INRZ10NO/227	1.12	121.3	4.08	2.02	4	36
INRZ10NO/026	0.80	67.1	22.48	1.59	4	36
INRZ10NO/162	1.07	82.7	7.48	1.83	3	36
INRZ10NO/005	1.00	59.3	7.88	1.61	3	36
INRZ10NO/327	1.18	162.4	7.43	2.20	5	36
INRZ10NO/148	1.23	121.0	17.48	2.43	4	34
INRZ10NO/200	1.23	134.7	11.00	2.27	4	34
INRZ10NO/269	0.87	83.6	2.63	1.69	3	34
INRZ10NO/189	0.83	109.1	2.23	1.69	3	33
INRZ10NO/025	1.15	112.8	9.08	1.94	4	33
INRZ10NO/237	0.74	76.6	9.43	1.59	4	33
INRZ10NO/030	0.99	85.2	7.08	2.06	3	33
INRZ10NO/301	0.93	87.9	0.00	1.93	4	33
INRZ10NO/341	1.22	116.2	14.68	2.39	4	33
INRZ10NO/259	0.89	110.9	8.00	1.86	4	32
INRZ10NO/246	1.15	118.2	2.43	2.40	4	32
INRZ10NO/285	0.79	114.4	0.00	1.67	4	32
INRZ10NO/231	1.14	133.1	7.38	2.44	4	32
INRZ10NO/204	0.84	73.2	0.00	1.80	4	32
INRZ10NO/192	0.87	79.9	14.25	1.97	3	31
INRZ10NO/173	0.80	78.1	11.10	1.82	3	31
INRZ10NO/296	1.15	112.5	4.55	2.54	4	31
INRZ10NO/017	1.04	73.7	6.58	2.39	3	31
INRZ10NO/106	1.44	161.5	14.15	3.34	4	31
INRZ10NO/282	1.01	129.4	1.60	2.11	3	31
INRZ10NO/161	0.96	109.8	9.60	2.20	4	30
INRZ10NO/280	0.73	87.0	0.00	1.60	3	30
INRZ10NO/185	0.89	99.6	13.33	2.10	4	30
INRZ10NO/175	0.69	49.9	7.68	1.98	4	30
INRZ10NO/032	1.22	103.2	2.08	2.27	2	29
INRZ10NO/233	0.66	59.4	8.58	1.63	3	29
INRZ10NO/094	1.20	130.0	5.60	2.92	4	29
INRZ10NO/143	0.83	76.9	0.00	2.07	4	29
INRZ10NO/205	0.87	94.5	1.45	2.31	4	28

Table 7. Green leaf biomass, green leaf area, SCMR, dead leaf biomass, visual evaluation and green leaf biomass proportion to total leaf biomass of 217 *Brachiaria* genotypes after 21 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia

Genotype	**Green leaf biomass (g plant^{-1})**	**Green leaf area (cm^2 plant^{-1})**	**SPAD chlorophyll meter reading (SCMR)**	**Dead leaf biomass (g plant^{-1})**	**Visual Evaluation (1-9)**	**Green leaf biomass proportion (%)**
INRZ10NO/183	1.02	97.6	3.33	2.58	5	28
INRZ10NO/187	0.86	79.8	10.78	2.31	5	28
INRZ10NO/240	0.78	80.4	0.00	1.89	3	28
INRZ10NO/171	1.14	99.9	12.83	2.64	4	28
INRZ10NO/137	1.03	113.4	1.50	3.11	4	28
INRZ10NO/350	0.69	68.0	0.33	1.68	3	28
INRZ10NO/354	0.70	60.0	7.03	1.95	3	27
INRZ10NO/155	0.74	62.4	0.00	1.99	3	27
INRZ10NO/177	0.77	40.3	0.00	1.96	3	27
INRZ10NO/181	0.39	23.5	13.83	1.21	3	27
INRZ10NO/256	0.69	87.4	19.25	1.85	3	27
INRZ10NO/100	1.15	103.7	4.73	2.97	4	26
INRZ10NO/344	0.66	57.5	6.68	1.89	3	26
INRZ10NO/034	0.93	43.4	10.65	2.57	2	25
INRZ10NO/062	0.78	63.8	9.60	1.89	4	25
INRZ10NO/348	0.88	67.8	0.00	2.61	3	25
INRZ10NO/264	0.62	68.1	6.30	1.84	3	25
INRZ10NO/245	0.76	84.4	0.00	2.03	3	25
INRZ10NO/140	0.77	94.4	0.00	2.61	4	24
INRZ10NO/020	0.76	53.6	7.00	2.44	3	24
INRZ10NO/336	0.50	56.9	0.00	1.59	3	24
INRZ10NO/235	0.76	71.8	0.00	2.46	3	23
INRZ10NO/002	1.00	125.1	4.00	3.02	3	23
INRZ10NO/131	0.74	68.4	1.20	2.45	3	23
INRZ10NO/292	0.42	46.3	3.80	1.44	3	22
INRZ10NO/306	0.43	26.8	6.75	1.51	2	22
INRZ10NO/261	0.62	71.3	5.15	2.32	3	22
INRZ10NO/086	0.57	72.6	0.00	2.09	3	20
INRZ10NO/324	0.69	87.9	11.13	2.43	3	20
INRZ10NO/091	0.60	33.3	2.55	2.34	2	20
INRZ10NO/114	0.62	54.0	5.00	2.19	2	19
INRZ10NO/068	0.75	67.9	0.00	3.19	3	19
INRZ10NO/194	0.54	57.1	5.30	2.27	3	19
INRZ10NO/172	0.52	43.3	8.03	2.28	3	18
INRZ10NO/307	0.45	33.0	0.00	1.90	2	18
INRZ10NO/127	0.43	54.4	0.00	2.06	3	18
INRZ10NO/226	0.54	67.1	0.00	2.72	3	17
INRZ10NO/195	0.48	48.4	0.00	2.28	3	17
INRZ10NO/267	0.43	42.7	0.00	1.88	3	17
INRZ10NO/014	0.55	27.9	1.25	2.73	3	17

Table 7. Green leaf biomass, green leaf area, SCMR, dead leaf biomass, visual evaluation and green leaf biomass proportion to total leaf biomass of 217 *Brachiaria* genotypes after 21 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia

Genotype	Green leaf biomass (g plant^{-1})	Green leaf area (cm^{2} plant^{-1})	SPAD chlorophyll meter reading (SCMR)	Dead leaf biomass (g plant^{-1})	Visual Evaluation (1-9)	Green leaf biomass proportion (%)
INRZ10NO/136	0.61	54.6	1.53	3.15	3	15
INRZ10NO/119	0.32	24.1	5.83	1.97	3	14
INRZ10NO/109	0.57	57.0	0.30	3.40	2	14
INRZ10NO/082	0.34	28.7	0.00	1.97	3	14
INRZ10NO/103	0.34	31.1	10.30	2.47	1	13
INRZ10NO/085	0.36	18.0	2.18	2.47	2	12
INRZ10NO/277	0.30	44.7	0.00	2.20	2	12
INRZ10NO/291	0.27	34.5	0.00	1.96	2	11
INRZ10NO/144	0.36	44.6	0.00	2.75	3	11
INRZ10NO/123	0.30	18.1	9.05	1.20	3	10
INRZ10NO/167	0.26	20.1	4.35	2.38	2	10
INRZ10NO/228	0.26	27.8	0.00	2.38	3	10
INRZ10NO/108	0.36	37.0	2.45	3.58	3	9
INRZ10NO/071	0.26	26.0	2.98	2.79	2	9
INRZ10NO/024	0.23	16.9	0.00	2.40	2	7
INRZ10NO/070	0.10	5.50	0.00	3.18	1	3
INRZ10NO/349	0.07	7.30	0.00	2.40	1	3
INRZ10NO/111	0.11	25.4	0.00	3.80	2	3
INRZ10NO/033	0.07	5.70	0.00	2.54	1	3
Mean	**1.26**	**114.24**	**9.88**	**1.84**	**4**	**39**
$LSD_{0.05}$	**0.69**	**58.76**	**8.79**	**0.58**	**1**	**17**

Significant positive correlations were found of the results obtained from replications 1 and 2 (Table 8). Visual evaluation, green leaf biomass and leaf area showed very high positive correlation with green leaf biomass proportion to total leaf biomass (Table 9). SCMR showed positive association and dead leaf biomass showed negative association with the green leaf biomass (Table 10).

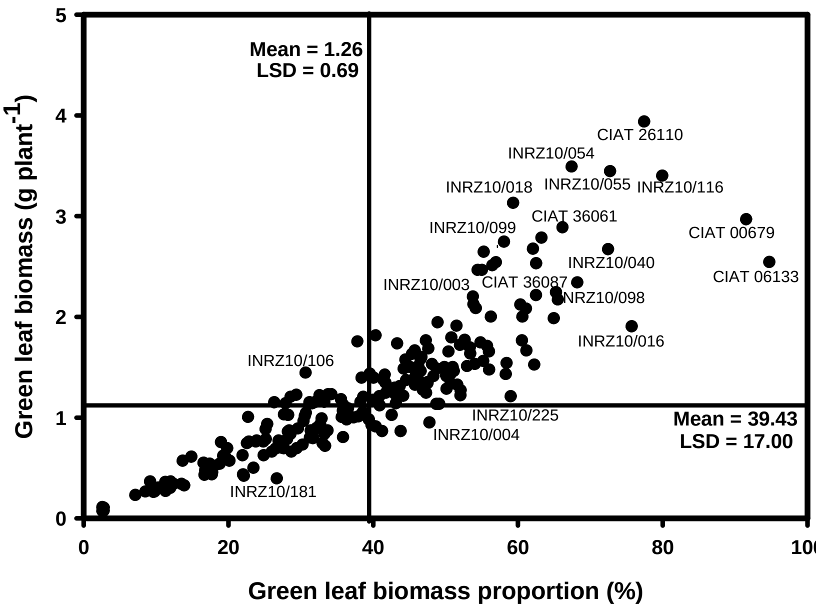


Figure 16. Relationship between green leaf biomass proportion (%) and green leaf biomass of 217 *Brachiaria* genotypes after 21 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia.

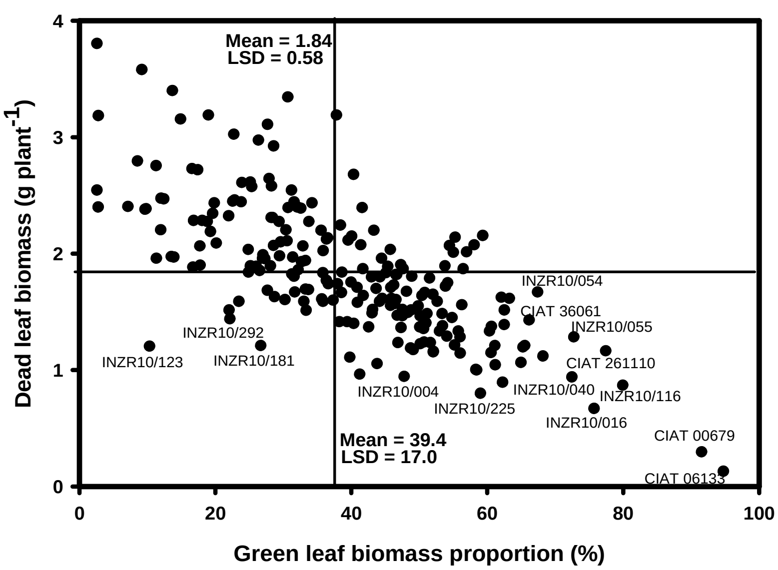


Figure 17. Relationship between green leaf biomass proportion (%) and dead leaf biomass of 217 *Brachiaria* genotypes after 21 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia.

Table 8. Correlation coefficients (r) between replication 1 and 2 among shoot traits of 217 *Brachiaria* genotypes after 21 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia

Plant traits	Correlation coefficient (r)
Green leaf biomass (g plant $^{-1}$)	0.55***
Green leaf area (cm^2 plant $^{-1}$)	0.35***
SCMR	0.34***
Dead leaf biomass (g plant $^{-1}$)	0.41***
Stem biomass (g plant $^{-1}$)	0.56***
Visual evaluation (1-9)	0.45***
Green leaf biomass proportion (%)	0.47***

*** Significant at 0.001 probability level.

Table 9. Correlation coefficients (r) between green leaf biomass proportion to total leaf biomass (%) and other shoot traits of 217 *Brachiaria* genotypes after 21 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia

Plant traits	Correlation coefficient (r)
SCMR	0.59***
Photosynthetic efficiency (fv'/fm')	0.49***
Green leaf area (cm^2 plant^{-1})	0.78***
Green leaf biomass (g plant^{-1})	0.88***
Dead leaf biomass (g plant^{-1})	-0.74***
Stem biomass (g plant^{-1})	0.40***
Total shoot biomass (g plant^{-1})	0.42***
Visual Evaluation (1-9)	0.82***

*** Significant at the 0.001 probability level.

Table 10. Correlation matrix (r) among shoot traits of 217 *Brachiaria* genotypes after 21 days of waterlogging in an Oxisol from Santander de Quilichao, Colombia

	SCMR	**Photosyn-thetic efficiency**	**Green leaf area**	**Green leaf biomass**	**Dead leaf biomass**	**Stem biomass**	**Shoot biomass**	**Visual Evaluation**
SCMR	1.00							
Photosynthetic efficiency	0.69***	1.00						
Green leaf area	0.42***	0.29***	1.00					
Green leaf biomass	0.54***	0.40***	0.85***	1.00				
Dead leaf biomass	-0.42***	-0.39***	-0.41***	-0.45***	1.00			
Stem biomass	0.29***	0.22***	0.39***	0.42***	-0.20***	1.00		
Shoot biomass	0.31***	0.20***	0.54***	0.62***	0.06*	0.88***	1.00	
Visual Evaluation	0.60***	0.48***	0.65***	0.73***	-0.56***	0.40***	0.42***	1.00

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

Conclusions

We evaluated 209 sexual hybrids of *Brachiaria* from INRZ10NO series along with 9 checks for their tolerance to waterlogging and identified four sexual hybrids (INRZ10NO/116, INRZ10NO/16, INRZ10NO/55 and INRZ10NO/40) as superior than the other sexual hybrids based on green leaf biomass proportion to total leaf biomass. Visual evaluation showed marked correlation with plant attributes measured and it could be useful to eliminate large number of hybrids from the breeding population.

1.6.6 Variation for root aerenchyma formation in accessions of *B. humidicola* under waterlogged and drained soil conditions

Contributors: Cardoso, J.A.; Jiménez, J.C.; Rincón, J.D.; Rao, I.M. (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. We previously investigated phenotypic differences in aerenchyma formation in *Brachiaria* genotypes and among them, *B. humidicola* showed high levels of root porosity in either drained or waterlogged conditions, suggesting that this could be a constitutive trait. Our objectives for this study were: 1) to investigate in greater detail the formation of aerenchyma in different parts of the root system with and without waterlogged conditions and 2) to evaluate aerenchyma formation in *B. humidicola* accessions that exhibit varied levels of waterlogging tolerance.

Materials and methods

A pot experiment was conducted in the forages patio area of CIAT-Palmira from September 13th to October 13th, 2010 to determine differences in aerenchyma formation in roots of *B. humidicola* accessions with varied tolerance to waterlogging. The classification of the genotypes is based on previous experiments. Genotypes tested included three accessions that are highly tolerant (CIAT 679, CIAT 6133, CIAT 6707) and three accessions that are less tolerant (CIAT 16080, CIAT 16183 and CIAT 16876) to waterlogging.

The trial was designed as a randomized complete block with four replications. Each experimental unit consisted of one pot filled with 1.25 kg of a mixture of top soil (0-20 cm) from Santander de Quilichao (Oxisol) and sand (50:50) 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 potting mix 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 30 days. Plants without waterlogged soils and maintained at field capacity (drained) were used as a control.

Proportion of aerenchyma and stele area: The percentage of aerenchyma and stele area of healthy adventitious roots (shoot-borne crown) was quantified. The percentage of aerenchyma and stele area was measured in transverse sections taken for each 50 mm of root length behind the root tip. Subsequently, hand cross sections were taken and photographed with a digital camera connected to a Leitz Ortholux II Microscope. The area of aerenchyma and stele within each image captured was measured using ImageJ software.

Results

The maximum temperature during the experimental period ranged from 26ºC to 32ºC while the minimum temperature ranged from 18ºC to 21ºC. The solar radiation ranged from 8.7 to 22.9 MJ m^{-2} d^{-1}.
For all *B. humidicola* accessions, with exception of CIAT 6707, a 30 day waterlogging treatment resulted in either a reduction of root or shoot biomass (Table 11) All *B. humidicola* accessions showed root aerenchyma in either drained or waterlogged soil conditions, but waterlogging treatment increased the percentage of total aerenchyma along the roots (Table 12: Figures 18 and 19). In both conditions, percentage of root aerenchyma increased from the root tip to the root-shoot junction (Table 12).

The accessions that showed higher levels of aerenchyma under drained conditions presented higher levels of aerenchymatous tissue under waterlogged soils also. As expected, the highly tolerant genotypes (CIAT 679, CIAT 6133 and CIAT 6707) showed higher % of aerenchyma formation than the less tolerant accessions under waterlogged conditions. Growth in waterlogged soil decreased the proportional area of stele of the highly adapted genotypes (Table 13). The percentage of aerenchyma formed under waterlogged conditions was highly correlated with total shoot biomass under waterlogged conditions (Figure 20).

Table 11. Influence of 30 days of waterlogging treatment on shoot and root biomass production compared with well drained conditions

	Shoot dry biomass (g pot^{-1})		Root dry biomass (g pot^{-1})	
Genotype	Drained	Waterlogged	Drained	Waterlogged
CIAT 16183	23.50 ± 1.73	16.46 ± 3.95	3.15 ± 0.99	1.59 ± 0.83
CIAT 16876	22.96 ± 3.80	20.52 ± 3.83	2.70 ± 0.98	1.15 ± 0.43
CIAT 16180	32.38 ± 4.94	25.53 ± 8.51	5.82 ± 1.42	1.99 ± 0.77
CIAT 6707	26.99 ± 1.23	27.86 ± 1.96	8.48 ± 1.17	9.87 ± 4.42
CIAT 6133	37.31 ± 5.26	32.76 ± 4.18	9.20 ± 1.61	5.59 ± 1.46
CIAT 679	28.85 ± 1.77	34.96 ± 8.08	9.58 ± 2.90	6.17 ± 1.05
LSD < 0.01	9.45	15.10	4.43	5.40

Values are the means of four replicates ± standard errors.

Table 12. Percentage of aerenchyma in adventitious roots of *B. humidicola* grown in well drained compared with waterlogged soil

	Drained			Waterlogged		
Genotype	50 mm	100 mm	150 mm	50 mm	100 mm	150 mm
CIAT 16183	4.08 ± 5.44	7.73 ± 6.89	11.36 ± 9.85	6.73 ± 8.83	9.48 ± 4.01	18.08 ± 4.56
CIAT 16876	3.49 ± 3.98	4.01 ± 6.07	8.75 ± 3.58	11.22 ± 5.45	14.57 ± 3.04	22.84 ± 2.56
CIAT 16180	0	7.45 ± 4.72	10.56 ± 4.09	21.53 ± 5.89	21.8 ± 6.06	25.06 ± 5.35
CIAT 6707	0	6.75 ± 2.13	13.21 ± 6.06	6.44 ± 9.19	14.62 ± 4.81	24.53 ± 5.68
CIAT 6133	0.05 ± 0.10	9.66 ± 5.48	11.94 ± 3.95	21.21 ± 6.94	29.12 ± 15.84	26.01 ± 6.39
CIAT 679	3.68 ± 4.06	9.66 ± 4.72	15.73 ± 3.23	28.99 ± 5.22	25.45 ± 7.94	33.09 ± 4.46
LSD < 0.05	N.S	N.S.	N.S	15.18	17.45	10.66

Aerenchyma (%) was measured on cross sections taken from adventitious at 50, 100 and 150mm from the root tip. Values are the means of four replicates ± standard errors. N.S.: Not significant

Table 13. Relative proportion (%) ocuppied by stele in adventitious roots of *B. humidicola* grown in drained or waterlogged soil

Proportion of stele in root cross sections (%)		
Genotype	Drained	Waterlogged
CIAT 16183	11.34 ± 0.89	12.47 ± 2.44
CIAT 16876	10.95 ± 2.35	15.2 ± 1.10
CIAT 16180	8.95 ± 0.59	9.4 ± 0.94
CIAT 6707	10.41 ± 0.59	6.5 ± 0.76
CIAT 6133	11.42 ± 1.8	6.15 ± 0.65
CIAT 679	10.3 ± 1.28	6.55 ± 0.93
LSD < 0.01	N.S.	3.45

Stele (%) was measured on cross sections taken from adventitious roots of ~150mm in length. Values are the means of four replicates ± standard errors. N.S. Not significant

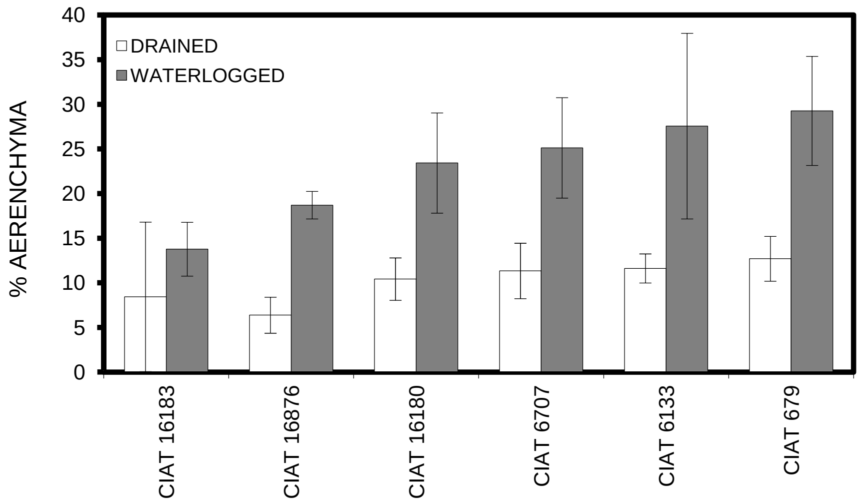


Figure 18. Percentage of aerenchyma in adventitious roots of *B. humidicola* grown in drained or waterlogged soil. Aerenchyma (%) was measured on cross sections taken from adventitious roots of ~150mm in length. Aerenchyma was calculated pooling data taken along the roots but not including values of 0% taken close to the root tip. Values are the means of four replicates ± standard deviation.

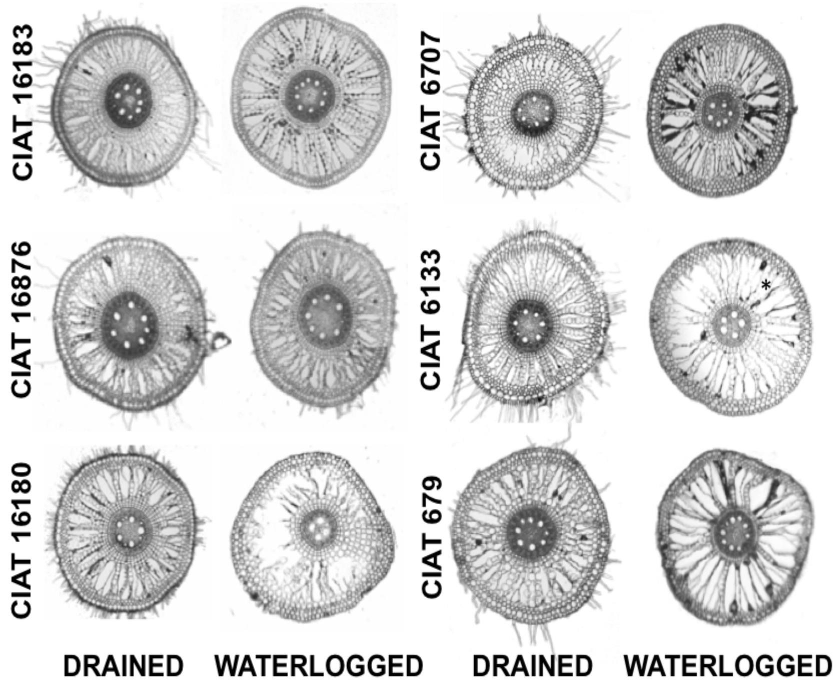


Figure 19. Formation of aerenchyma in roots of *B. humidicola* under drained and waterlogged soil. Sections taken at 100 mm from the root apex. Asterisk represents aerenchyma. Note the relatively unchanged size of the stele in waterlogged conditions of the genotypes CIAT 16876 and CIAT 16183.

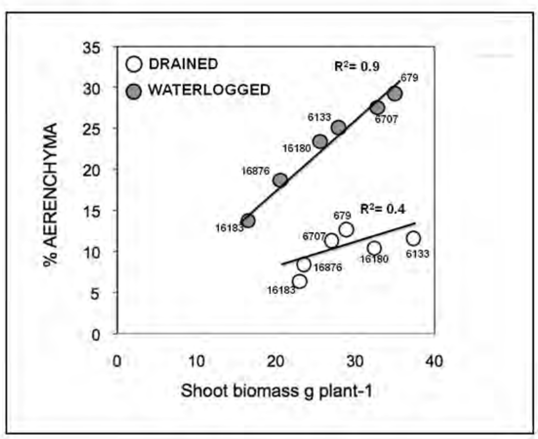


Figure 20. Relationship between percentage of aerenchyma in adventitious roots and shoot biomass after 30 days of waterlogging. Plotted data are means of four replicates.

Conclusions

This study supports the current hypothesis that aerenchyma is formed constitutively in *B. humidicola*. All genotypes responded to soil waterlogging by increasing the formation of aerenchyma. Results indicate that a higher percentage of aerenchyma formed under drained conditions would be beneficial since a plant possessing aerenchyma under non-waterlogged conditions, may be able to adapt faster to hypoxic conditions when these occur. In addition, roots with a smaller stele volume relative to the whole root could be able to adapt better to waterlogging stress due to: i) a pontentially greater cortex in which aerenchyma can be formed, and ii) a lower demand for O_2 consumption. These results indicate that the capacity to increase the proportional area of aerenchyma together with the reduction in the relative proportion of stele under waterlogged conditions should be of adaptive advantage at the onset as well as during waterlogged conditions.

1.6.7 Field evaluation of promising hybrids of *Brachiaria* in an Oxisol near Puerto López in the Llanos region of Colombia

Contributors: Ricaurte, J.; Vergara, D,; García, G.; Borrero, G.; Miles, J.W.; Rao, I.M. (CIAT)

Rationale

Previous research conducted on field evaluation of a number *Brachiaria* hybrids under infertile acid soil conditions in the Llanos of Colombia has shown that low or high amounts of initial application of fertilizer, and application of maintenance fertilizer with half of the amounts of initial applications at 2 year intervals, improved the persistence of several hybrids but not allowed to distinguish differences between moderately adapted cultivars (cv. Marandú) and the promising hybrids. Therefore a field experiment was established in May 2009 with 8 hybrids along with 2 parents and one check with low amounts of initial application of fertilizer and no maintenance fertilizer application to select hybrids that persist and produce green forage under acid infertile soil conditions. In August 2009, we tested the performance of these hybrids in the dry season at 3.5 months after establishment. The same group of genotypes was evaluated in June 2010 in the rainy season at 13 months after establishment.

Materials and Methods

A field trial was established at El Porvenir farm, near Puero López in the Llanos of Colombia, in May 2009. The soil is an Oxisol with a clay loam texture in top 10 cm and clay texture from 10 to 80 cm soil depth, low organic matter content, low levels of exchangeable potassium (K), calcium (Ca) and magnesium (Mg), high level of exchangeable aluminum (Al) and Al saturation with low levels of available P and micronutrients (Table 14). The trial included two parents (*B. decumbens* CIAT 606 and *B. brizantha* CIAT 6294) of the *Brachiaria* breeding program and 8 *Brachiaria* hybrids (BR02NO/1752; BR02NO/1794, BR06NO/0204; BR06NO/0531; BR06NO/1000; BR06NO/1454; BR06 NO/1932 and BR06NO/2020), and one *Brachiaria* commercial hybrid (CIAT 36087- Mulato II) as a check. The trial was planted as a randomized complete block with 4 replications. Only a low level of initial fertilizer application (kg ha^{-1} of 20P, 20K, 33Ca, 14 Mg, 10S) was made with no micronutrients at the time of establishment. Maintenance fertilizer was not scheduled for application in order to identify genotypes that are better adapted to infertile acid soil conditions. The plot size was 3.5 m x 3 m (6 rows with a row-to-row spacing of 0.5 m and with a plant-to-plant spacing of 0.5 m). A number of plant attributes including forage yield, dry matter distribution, chlorophyll content (SPAD chlorophyll meter reading), quantum yield of photosynthesis, canopy temperature depression (ambient temperature minus canopy temperature) and stomatal conductance were measured after a short dry season at 3.5 months after establishment (August 2009). Plant attributes such as forage yield, dry matter distribution, nutrient uptake in living shoot biomass, stem and leaf content of ash and total nonstructural carbohydrates were determined in rainy season at 13 months after establishment (June 2010). The field view of the trial during the establishment period is shown in Photo 5.

Table 14. Soil characteristics of a field site near Puerto López, in the Llanos of Colombia

SD (cm)	TC	*SOM* *(g kg^{-1})*	K (cmol$_c$ kg^{-1})	Ca	Mg	Al	Als (%)	P (µg g^{-1})	S	Fe	Mn	Zn	Cu	B
0-5	Cl	*31.0*	0.059	0.590	0.089	1.84	72	2.7	19.3	39.0	2.45	1.02	0.32	0.29
5-10	Cl	*24.5*	0.053	0.346	0.054	1.71	79	1.7	17.9	27.2	1.21	0.63	0.23	0.23
10-20	C	*16.2*	0.031	0.179	0.036	1.48	86	1.4	16.6	19.2	0.81	0.62	0.18	0.17
20-40	C	*8.6*	0.023	0.178	0.044	1.15	82	1.5	9.5	11.8	0.49	0.40	0.12	0.13
40-60	C	*6.5*	0.028	0.106	0.030	0.92	85	1.4	11.6	7.1	0.39	0.49	0.13	0.12
60-80	C	*5.4*	0.031	0.108	0.030	0.87	84	1.6	9.6	7.1	0.40	0.55	0.10	0.11

SD= soil depth;TC= texture class (Cl = clay loam, C= clay); SOM= soil organic matter; K, Ca, Mg and Al = exchangeable potassium, calcium, magnesium and aluminum, respectively; Als= Al saturation; P, S, Fe, Mn, Zn, Cu and B= available phosphorus, sulfur, iron, manganese, zinc, copper and boron, respectively)

Photo 5. A field view of the trial during the establishment period in a farm near Puerto López in the Llanos of Colombia.

Results and Discussion

After 3 months of establishment, three hybrids (BR02NO/1794, BR06 NO/1932 and BR02NO/1752), one parent (*B. brizantha* CIAT 6294) and one check hybrid (CIAT 36087) showed greater amounts of living shoot biomass (Figure 21). These five genotypes also showed higher values of canopy temperature depression than four other genotypes (Figure 22). One of the parents, *B. brizantha* CIAT 6294 was outstanding in keeping its canopy cooler as reflected by lower value of canopy temperature and higher value of canopy temperature depression. Measurements of stomatal conductance to water vapor in fully expanded leaf revealed that one parent (*B. brizantha* CIAT 6294) and four hybrids (BR06NO/1932, BR06NO/1454, BR06NO/0204 and BR06NO/2020) were superior than the other genotypes in keeping their stomata open under ambient high temperature (34°C) conditions (Figure 23). Results on correlation coefficients indicated significant positive association between green forage yield (living shoot biomass) and a number of plant attributes including leaf biomass, stem biomass and total shoot biomass (Table 15). No significant association between forage yield and physiological attributes such as canopy temperature, canopy temperature depression, stomatal conductance, chlorophyll content (SPAD) and quantum yield of photosynthesis of fully expanded leaf at 3.5 months after establishment.

After 13 months of establishment, the average value of forage yield (1938 kg ha^{-1}) for 11 genotypes was markedly lower than that of the average value at 3.5 months after establishment (3470 kg ha^{-1}). One parent (*B. brizantha* CIAT 6294), three hybrids (BR02NO/1794, BR02NO/1752 and BR06 NO/1932) and one check (CIAT 36087) showed greater production of living shoot biomass (Figure 21). Leaf biomass was an important contributor to forage yield for *B. brizantha* CIAT 6294 and CIAT 36087 while stem biomass was major contributor to forage yield for BR02NO/1794 hybrid (Figure 21). Shoot nutrient uptake was greater with three hybrids (BR02NO/1794, CIAT 36087, BR02NO/1752) while it was lower with *B. decumbens* CIAT 606 (Figure 24). Significant genotypic differences were found in shoot N, P, Ca and Mg uptake but not in shoot K uptake. Three genotypes (BR02NO/1794, CIAT 36087 and CIAT 6294) were found superior in N and P uptake. The check hybrid (CIAT 36087) was superior in both living shoot biomass production and animal intake than the other genotypes tested (Figure 25).

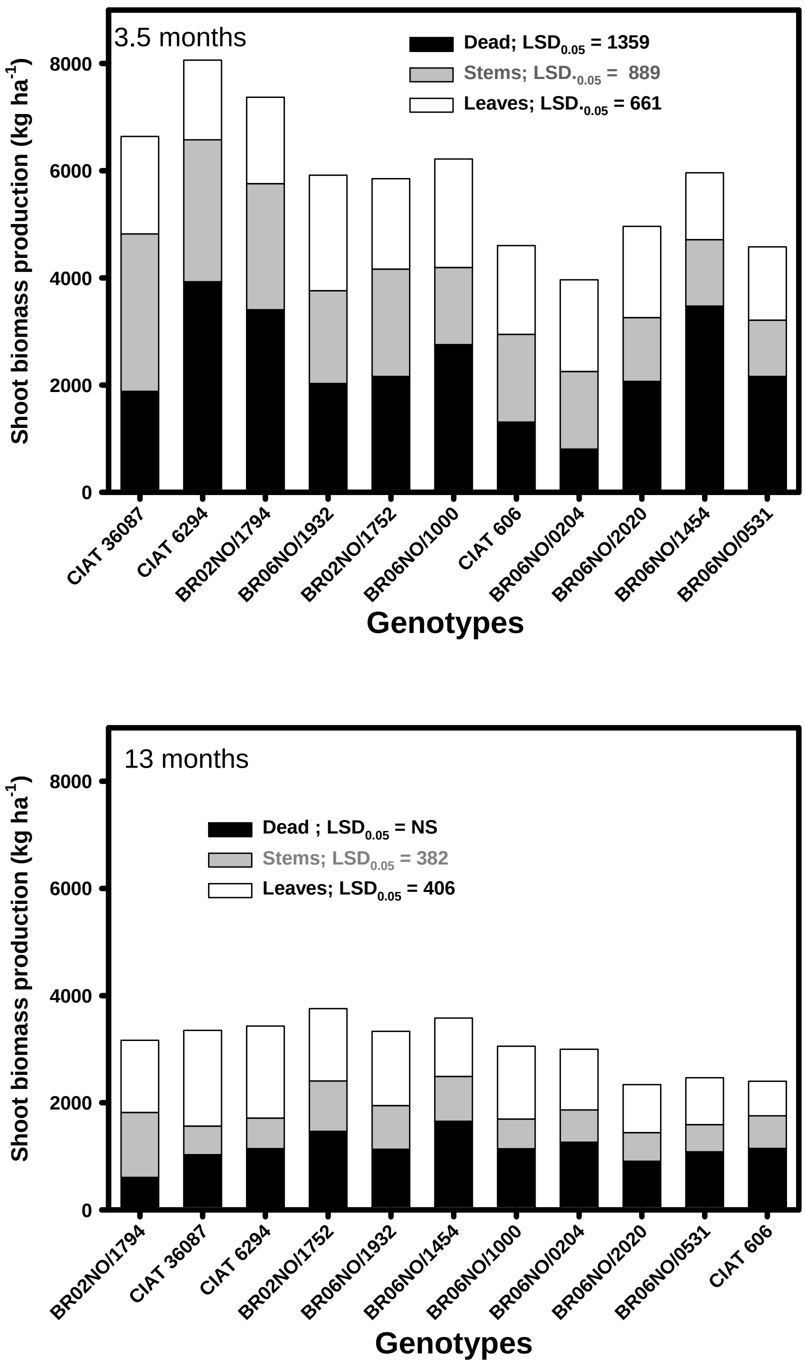


Figure 21. Genotypic variation in shoot biomass production (forage yield) of 11 *Brachiaria* genotypes grown in an Oxisol near Puerto López in the Llanos of Colombia. Measurements were made at 3.5 months (dry season-August 2009) and 13 months (rainy season-June 2010) after establishment. LSD values are at the 0.05 probability level.

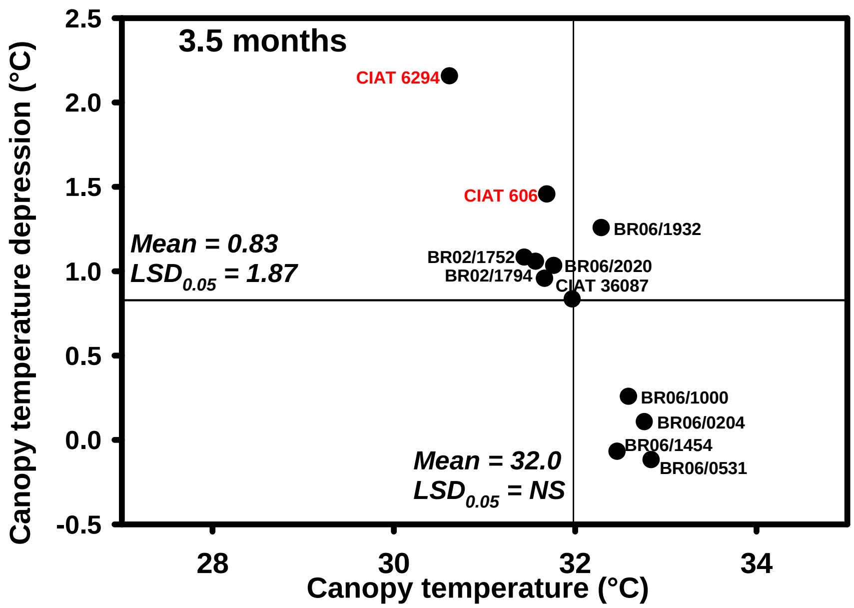


Figure 22. Relationship between canopy temperature and canopy temperature depression of 11 *Brachiaria* genotypes grown in an Oxisol near Puerto López in the Llanos of Colombia. Measurements were made at 3.5 months (dry season-August 2009) after establishment. LSD values are at the 0.05 probability level.

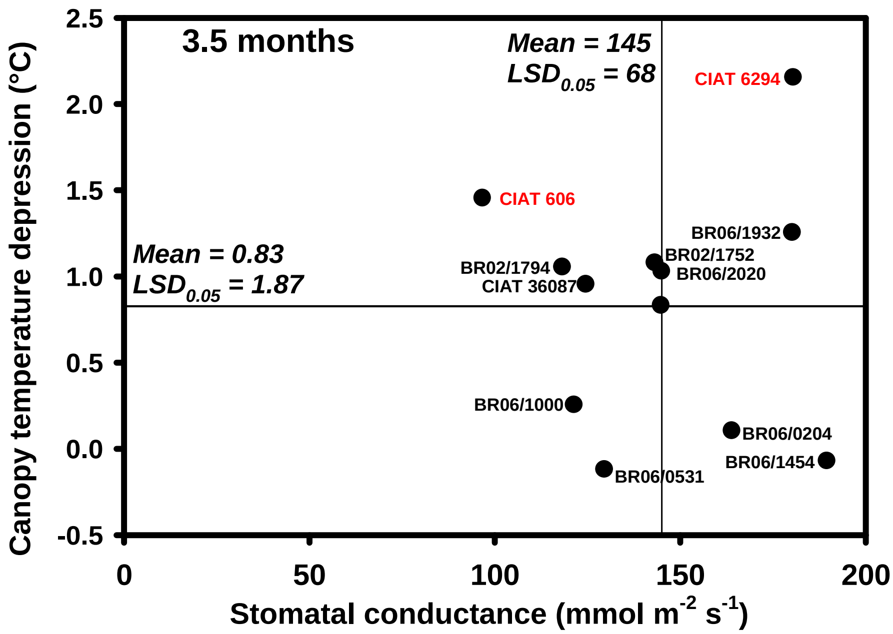


Figure 23. Relationship between canopy temperature depression and stomatal conductance of 11 *Brachiaria* genotypes grown in an Oxisol near Puerto López in the Llanos of Colombia. Measurements were made at 3.5 months (dry season-August 2009) after establishment. LSD values are at the 0.05 probability level.

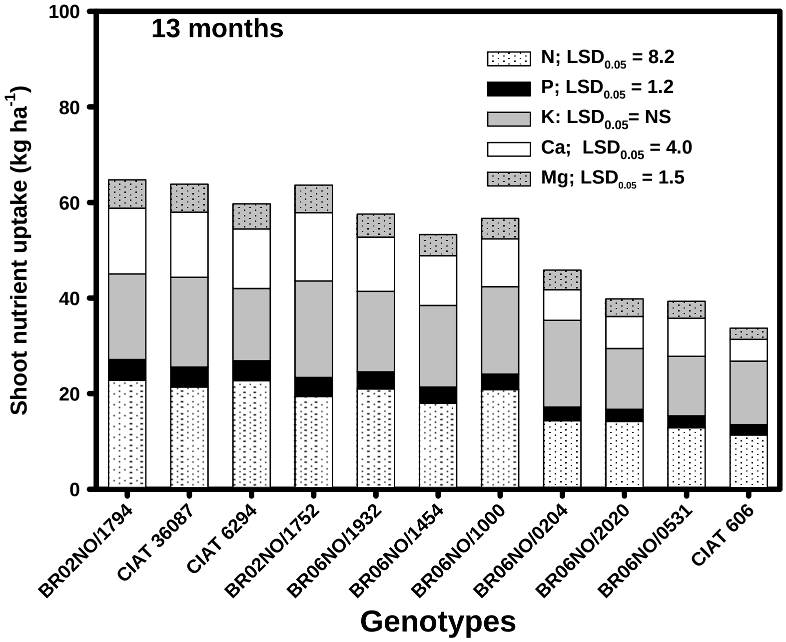


Figure 24. Genotypic variation in nutrient (N, P, K, Ca and Mg) uptake in living biomass of 11 *Brachiaria* genotypes grown in an Oxisol near Puerto López in the Llanos of Colombia. Measurements were made at 13 months (rainy season – June 2010) after establishment. LSD values are at the 0.05 probability level.

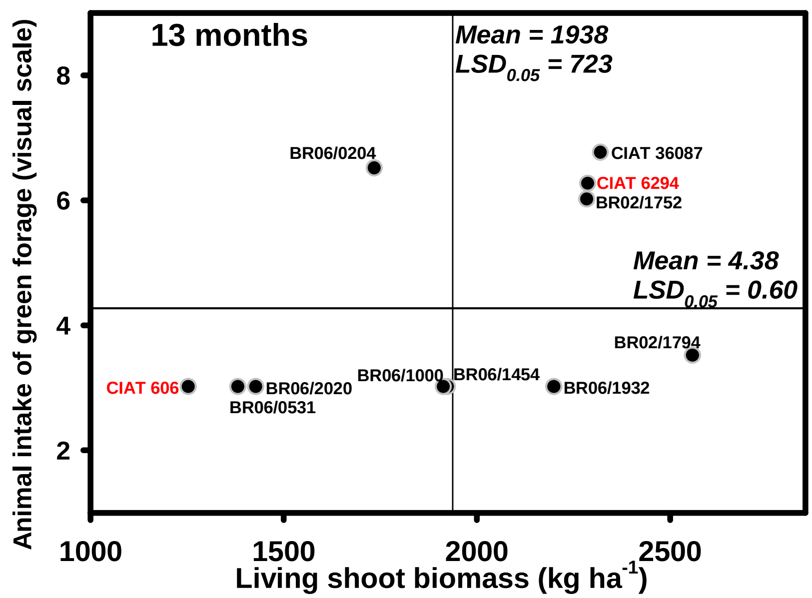


Figure 25. Relationship between animal intake of green forage (based on a visual scale, 1 is low and 9 is high) and living shoot biomass (forage yield) of 11 *Brachiaria* genotypes grown in an Oxisol near Puerto López in the Llanos of Colombia. Measurements were made at 13 months (rainy season – June 2010) after establishment. LSD values are at the 0.05 probability level.

Table 15. Correlation coefficients (r) between green forage yield (kg ha^{-1}) and other shoot attributes of *Brachiaria* genotypes grown in an Oxisol near Puerto López in the Llanos of Colombia. Measurements were made at 3.5 months (dry season-August 2009) and 13 months (rainy season-June 2010) after establishment

Shoot traits	3 months after establishment	13 months after establishsment
Total (live + dead) shoot biomass (kg ha^{-1})	0.78 ***	0.80 ***
Dead shoot biomass (kg ha^{-1})	0.30*	0.28
Leaf biomass (kg ha^{-1})	0.75 ***	0.88 ***
Stem biomass (kg ha^{-1})	0.92 ***	0.78 ***
Leaf N content (%)		0.24
Leaf P content (%)		-0.11
Leaf ash content (%)		0.25
Leaf TNC content (mg g^{-1})		0.01
Stem N content (%)		0.05
Stem P content (%)		-0.21
Stem ash content (mg g^{-1})		0.36*
Stem TNC content (mg g^{-1})		0.11
Shoot N uptake (kg ha^{-1})		0.93 ***
Shoot P uptake (kg ha^{-1})		0.94 ***
Shoot K uptake (kg ha^{-1})		0.81***
Shoot Ca uptake (kg ha^{-1})		0.89***
Shoot Mg uptake (kg ha^{-1})		0.92***
Animal intake of green forage (scale 1-9)		0.31 *

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

Results on correlation coefficients indicated significant positive association between green forage yield (living shoot biomass) and a number of plant attributes including leaf biomass, stem ash content, shoot nutrient uptake (N, P, K, Ca and Mg) at 13 months after establishment (Table 15). Animal intake of green forage was found related to greater leaf biomass ((r=0.49***), living shoot biomass production (r=0.31*), leaf ash content (r=0.59***), leaf Mg, P, Ca, K uptake (r =0.64***, 0.54***, 0.52***, 0.39**, respectively), and shoot Mg, P and Ca uptake (r=0.39**, 0.36* and 0.33*, respectively). Three genotypes (CIAT 36087, BR02NO/1752, CIAT 6294) were identified as superior based on living shoot biomass and animal intake of green forage (Figure 25).

Conclusions

We identified three *Brachiaria* hybrids (CIAT 36087=cv Mulato II, BR02NO/1794 and BR02NO/1752), and one cultivar (*B. brizantha* CIAT 6294= cv Marandú) as superior performers during establishment under low fertility acid soil conditions. Among the genotypes tested, two *Brachiaria* hybrids (CIAT 36087 and BR02NO/1752) and one parent (*B. brizantha* CIAT 6294) were identified as more productive in terms of living shoot biomass and animal intake of green forage. Forage yield was found to be related to greater values of leaf biomass production, leaf nutrient uptake and shoot nutrient uptake.

1.7 Evaluate forage legumes for tolerance to major abiotic constraints, forage quality attributes, and seed production potential, and identify promising germplasm accessions

Highlight

- Phenotypic evaluation under greenhouse conditions indicated that drought resistance of *canavalia* under low soil fertility conditions is associated with deep rooting ability and vigorous fine root development to explore greater volume of soil. Two *Canavalia brasiliensis* accessions (CIAT 7969 and CIAT 905) were found to be outstanding in their total root length production across soil depth under combined stress factors of low soil fertility and drought.

1.7.1 Canavalia, a forage legume that adapts to combined stress factors of low soil fertility and drought

Contributors: Polania, J.; van der Hoek, R.; Franco, L.H.; Peters, M.; Rao, I.M. (CIAT); Douxchamps,S.; Oberson, A.; Frossard, E. (Institute of Plant Sciences, ETH-Zurich, Switzerland)

Rationale

Canavalia brasiliensis, a highly drought adapted cover legume (stays green during 5 months of dry season), native from Central America, was introduced into the smallholder traditional crop-livestock production system of the Nicaraguan hillsides to overcome soil fertility decline. Canavalia increases available forage biomass and augments milk production in the dry season. However, there is very limited knowledge on the physiological basis of adaptation of canavalia to either individual or combined stress factors of drought and low soil fertility. We tested the hypothesis that the superior tolerance of canavalia to long dry season under low soil fertility conditions is related to its deep rooting ability. We used a greenhouse soil cylinder method to quantify phenotypic differences in root development and distribution of 4 germplasm accessions of canavalia under simulated soil drying (terminal drought) combined with low soil fertility (without fertilizer application).

Materials and methods

A greenhouse study was conducted at CIAT-Palmira in 2009 using a mix of an Andisol (from Darien of Colombia) with river sand (2:1 w/w). Plants were grown for 35 days in plastic cylinders (80 cm long with 7.5 cm diameter) that were inserted in PVC tubes. The trial included 4 canavalia genotypes: *Canavalia brasiliensis* CIAT 17009, *Canavalia brasiliensis* CIAT 905, *Canavalia brasiliensis* CIAT 7969 and *Canavalia sp*. CIAT 21014 to determine genotypic differences in root development and distribution under individual and combined stress of low fertility and drought. The trial was planted as a randomized complete block arrangement with two levels of water supply: 90% field capacity (well-watered) and withholding of watering (progressive soil drying to simulate terminal drought stress conditions) and two levels of fertilizer application: 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 without fertilizer application as main plots and genotypes as sub-plots with four replications. Treatments of water stress were imposed after 8 days of initial growth of plants that were established with seed. The initial soil moisture for all the treatments was of 90% 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 drought stress were monitored for water stress by weighing each cylinder every two days for determination of decrease in soil moisture. Plants were harvested at 35 days after establishment, i.e., 27 days of withholding of water application.

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 (35 days after planting; 27 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, root dry weight, fine root proportion (root length below 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 33 ^{o}C and 21^{o}C, respectively (Figure 26). The final soil moisture with terminal drought stress was at 8% of the field capacity. No significant genotypic differences were observed in leaf area production under both fertilizer and water regimes. The genotypes CIAT 7969 and CIAT 905 were outstanding in leaf area production under both fertilizer and water regimes (Figure 27). The genotype *Canavalia sp*. CIAT 21014 showed lower values of leaf area under both fertilizer and water regimes.

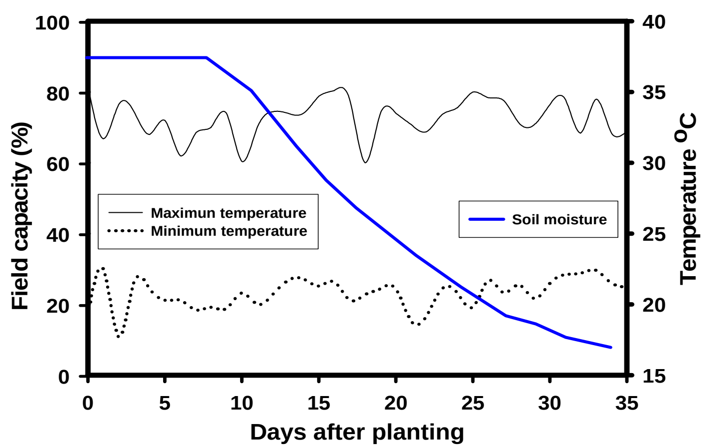


Figure 26. Soil moisture (field capacity), maximum and minimum temperature during soil drying and root development in soil tubes under greenhouse conditions of CIAT, Palmira.

No significant genotypic differences were observed in photosynthetic efficiency at 24 days after planting under individual low fertility and combined low soil fertility and drought stress. Under individual drought stress conditions (high fertilizer + terminal drought) the genotype CIAT 7969 showed the highest photosynthetic efficiency, while the genotype CIAT 17009 was outstanding in photosynthetic efficiency under combined low fertility and drought stress (Table 16). The leaf chlorophyll content (SPAD) was markedly lower for CIAT 21014 than the other genotypes tested under both fertilizer and water regimes.

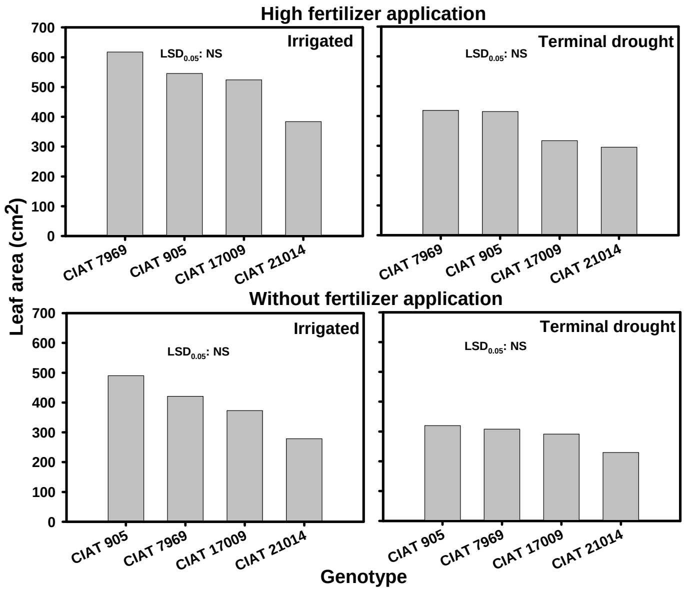


Figure 27. Influence of individual and combined stress of low soil fertility and drought on leaf area of 4 canavalia genotypes that were grown under greenhouse conditions of CIAT, Palmira

No significant genotypic differences were observed in leaf conductance, however, the genotype CIAT 905 showed the lower value of leaf conductance under individual drought stress conditions (high fertilizer + terminal drought) and combined low soil fertility and drought stress indicating the ability for stomatal control (Table 17). The genotype CIAT 21014 showed the lowest amount of water lost through evapotranspiration under both fertilizer and water regimes, and this was reflected through high value of leaf conductance at 24 days after planting (Table 17).

Table 16. Influence of individual and combined stress factors of low soil fertility and terminal drought on photosynthetic efficiency and leaf chlorophyll content of 4 canavalia genotypes that were grown under greenhouse conditions of CIAT, Palmira

Genotype	Photosynthetic efficiency at 24 days after planting (fv'/fm')				Leaf chlorophyll content at 24 days after planting (SPAD)			
	High fertilizer		Without fertilizer		High fertilizer		Without fertilizer	
	Irrigated	Drought	Irrigated	Drought	Irrigated	Drought	Irrigated	Drought
CIAT 17009	0.533	0.515	0.521	0.549	39.7	45.2	40.9	42.7
CIAT 7969	0.566	0.572	0.499	0.554	47.3	45.4	40.0	39.3
CIAT 905	0.531	0.527	0.500	0.501	43.5	42.5	42.5	33.3
CIAT 21014	0.500	0.443	0.507	0.508	35.7	24.3	30.8	28.2
Mean	0.533	0.514	0.507	0.528	41.5	39.3	38.5	35.9
$LSD_{0.05}$	NS	0.08	NS	NS	5.4	10	NS	NS

Table 17. Influence of individual and combined stress factors of low soil fertility and terminal drought on leaf conductance and water lost through evapotranspiration of 4 canavalia genotypes that were grown under greenhouse conditions of CIAT, Palmira

Genotype	Leaf conductance at 24 days after planting (mmol m^{-2} s^{-1})				Water lost through evapotranspiration (g per plant/27 days)			
	High fertilizer		Without fertilizer		High fertilizer		Without fertilizer	
	Irrigated	Drought	Irrigated	Drought	Irrigated	Drought	Irrigated	Drought
CIAT 17009	309.5	97.0	275.6	103.2	1863	893	1390	779
CIAT 7969	396.7	82.4	308.6	105.6	2284	892	1630	841
CIAT 905	266.6	75.1	254.8	86.4	2096	859	1868	751
CIAT 21014	427.0	95.3	354.2	136.2	1447	495	1065	596
Mean	**349.9**	**87.5**	**298.3**	**107.8**	**1922**	**785**	**1488**	**742**
$LSD_{0.05}$	**NS**	**NS**	**NS**	**52**	**470**	**152**	**NS**	**83**

Genotypic differences were observed in deep rooting ability among treatments especially at early stages of forage legume development. All the genotypes, except CIAT 21014, showed a greater deep rooting ability under individual drought stress and combined low soil fertility and drought stress (Figure 28). The genotypes CIAT 17009 and CIAT 7969 were superior in their deep rooting ability under individual low soil fertility conditions. The genotypes CIAT 17009 and CIAT 7969 showed greater ability for deep rooting under drought conditions with and without fertilizer application (Figure 28).

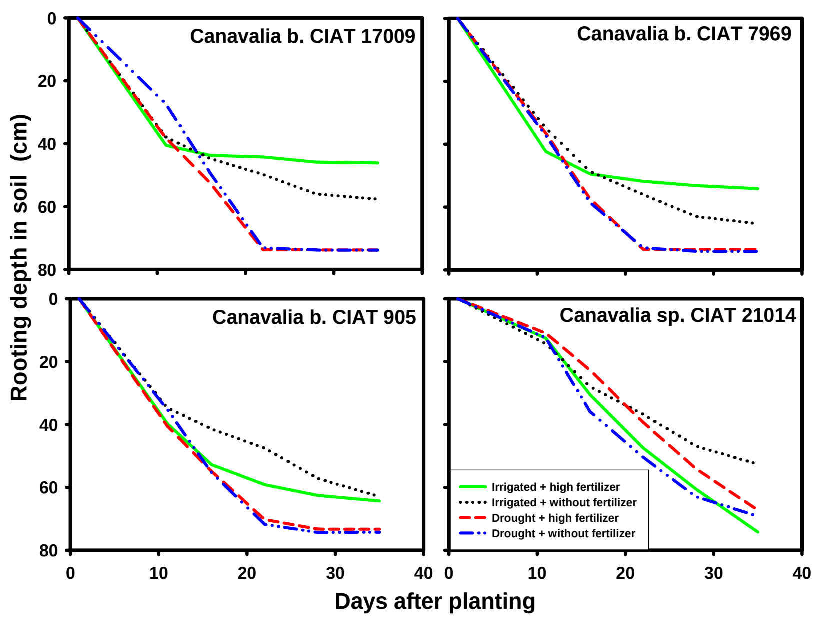


Figure 28. Influence of individual and combined stress factors of low soil fertility and drought on rooting depth of 4 canavalia genotypes that were grown under greenhouse conditions of CIAT, Palmira.

Genotypic differences were observed in total root length under individual terminal drought and individual low fertility conditions (Figure 29). The genotypes CIAT 905 and CIAT 7969 were superior in root length production under individual terminal drought conditions and individual low soil fertility conditions (Figure 29). The genotypes CIAT 905 and CIAT 7969 were found to be superior in their total root length production across soil depth under combined stress of low soil fertility and drought (Photos 6 and 7). The *Canavalia sp*. CIAT 21014 showed the lowest value of total root length production among soil fertility and water regimes tested (Figure 29).

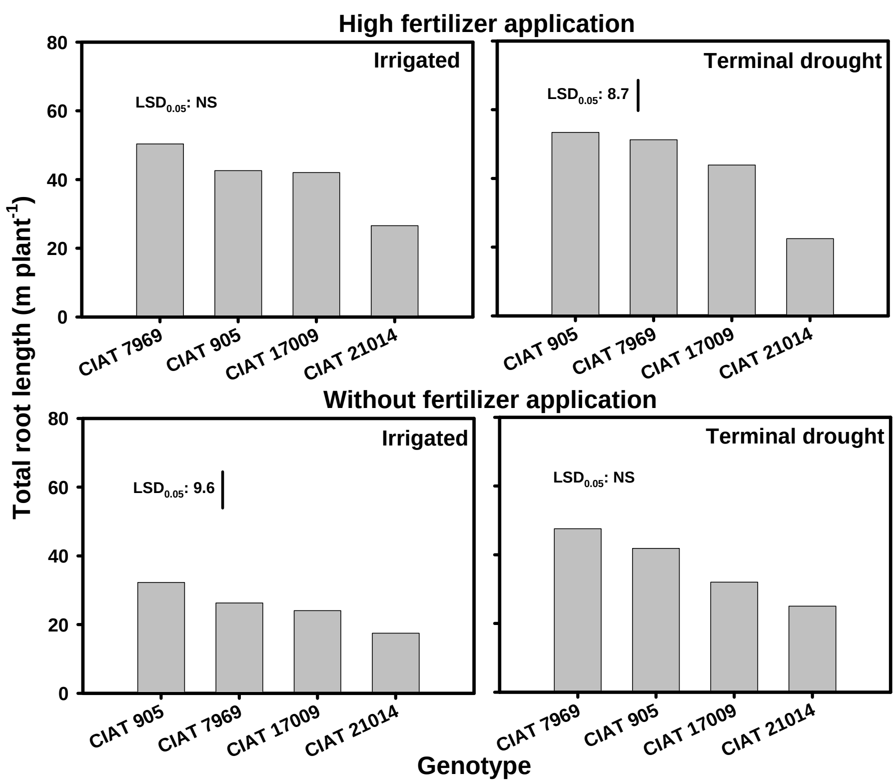


Figure 29. Influence of individual and combined stress of low soil fertility and drought on total root length of 4 canavalia genotypes that were grown under greenhouse conditions of CIAT, Palmira.

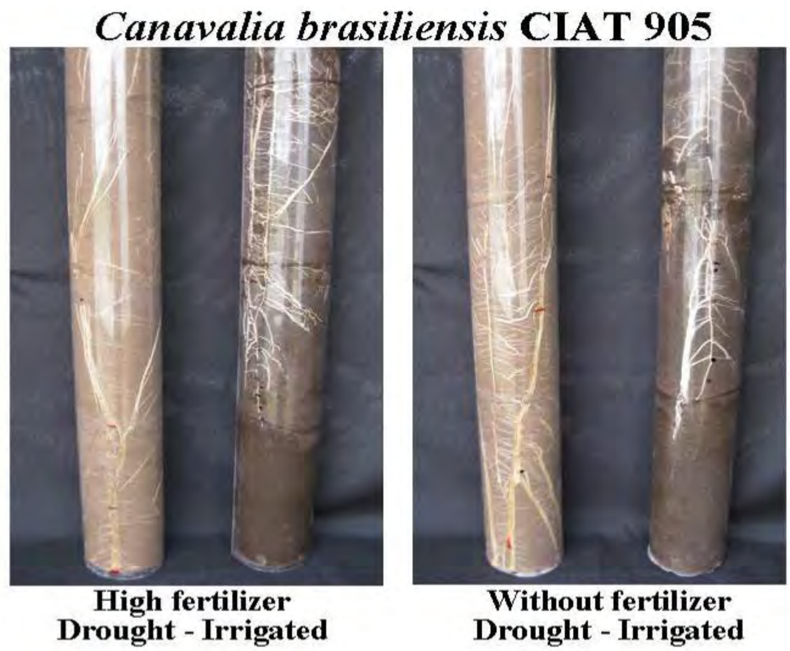


Photo 6. Influence of individual and combined stress factors of low soil fertility and drought on root development of *Canavalia brasiliensis* CIAT 905, grown under greenhouse conditions of CIAT, Palmira.

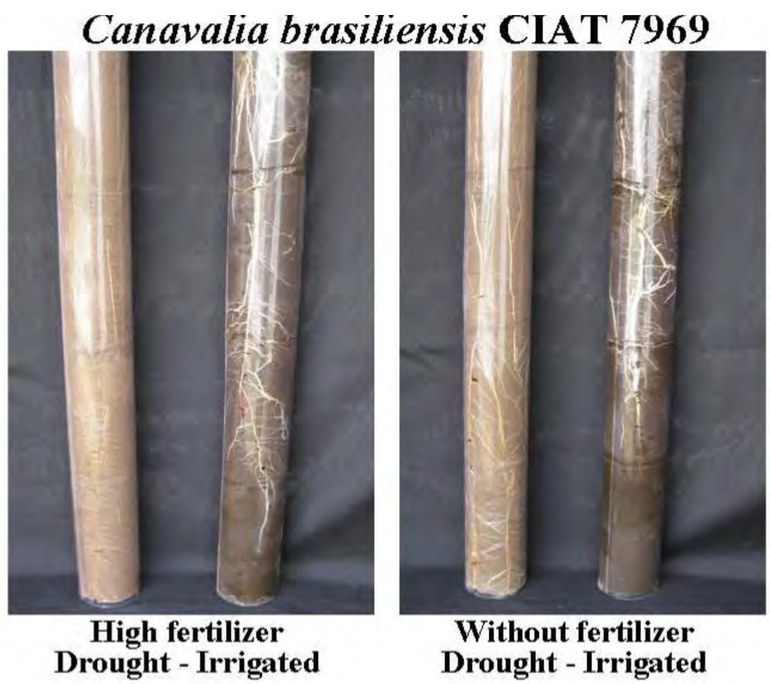


Photo 7. Influence of individual and combined stress factors of low soil fertility and drought on root development of *Canavalia brasiliensis* CIAT 7969, grown under greenhouse conditions of CIAT, Palmira.

Drought stress increased the root length development in deep soil layers than under irrigated conditions. Two genotypes, *Canavalia brasiliensis* CIAT 7969 and CIAT 905 showed greater values of root length at soil depth of 60-75 cm under individual drought stress and under combined stress of low soil fertility and drought (Figure 30). The *Canavalia sp*. CIAT 21014 showed poor root development at soil depth of 60-75 cm than the other genotypes under individual and combined low soil fertility and drought stress conditions (Figure 30).

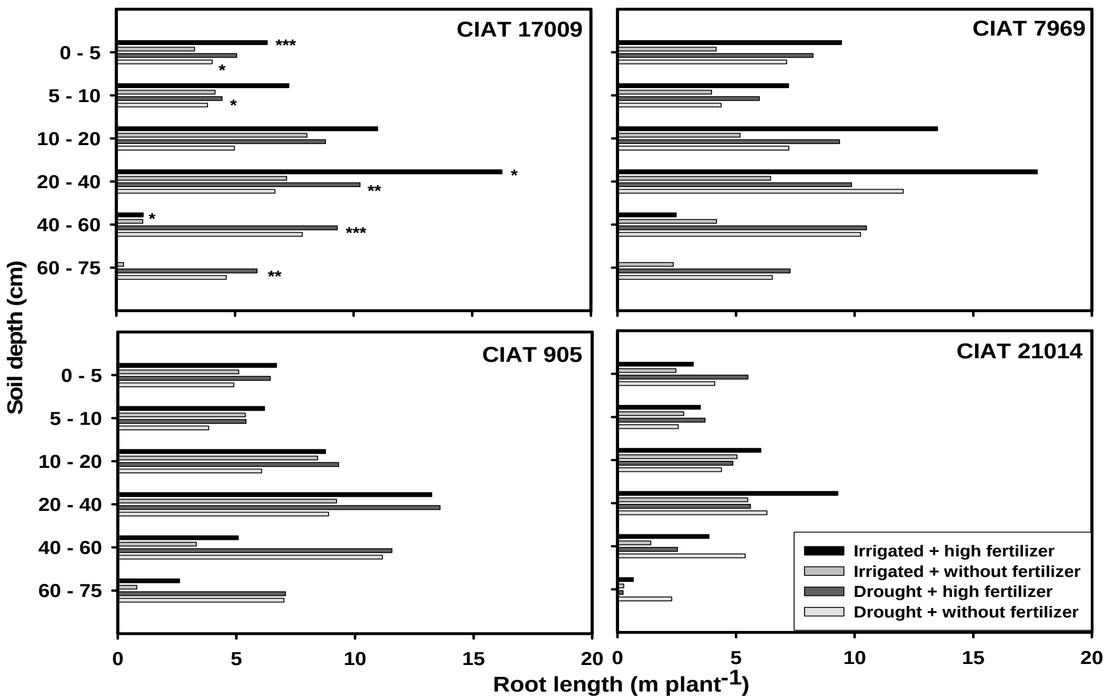


Figure 30. Influence of individual and combined stress factors of low soil fertility and drought on root length distribution across soil depth of 4 canavalia genotypes that were grown under greenhouse conditions at CIAT, Palmira.

Conclusions

Results from this greenhouse study indicated that drought resistance of canavalia under low soil fertility conditions is associated with deep rooting ability and vigorous fine root development to explore greater volume of soil. Two *Canavalia brasiliensis* accessions (CIAT 7969 and CIAT 905) were found to be outstanding in their total root length production across soil depth under combined stress factors of low soil fertility and drought.

1.7.2 Quantify livelihood and environmental benefits

1.7.2.1 Eco-efficient crop and livestock production for the poor farmers in the sub-humid hillside areas of Nicaragua

Highlight

- Activities have started to develop crop-livestock climate-smart systems with small scale farmers in northern Nicaragua.

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Rationale

Recent work conducted by CIAT and its partners in Honduras and Nicaragua has shown that the Quesungual Slash and Mulch Agroforestry System (QSMAS)[1] can not only improve smallholder livelihoods but also protect the environment through efficient use and conservation of natural resources for production of maize (*Zea mays*) and common bean (*Phaseolus vulgaris*). Other important recent products of CIAT and its partners are the development of drought adapted forage grasses (*Brachiaria* hybrid “Mulato 2”) and the identification of shrub legumes with good nutritional quality (*Cratylia argentea*). A next step forward to contribute to eco-efficiency[2] of smallholder farming production in Central America is integration and optimization of these crop and livestock production alternatives where both QSMAS and improved forage technologies are being adopted.

The goal of this research for development project is to improve livelihoods of rural poor in sub-humid hillsides of Nicaragua by enhancing eco-efficiency in rural landscapes. The purpose is to enhance the adoption of the QSMAS with improved maize, bean and forage components by improving its productivity and profitability through integrating stress adapted crop and forage options that facilitate generation of ecosystem services. The outputs are: (1) Improved food crop (maize and beans) and forage (grass and legume) options integrated into QSMAS and naturalized pastures to improve productivity and profitability; (2) Environmental benefits from crop-livestock systems adapted to climate change assessed; (3) Sociocultural and socioeconomic factors driving the adoption of eco-efficient crop-livestock systems including linkages with markets for food products and opportunities for ecosystem services identified; and (4) Implementation strategies and tools developed for adaptation and dissemination of eco-efficient agroforestry and livestock systems suitable for the sub-humid tropics.

Materials and Methods

CIAT and its partners in Nicaragua proposed that improved eco-efficiency in the production of commodities and ecosystem services in crop-livestock systems can be achieved through the use of high yielding - stress tolerant crops (improved varieties of maize and common beans) and forages

[1] QSMAS is a smallholder production system that employs a suite of technologies for the sustainable management of vegetation, soil and water resources in hillsides of the sub-humid tropics. Developed in Honduras in the early 1990’s with the participation of farmers, FAO and other institutions, QSMAS has been adopted by over 10,000 farmers in Honduras, Guatemala, Nicaragua and Mexico as an alternative to traditional slash-and-burn agriculture.
[2] Eco-efficient crop and livestock production uses resources more efficiently to produce more food, enables family farms to be more competitive, and delivers sustainable increases in productivity, while avoiding natural resource degradation and negative externalities.

(i.e., *Brachiaria* grasses and shrub legumes like *Cratylia argentea* and *Leucaena leucocephala*) into agroforestry systems.

Two target sites in northern Nicaragua were selected for the evaluation of these options: Somotillo, where QSMAS has been in a successful process of farmer-to-farmer dissemination since introduced in 2005; and Condega, where improved forage options have been evaluated and disseminated since 2007. Integration of these crop-livestock technologies in farming systems will include the adoption of QSMAS in Condega (as an option to improve traditional cropping systems) and of enhanced forages in Somotillo (as an option to improve pastures and use of crop residues). A representation of its integration in the landscape is shown in Figure 31.

Selection of crop-livestock systems components. The first semester of activities included the participatory selection of improved materials of maize and common bean to be used for the improvement of QSMAS. Participatory selection of varieties of maize was carried out in January 2011, through the review of experiences of both farmers and INTA with recently (released within the last 10 years) improved materials. For common bean, 36 farm trials (6 in Somotillo and 30 in Condega) including two improved materials (INTA Rojo and JM-Pueblo Nuevo) and the local variety ("criollo") were established in second part of the rainy season in 2010. Plots were managed following the standard timing, spatial arrangement and management practices. Participatory evaluation of the materials was performed through field days in the target sites, in November 2010 and January 2011 with the participation of farmers and technicians of INTA, UNA and CIAT.

Farmer-to-farmer transfer of technology. A field day was organized in Somotillo in November 2011 to introduce QSMAS to over 40 farmers and technicians of Condega. Information was exchanged between farmers and the establishment of a Quesungual plot starting from a secondary forest was demonstrated.
Extrapolation domain analysis (EDA). A preliminary map with the most similar areas to the project sites was developed, based on a limited set of variables supplied by the CIAT-GIS unit. Two Bayesian methods (Weights of Evidence, WofE, and Logistic Regression, LR), were used to incorporate variables as evidences of similarity or dissimilarity to the project locations. The first step was the identification of research sites. These were provided by field researchers and locations were limited to the communities inside the municipalities of Somotillo and Condega. An approximate location was generated using a random technique to produce a shapefile with 50 sites per municipality. A collection of geographical secondary data for Nicaragua provided by CIAT warranted geographical projections consistency and spatial match. Both the shapefile and a selection of the listed variables were inserted in the Spatial Data Modeler System (SDMS), which is an extension in the ArcGIS software. The biophysical variables used in this initial search were: altitude, slope, total annual precipitation, mean annual temperature, and land use (annual crops, pastures and secondary forest). Results were displayed in map layers for representation, and also included an estimation of the conditional independence between variables.

Results and Discussion

Farmers and technicians selected the improved varieties of maize and common bean (INTA-Rojo), to be included in the evaluation of QSMAS plots in 2011. The establishment of field trials for the evaluation and selection of improved varieties of common bean contributed to highlight the advantages of planting annual crops on hillsides and pastures in less steep areas, as recommended for these regions. This is to facilitate drainage of rain water for crop production while restricting grazing to less vulnerable parts. The trials established in plain areas were unfortunately lost due to excess rainfall as a consequence of the climatic phenomenon "La Niña". Those established on hillsides (particularly those within existing QSMAS) did well. Besides contributing to food security, the crops provided income (bean prices increased at least by 20% in Central America during the second semester of 2010).

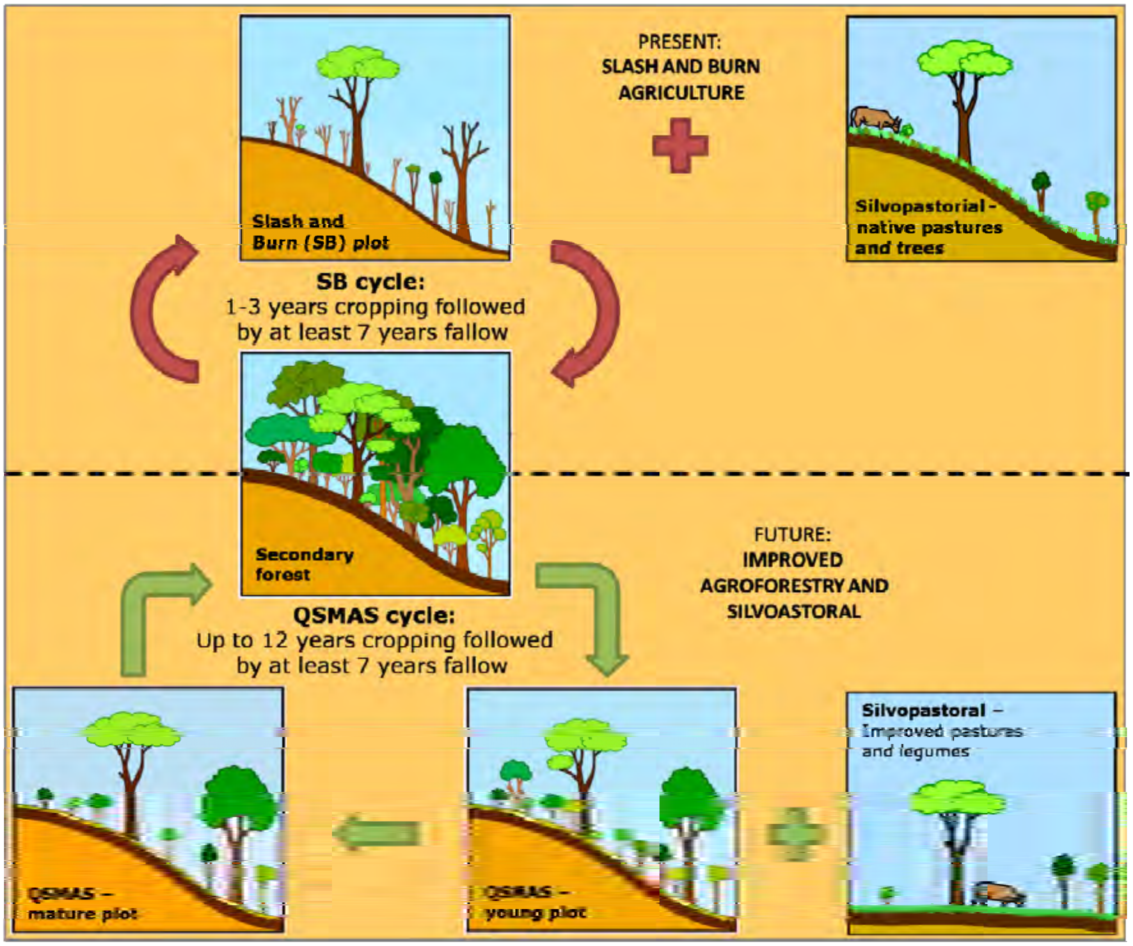

Figure 31. Present scenario (top), with crop production and livestock on hillsides managed with traditional (slash and burn) systems; and the expected eco-efficient scenario (bottom), with crop production on hillsides under agroforestry systems and livestock production on piedmonts on improved pastures.

During the visit of farmers and technicians from Condega to Somotillo, many farmers expressed their intention to adapt and evaluate QSMAS in their farms. In addition, several Nicaraguan NGOs have expressed their interest in participating in activities of the project using their own resources, in particular ASOGAPCON (Association of farmers with livestock of Condega) for technology validation and Nitlapan (Institute of Applied Research and Local Development) for payment for biodiversity conservation. Other results include the identification of the experimental sites within the target areas (La Danta and La Flor communities in Somotillo; and Los Cerritos, Santa Teresa and Potrerillo in Condega) and identification of farmers (9 in Somotillo, 8 in Condega). Farmers are participating in the project through establishment and management of the experimental plots within their farms where the different treatments are being established.

Regarding the EDA, Figure 32a shows the location of the pilot sites whereas Figure 32b shows the probability of finding similar areas to those signaled by the points based on the included variables. This first draft of the EDA will be validated with national experts of Nicaragua applying a set of key questions to improve the selection of variables (also including socio-economic) and the identification of other potential implementation sites. New maps will be generated based on the exact location of the experimental plots within the farms and the information provided by the experts.

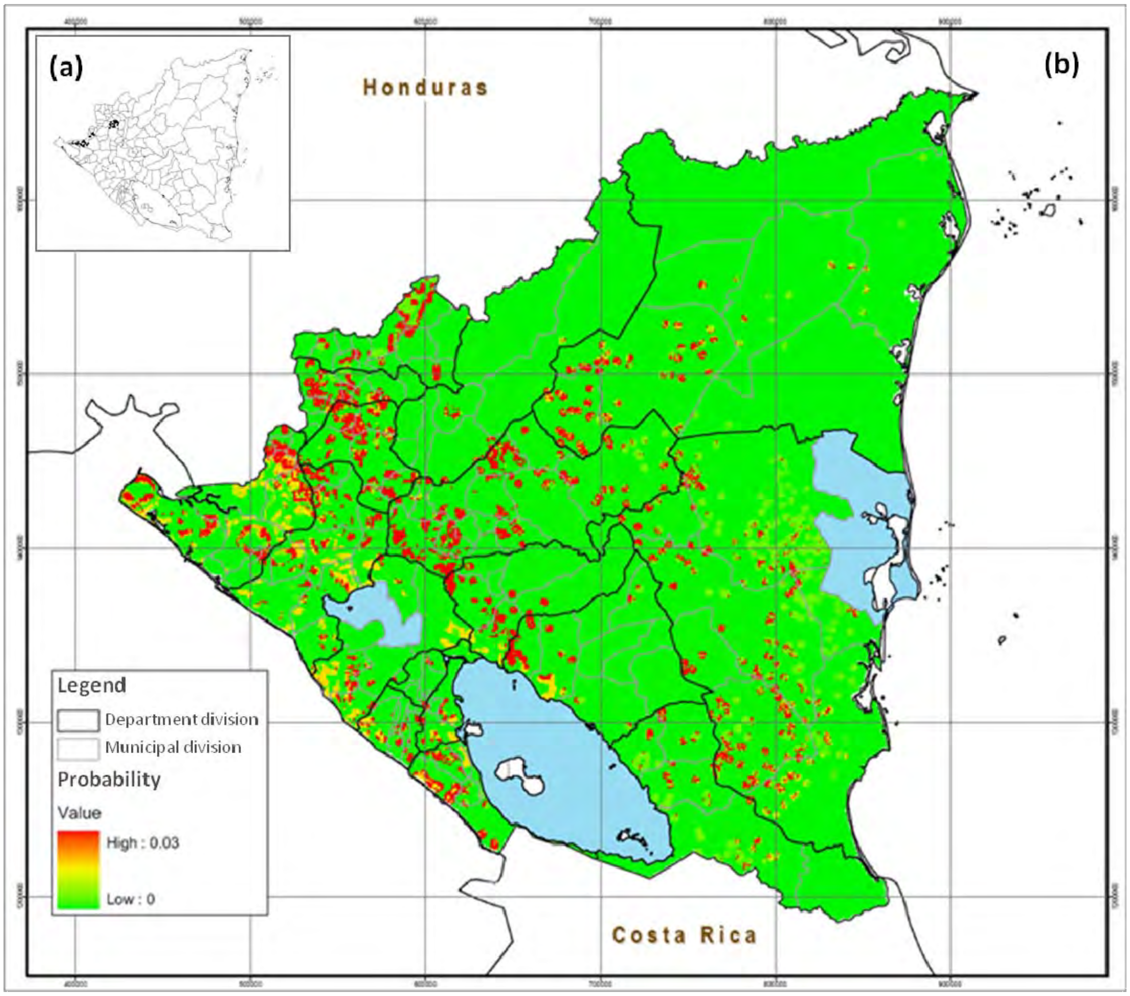

Figure 32. Approximate location of research sites for the evaluation of the proposed crop-livestock systems in northern Nicaragua (a) and estimation of similar areas for the potential adoption of these systems (b). Those in red showing highest similarity. The concentration of similar areas in the Pacific region of the country coincides with the location of mixed systems farms (Atlantic region plains are mostly used for cattle ranching).

1.8 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 8).

Photo 8. *Tadehagi triquetrum* collection established in Quilichao.

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.

The growth habit of plants was determined by measuring plant height and diameter and by visual observations of the way and direction the plant stems grow, realized in the fourth repetition of the phenology evaluations, nine months after the transplantation to the field 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, ascendant and erect habits (Tables 18, 19 and 20).

Dry matter yields were measured in the dry season and wet season, with one cut per season over three years. Samples for forage quality were taken once in the dry and once in the wet season and analyzed for IVDMD and Crude Protein.

Table 18. Growth habit indicator: Values > de 0.69 to erect *Tadehagi triquetrum* accessions (9 months in the field) in Quilichao

Accession	Indicator*	Height	Diameter
	Scale >0.69	cm	
CIAT 422	1.20	81	67
CIAT 23751	0.85	71	83
CIAT 23112	1.05	81	77
CIAT 899	0.94	86	91
CIAT 880	0.98	75	76
CIAT 761	1.16	72	62
CIAT 33110	0.84	66	78
CIAT 23953	0.77	41	53
CIAT 13996	0.73	75	102
CIAT 23750	1.02	71	69
CIAT 21913	1.66	91	78
CIAT 21916	0.85	47	55
CIAT 21912	0.97	69	71
CIAT 918	0.91	63	69
CIAT 21911	0.87	57	65

* Height/diameter

Table 19. Growth habit indicator: Values of 0.39 to 0.69 to ascendant *Tadehagi triquetrum* accessions (9 months in the field) in Quilichao

Accession	Indicator*	Height	Diameter	Accession	Indicator*	Height	Diameter
	Scale 0.39 to0.69	cm			Scale 0.39 to0.69	cm	
CIAT 21921	0.50	53	104	CIAT 21928	0.46	41	88
CIAT 23428	0.55	64	115	CIAT 13540	0.55	38	68
CIAT 13277	0.66	62	93	CIAT 21914	0.48	33	68
CIAT 23950	0.50	47	93	CIAT 33393	0.55	47	85
CIAT 13726	0.42	45	107	CIAT 13728	0.56	57	101
CIAT 23113	0.41	38	92	CIAT 23227	0.51	43	84
CIAT 23749	0.69	59	85	CIAT 33418	0.56	43	76
CIAT 23943	0.53	57	107	CIAT 13542	0.61	33	54
CIAT 13270	0.47	50	105	CIAT 13273	0.61	58	95
CIAT 23424	0.53	55	102	CIAT 23939	0.95	79	83
CIAT 23427	0.48	61	126	CIAT 23941	0.49	41	83
CIAT 23753	0.55	55	99	CIAT 13269	0.45	49	108
CIAT 21929	0.54	55	101	CIAT 13730	0.62	64	103
CIAT 13727	0.48	51	105	CIAT 465	0.56	42	74
CIAT 33456	0.47	32	68	CIAT 13274	0.67	66	98
CIAT 23426	0.56	56	100				

* Height/diameter

Table 20. Growth habit indicator: Values of 0.1 to 0.38 to prostrate *Tadehagi triquetrum* accessions (9 months in the field) in Quilichao

Accession	Indicator*	Height	Diameter	Accession	Indicator*	Height	Diameter
	0.1 to 0.38	cm			0.1 to 0.38	cm	
CIAT 21923	0.31	35	112	CIAT 21979	0.35	24	68
CIAT 21925	0.28	29	102	CIAT 21915	0.37	29	77
CIAT 13268	0.34	36	105	CIAT 13544	0.38	38	99
CIAT 21918	0.30	32	105	CIAT 21927	0.33	29	86
CIAT 23945	0.33	35	103	CIAT 33397	0.33	23	68
CIAT 33423	0.29	32	107	CIAT 23957	0.38	27	70
CIAT 21919	0.26	21	78	CIAT 21920	0.33	25	75
CIAT 23952	0.32	29	89	CIAT 21917	0.34	32	92
CIAT 23236	0.37	39	105	CIAT 23114	0.38	40	104
CIAT 13724	0.34	37	108	CIAT 21940	0.35	22	62
CIAT 23947	0.37	31	83	CIAT 23756	0.38	40	103
CIAT 33438	0.35	28	79	CIAT 13723	0.35	32	89
CIAT 23956	0.34	36	103	CIAT 21958	0.18	20	106
CIAT 23228	0.34	29	84	CIAT 21924	0.16	16	98
CIAT 23955	0.37	25	66	CIAT 23755	0.31	23	73
CIAT 33384	0.36	31	86	CIAT 21922	0.29	17	58
CIAT 33424	0.29	32	109	CIAT 13275	0.33	30	89
CIAT 21939	0.32	24	74	CIAT 21930	0.21	14	64
CIAT 23954	0.33	27	81	CIAT 21926	0.35	28	78

* Height/diameter

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 9). Large differences were found in initial development and 50% of the accessions needed replanting; leaf eaters and leaf suckers were observed, in addition to some fungal infection, in some cases resulting in death of plants.

The majority of accessions were early in flowering and seed set, in many cases with abundant flower and seed production. During the establishment phase (5 months) Ninety-six percent of accessions flowered and 79% of these accessions produced 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 ascendant and prostrate accessions was performed.

Among the erect accessions (Table 21), a large variation in plant height was found, partly due to the replanting of a number of accessions. Accessions that reached 0.7 m or more in height were CIAT 761, 880, 899, 422, 23111, 21912 and 21913. Accession CIAT 21911 was the least vigorous.

There was similar variation among the ascendant accessions (Table 22). Three accessions, i.e., CIAT 21921, 23428 and 13277 reached more than 1 m in diameter and showed vigorous growth.

Photo 9. *Tadehagi triquetrum* growth habits.

In Tables 21, 22 and 23, the performance of plants in the establishment phase, separated according to growth habit, is shown.

Table 21. 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 23112	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 22. 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 (Table 23), with accessions CIAT21923, 21925, 13268, 21918, 23945, 33423, 21919, 23952, 23236, 13724, 23947 and 33438 extending more than 1 m in diameter.

During the time of the experiment, a few accessions were lost, as some were not adapted to the conditions at Quilichao and some were affected by the frequent-cut regime imposed (Photos 10 and 11).

Photo 10. *Tadehagi triquetrum* collection production phase during dry seasons in Quilichao.

Table 23. 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 23952	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

Photo 11. *Tadehagi triquetrum* collection production phase during wet seasons in Quilichao.

Results of evaluations during the production phase during dry and wet seasons are shown in Tables 24, 25 and 26.

Table 24. Agronomic evaluation of a collection of *Tadehagi triquetrum* in Quilichao. Data of six evaluation cuts (three 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
Erect	45	61	33	31	70	78	34	82
Ascendant	34	73	49	41	53	94	54	120
Prostrate	22	67	41	31	31	84	50	82
Mean	34	67	41	35	51	85	46	96
LSD (P<0.05)				5.03				13.95

DM yields differed significantly (P<0.01) among growth habits and accessions (table 24). In general, yields were lower in the dry than in the wet season, with on average 35 and 96 g/plant, respectively. Highest yields were recorded in both seasons for the ascendant types, as well as average plant height, diameter and number of regrowing points.

Among the erect types, highest dry season yields were measured for accessions CIAT 13996, 899, 33110, 21913, 23112 and 21912 while in the wet season accessions CIAT 13996, 21913, 33110 and 899 performed best with more than 100 g/plant for the 8-week regrowth (Table 25).

Table 25. Agronomic evaluation of a collection of erect *Tadehagi triquetrum* accessions in Quilichao. Data of six evaluation cuts (three 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
CIAT13996	46	78	54	54	78	118	50	194
CIAT 899	59	77	36	51	89	102	36	116
CIAT 33110	46	62	42	50	70	82	50	121
CIAT 21913	65	66	38	42	96	82	36	122
CIAT 23112	60	61	36	41	83	82	31	88
CIAT 21912	46	57	34	41	71	76	35	95
CIAT 880	47	63	31	36	75	84	34	82
CIAT 761	44	56	35	26	73	70	25	66
CIAT 21911	39	56	28	23	57	72	28	55
CIAT 422	37	62	27	22	72	71	33	43
CIAT 918	42	57	29	20	61	74	36	66
CIAT 23751	36	60	31	19	69	83	31	59
CIAT 23750	45	56	31	19	69	69	30	55
CIAT 21916	32	48	21	9	49	59	27	31
CIAT 23953	28	51	23	7	43	57	29	32
Mean	45	61	33	31	70	79	34	82
LSD (P<0.05)				27.13				52.41

Among the ascendant accessions, CIAT 23427, 23428, 23943, 23424, 13270, 13269, 23426, 13726, 13728 and 21929 yielded more than 150 g/plant in the wet season, while in the dry season only accessions CIAT 23427, 23943, 13726, 23426, 13269, 23424, 13270 and 13728 had yields above 50 g/plant (Table 26).

Table 26. Agronomic evaluation of a collection of ascendant *Tadehagi triquetrum* accessions in Quilichao. Data of six evaluation cuts (three 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
CIAT23427	42	96	78	82	71	138	74	320
CIAT 23943	40	86	61	74	66	111	81	225
CIAT 13726	30	80	63	63	47	113	71	165
CIAT 23426	38	78	60	62	60	108	60	168
CIAT 13269	33	81	61	62	49	109	58	172
CIAT 23424	36	77	56	59	65	107	55	210
CIAT 13270	35	79	62	53	53	106	75	182
CIAT 13728	30	81	66	52	52	95	74	159
CIAT 23113	28	85	53	47	35	101	55	103
CIAT 23428	43	86	62	47	71	120	69	247
CIAT 21928	32	79	47	45	47	99	66	109
CIAT 13727	34	74	55	44	54	98	60	117
CIAT 23950	30	78	54	44	50	99	54	112
CIAT 21921	33	84	57	42	49	109	80	146
CIAT 23941	29	68	35	42	39	81	46	99
CIAT 21929	36	73	54	41	55	101	67	147
CIAT 465	34	66	36	40	45	83	42	86
CIAT 33418	25	68	36	39	43	79	41	49
CIAT 13730	38	69	47	39	61	91	46	114
CIAT 33393	33	71	44	37	45	87	46	75
CIAT 13274	40	64	52	36	64	86	53	109
CIAT 13273	40	68	45	32	57	89	53	84
CIAT 23227	26	66	51	28	43	82	59	94
CIAT 23749	47	69	37	26	62	85	40	59
CIAT 23939	43	65	36	24	88	84	35	69
CIAT 13277	35	72	32	24	62	82	35	57
CIAT 23753	33	68	48	22	53	96	50	93
CIAT 13540	32	60	33	18	43	73	34	41
CIAT 33456	30	64	33	15	35	72	35	39
CIAT 21914	32	62	30	14	39	73	29	38
CIAT 13542	28	47	25	9	35	55	27	35
Mean	34	73	49	41	53	94	54	120
LSD (P<0.05)				44.12				132.47

For the prostrate growth habit, in the dry season only accessions CIAT 23956, 33423, 21958, 13275, 13724, 23114, 33424, and 13268 yielded more than 50 g /plant while in the wet season CIAT 23114, 13268, 23956, 21923, 33424, 33423, and 21958 were the accessions with wet season yields above 139 g/plant (Table 27).

Table 27. Agronomic evaluation of a collection of prostrate *Tadehagi triquetrum* accessions in Quilichao. Data of six evaluation cuts (three 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	29	87	70	80	41	106	79	178
CIAT 33423	25	86	58	68	34	111	64	156
CIAT 21958	22	80	50	64	24	104	83	139
CIAT 13275	22	75	51	64	33	89	49	86
CIAT 13724	26	80	72	64	37	106	80	129
CIAT 23114	30	86	54	62	44	111	58	217
CIAT 33424	24	80	55	59	42	109	58	158
CIAT 13268	21	92	82	58	32	111	106	197
CIAT 21926	23	70	46	48	29	80	40	71
CIAT 21918	26	83	52	39	34	103	57	104
CIAT 23236	35	77	49	38	54	97	57	135
CIAT 21924	19	72	48	37	20	95	59	100
CIAT 23952	29	73	41	35	34	93	64	121
CIAT 23947	24	71	41	33	32	84	49	71
CIAT 23945	25	74	47	32	36	91	45	70
CIAT 21925	25	75	47	31	31	101	88	107
CIAT 33438	17	64	43	30	26	81	47	70
CIAT 21930	12	55	31	26	15	65	55	55
CIAT 13544	24	69	43	24	37	92	46	74
CIAT 21923	23	77	54	23	39	106	93	165
CIAT 23228	22	64	27	21	30	81	40	49
CIAT 23756	25	62	33	20	44	81	35	61
CIAT 23954	22	66	40	20	28	74	43	55
CIAT 23755	15	56	31	20	22	73	33	65
CIAT 21940	21	63	30	18	24	66	27	31
CIAT 21939	20	61	27	18	28	78	44	60
CIAT 23957	19	55	30	18	29	62	38	34
CIAT 33384	19	59	34	16	29	65	39	38
CIAT 21927	19	54	32	16	30	68	34	34
CIAT 13723	17	51	35	15	28	60	38	30
CIAT 21920	17	52	31	14	26	69	37	36
CIAT 33397	18	58	31	13	23	67	39	33
CIAT 21919	20	56	24	13	23	73	34	37
CIAT 21917	23	50	29	12	34	68	29	26
CIAT 21979	22	57	22	11	26	64	28	23
CIAT 23955	18	56	23	11	24	65	31	26
CIAT 21915	19	43	21	8	28	69	32	34
CIAT 21922	16	51	22	8	18	62	30	23
Mean	22	67	41	31	31	84	50	82
LSD (P<0.05)				37.639				99.234

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; in general, values were <45% and <16%, respectively (Table 28). In the wet season, IVDMD and CP varied significantly (P<0.01) among accessions, with, in general, values <44% and <19%, respectively (Table 29). Digestibility and CP content were low compared with other forage legumes.

Table 28. 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)							13.61	2.28

Table 29. Forage quality of *Tadehagi triquetrum* accessions evaluated in the wet season in Quilichao

Accession	IVDMD %	CP	Accession	IVDMD %	CP	Accession	IVDMD %	CP
CIAT 21918	44	16	CIAT 13996	38	16	CIAT 21929	35	16
CIAT 13269	43	16	CIAT 21958	38	15	CIAT13275	35	15
CIAT 918	42	16	CIAT 21914	38	16	CIAT 33438	34	15
CIAT 21920	42	16	CIAT 422	38	17	CIAT 21911	34	13
CIAT 13724	42	16	CIAT 465	37	17	CIAT 23750	34	16
CIAT 23113	42	17	CIAT 23427	37	16	CIAT 21913	34	15
CIAT 33384	41	16	CIAT 23227	37	16	CIAT 13268	34	15
CIAT 33424	41	14	CIAT 13542	37	16	CIAT 21927	34	16
CIAT 21922	41	16	CIAT 23228	36	15	CIAT 23954	34	15
CIAT 21979	40	15	CIAT 21925	36	15	CIAT 13728	34	15
CIAT 23957	40	15	CIAT 23114	36	16	CIAT 880	34	17
CIAT 21923	40	15	CIAT 21930	36	16	CIAT 13270	34	16
CIAT 21939	40	15	CIAT 23426	36	17	CIAT 33423	34	16
CIAT 21926	40	16	CIAT 33110	36	19	CIAT 13277	33	16
CIAT 13544	39	16	CIAT 23943	36	16	CIAT 33393	33	16
CIAT 21924	39	16	CIAT 23945	36	15	CIAT 23953	33	16
CIAT 13540	39	15	CIAT 761	36	16	CIAT 21928	33	17
CIAT 13730	39	16	CIAT 23756	35	16	CIAT 23753	33	14
CIAT23955	39	16	CIAT 33456	35	15	CIAT 13723	33	15
CIAT 23947	39	16	CIAT 21916	35	16	CIAT 23939	33	15
CIAT 23950	39	17	CIAT 21940	35	15	CIAT 13273	32	15
CIAT 23941	39	16	CIAT 23428	35	16	CIAT 13726	32	15
CIAT 21915	38	16	CIAT 21917	35	14	CIAT 23751	32	15
CIAT 21919	38	14	CIAT 23424	35	15	CIAT 13274	32	16
CIAT 23112	38	16	CIAT 21912	35	16	CIAT 33418	31	16
CIAT 23956	38	15	CIAT 899	35	16	CIAT 23749	30	15
CIAT 23952	38	16	CIAT 13727	35	15	CIAT 33397	30	15
CIAT 21921	38	15	CIAT 23755	35	15	CIAT 23236	26	14
Mean							36	16
LSD (P<0.05)							11.42	2.8

For 11 accessions, selected for their agronomic performance, fibre analysis including Neutral Detergent Fibre (NDF), Acid Detergent Fibre (ADF) and Acid Detergent Lignin (ADL) and Condensed Tannins (soluble and insoluble) was carried out. However, no significant (P<0.05) differences were detected in dry and wet season samples (Table 30). NDF increased in the wet season, while ADF and ADL decreased. Condensed tannins were low compared to other forage legumes.

Principal Component Analysis indicated that Principal Component (PRIN) 1 is related to DM production, diameter, regrowth and vigor, while PRIN 2 is related to height and PRIN 3 to forage quality (CP and IDVMD. Following the Principal Component Analysis, then Cluster analysis using the method of Ward was carried out to differentiate the 84 accessions under evaluation into 8 groups, with 65.1% of the variation explained by the statistical model (Figure 33).

Table 30. DM yield and forage quality of selected accessions of *Tadehagi triquetrum* evaluated in the dry and wet season in Quilichao (DM, IVDMD und CP taken from previous Tables)

Accession	DM	IVDMD	CP	NDF	ADF	ADL	DM	IVDMD	CP	NDF	ADF	ADL	TCT
	g/pl			%			g/pl			%			%
			Dry							Wet			
CIAT 13275	64	39	13	40	44	25	86	35	15	62	40	27	5,4
CIAT 13724	64	45	14	46	40	28	129	42	16	59	34	27	1,5
CIAT 13996	54	33	13	44	44	44	194	38	16	63	35	19	4,3
CIAT 21913	42	38	13	46	44	51	122	34	15	65	37	28	2,4
CIAT 21958	64	41	13	46	41	32	139	38	15	63	36	35	2,3
CIAT 23426	62	39	15	46	40	27	168	36	17	64	39	22	0,7
CIAT 23427	82	41	15	47	40	29	320	37	16	62	35	27	1,6
CIAT 23943	74	35	14	43	40	27	225	36	16	61	37	20	1,4
CIAT 23956	80	41	13	47	44	27	178	38	15	61	39	40	1,5
CIAT 33423	68	37	14	41	42	27	156	34	16	61	39	29	6,4
CIAT 33424	59	41	13	44	39	29	158	41	14	63	33	28	2,0
Mean	65	39	14	45	42	31	170	37	15	62	37	27	2,7
LSD (P<0.05)				8.29	8.37			5.77	9.54				

The eight clusters are as follows:

Group 1: Contains 17 accessions: CIAT 23947, 13540, 23945, 13544, 23954, 21925, 21940, 21919, 21917, 21911, 13273, 13275, 33393, 33397, 33438, 23228, 23753. Originating from China (5 accessions), Vietnam (5), Thailand (5) and Indonesia, the accessions were collected at altitudes between 20 and 930 m asl, in hillside environments. Soils were variable, from sandy to clayey, low to medium fertility with good drainage. Annual rainfall at collection sides varied from 1100 to 3120 mm. Most accessions in this group are prostrate (12) but ascendant (4) and erect (1) accessions were present as well. The group is characterized by low forage quality and biomass production.

Group 2: Includes 16 accessions: CIAT 422, 918, 21914, 21915, 21916, 21920, 21922, 21927, 21939, 21979, 13542, 23955, 23957, 33384, 33456, 23755; collected in Vietnam (10), China (3), Thailand (2) and Indonesia (1), at altitudes ranging between 30 and 400 m asl in hillside environments. Soils were of intermediate texture, low to medium fertility, and good drainage; average annual rainfall ranged from 1260 to 4020 mm. Most accessions in this group were prostrate (10), but some ascendant (3) y erect (3) accessions were included as well. This group had the weakest agronomic performance, characterized by low yields, vigor, height, diameter and limited regrowth capacity, in addition to low protein content and a low digestibility.

Group 3: Contains 11 accessions: CIAT 465, 21928, 21929, 21930, 13277, 33110, 33418, 13723, 23227, 23756, 23953; with origin in Vietnam (4), Thailand (3), Indonesia (3) and China (1), collected at altitudes of 60 to 1320 asl, in hillside environments, on soils of intermediate texture and fertility, good to medium drainage, and annual rainfall ranging from 1270 to 3710 mm. Growth habit was variable, including ascendant (6), prostrate (3) and erect (2) accessions. This group is characterized by the highest protein content but lowest digestibility in the collection, and low DM yield.

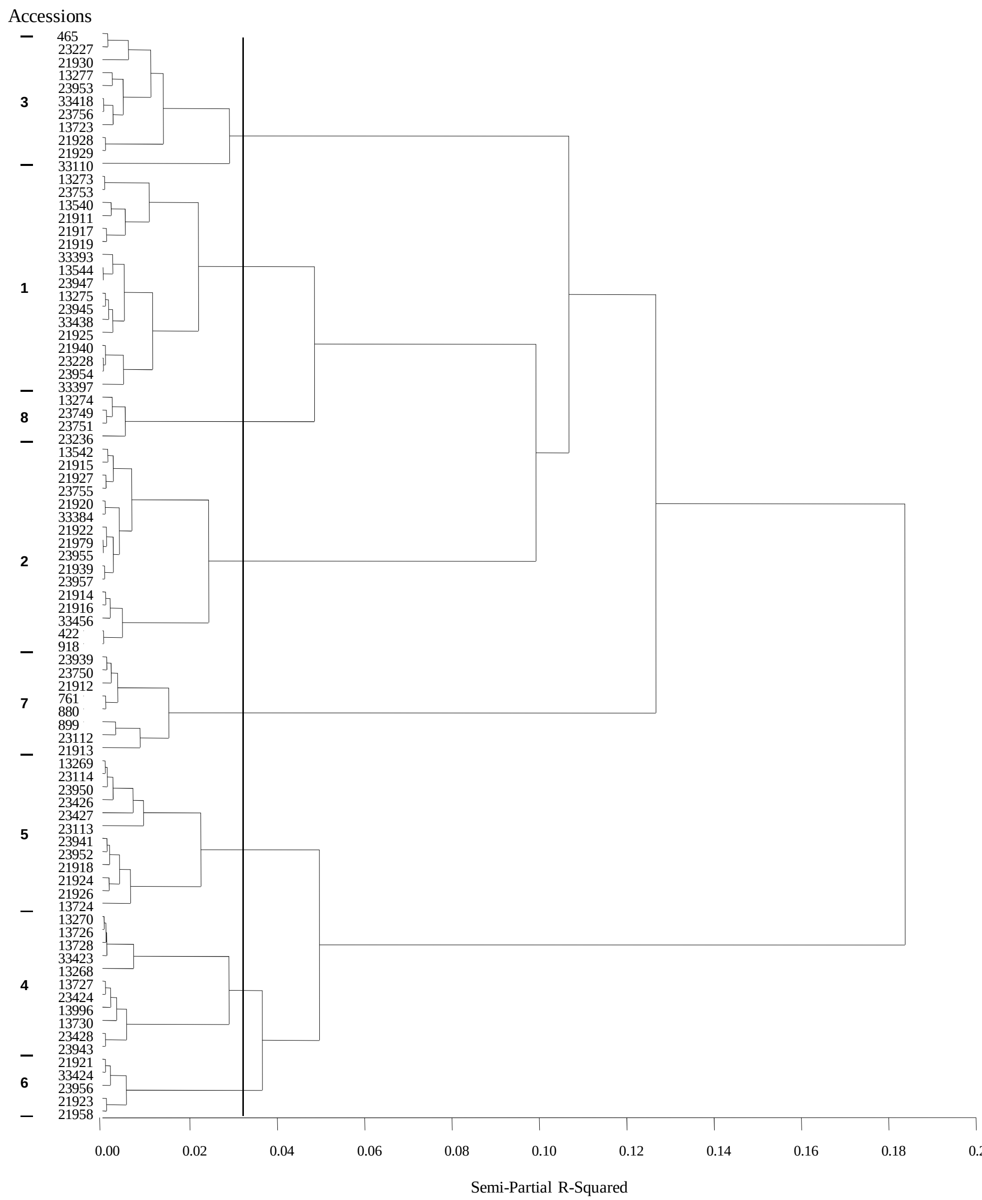


Figure 33. Dendrogram for the classification of 84 accessions of *Tadehagi triquetrum* truncated at the level of eight clusters.

Group 4: Includes 11 accessions: CIAT 13268, 13270, 13726, 13727, 13728, 13730, 33423, 23424, 23428, 13996, 23943; origin Thailand (7), Indonesia (2), Papua Guinea (1) and China (1), collected at altitudes of 30 to 1007 m asl, in hillside environments, with soil texture ranging from sandy to clayey, medium fertility, good or average drainage, and average annual rainfall between 1200 and 3190 mm. Most accessions were ascendent (8), but prostrate (2) and erect (1) accessions were also present. This group had the highest dry matter production and good vigor. However, forage quality was low.

Group 5: Integrates 12 accessions: CIAT 13724, 23113, 23114, 23426, 23427, 21918, 21924, 21926, 23941, 23950, 23952, 13269; origin Indonesia (5), Vietnam (3), China (3) and Thailand (1), collected at altitudes between 50 and 610 m asl, in hillside environments. Soils are with intermediate texture and fertility, and well drained. Annual rainfall ranges from 1510 to 2900 mm. In this group, ascendent (6) and prostrate (6) accessions are included. It is characterized by good DM production and vigor, the highest digestibility of the collection but low protein content.

Group 6: Includes the 5 accessions CIAT 21921, 21923, 21958, 23956, 33424; collected in Vietnam (3), China (1) and Thailand (1) at sites with annual rainfall ranging from 1800 to 3110 mm and altitudes from 40 to 160 m asl. Hillside environments with soils of intermediate to clayey texture, medium fertility, well drained. Includes prostrate (4) and ascendent (1) accessions. This group includes the accessions with the best ability to regrow, highest vigor and digestibility, and second highest DM production.

Group 7: Contains 8 accessions: CIAT 761, 880, 899, 21912, 21913, 23112, 23750, 23939; origin Vietnam (5), Indonesia (2) and China (1), annual rainfall ranging from 1500 to 1950 mm, soils of intermediate to clayey texture, of low fertility, well drained. Altitudes varying from 40 to 380 m asl, hillside topography. Characterized by low digestibility, but highest protein content in the collection, low DM yield and capacity to regrow.

Group 8: Contains the 4 accessions CIAT 23236, 23749, 23751, 13274; collected in Indonesia (3) and Thailand (1) in undulating topography, altitudes between 60 and 690 m asl, soils of intermediate to clayey texture, medium fertility, with good to average drainage. Annual rainfall between 1700 and 3200 mm. 2 accessions were of ascendent, 1 of prostrate and 1 of erect growth habit. Has the accession with the lowest digestibility of the collection, low DM production and intermediate protein content.

In addition to the agronomic evaluation, phenological observations were carried out for all 114 accessions (Photo 12 and 13). 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 defined to 77% by the number of flowers/plant, and the 2nd component defined to more than 70% by flowering time and seed set. The 3rd component is related with 58% to plant height.

Photo 12. Inflorescenses of *Tadehagi triquetrum*.

Photo 13. Ripe pods and seed of *Tadehagi triquetrum*.

Accessions CIAT 23956, 23115, 23228 and 21930 had a particularly high number of flowers, accessions CIAT 23751 and 23114 were particularly late flowering (289 and 299 days after transplanting to the field, respectively), with the latter also having high flower and seed production.

Mostly based on the information of number of inflorescences per plant, number of days to 1st flower and to 50% flowering, number of days to seed set and to 50% of seed formed as the most distinguishing traits, five cluster groups were defined (Figure 34):

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 1^{st} flower emerging 152 days after transplanting, and an average of 28 inflorescences per plant.

Group B: Composed of 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 per plant is 96.

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 (on average, 45 days after transplanting) and an intermediate number (91) of inflorescences per plant.

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 at 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).

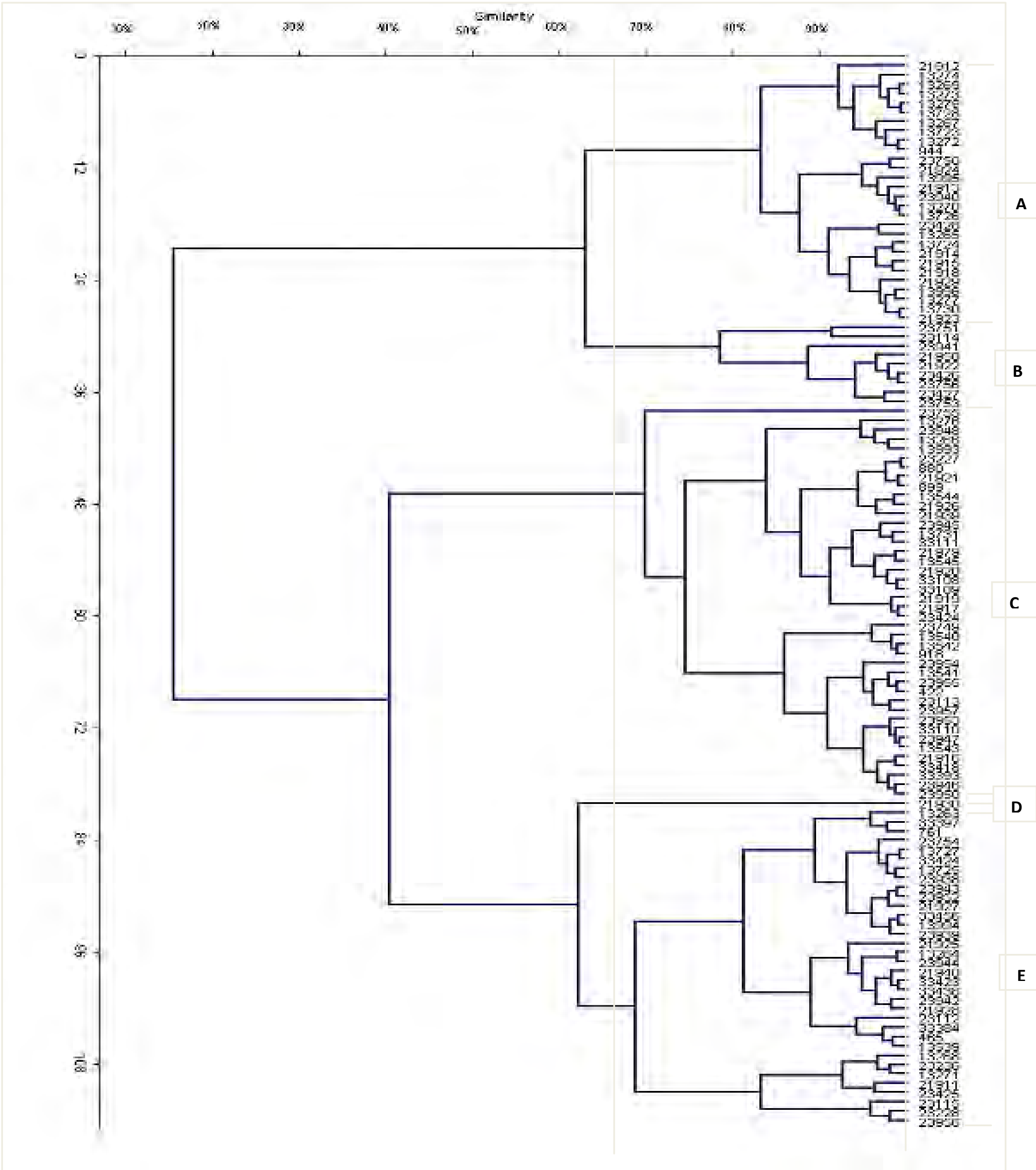


Figure 34. Dendrogram for the classification of 114 accessions of *Tadehagi triquetrum* truncated at the level of five clusters.

1.9 Evaluation of adaptation of a core set of tropical forage legumes in South Kivu province of DR Congo

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

Rationale

Whenever rural people in South Kivu province of DRC have been interviewed about their livestock production (Maass et al. 2010; Zozo et al. 2010), one of the most important challenges voiced by them was the lack of sufficient feed resources, especially during the dry season. Improved forage legumes and grasses, adapted to low fertility sites of tropical America have been developed by CIAT; however, their adaptation to locations with comparable agro-ecology in Africa is unknown. The objectives of the present research are, consequently, to assess the adaptation potential of selected, improved legumes and grasses to the agro-ecological conditions of the four *groupements* chosen for the project 'More Chicken and Pork in the Pot, and Money in Pocket: Improving Forages for Monogastric Animals with Low-income Farmers' in South Kivu province, namely Mulungu, Nyangezi, Kamanyola and Tubimbi. In these four *groupements*, so-called '*Synergies*' have been founded that connect villagers with a similar interest in the production of monogastric livestock. To encourage these people to participate in the project, pools of rabbits, cavies and swine have been created that allow *Synergy* participants to stock up their livestock numbers. *Synergy* participants also assist in field work and assessments. In addition, in every *groupement*, a facilitator has been assigned who links to the overall project coordination for DRC and collects data as deemed necessary.

Material and methods

Locations. 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 in South Kivu province of DRC (Table 31). This trial aims to identify the forages that are agro-ecologically best adapted and most appreciated by local evaluators 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 (see sections 1.10 and 1.11). While two sites are located at mid altitude (Mulungu, Nyangezi), the other two are at relatively low altitude (Kamanyola, Tubimbi), providing different temperature regimes for the experiment. In addition, soil fertility varies greatly, being relatively high at the first and very low at the second location of each altitude (Table 31). Soils are mostly sandy clay loams, with very acid (Nyangezi, Tubimbi) to moderately acid (Kamanyola) pH, and especially low cation exchange capacity at Nyangezi and Tubimbi, resulting in very low availability of plant nutrients. 7

Agronomic evaluation. Seed of 11 herbaceous and up to 15 different shrub legume species/accessions was provided by CIAT, except for that of the local checks that was received from ISAR, Rwanda. Plots established in the four locations in 2009 were regularly cut every two months in an area of 1 m^2 or the three center plants, respectively, for herbs and shrubs. The cutting regime started as soon as 50% of the plants flowered both in herbs and shrubs, however, in shrubs it only served as a standardization cut without any biomass assessment. Herbage biomass was assessed by separating leaves and stems, and dry matter (DM) was calculated after drying subsamples for almost three months under roof in Bukavu. A number of characteristics (soil cover (%), plant vigor (scores), plant height (cm), pest and disease susceptibility (scores), among others) was assessed monthly during the establishment phase and, afterwards, immediately before every cut. Detailed data will be reported elsewhere.

Table 31. Some characteristics of the locations for forage evaluation in South Kivu province, D.R. Congo [#]

Location	Altitude (m asl.)	Soil texture	Soil pH (Water)	CEC* (meq/100 g)	Slope	Climate
Mulungu (INERA)	1700	Clay loam	5.2	18.0	Almost plain	Sub-humid
Nyangezi	1650	Sandy clay loam	4.1	3.0	Steep	Relatively dry
Kamanyola	900	Sandy clay loam	6.6	33.5	Plain	Relatively dry
Tubimbi	1100	Sandy clay loam	4.4	4.0	Partly steep	Sub-humid

* CEC, Cation Exchange Capacity; [#] Soil analyses by CIAT-TSBF, Nairobi, Kenya.

Participatory evaluation. Before starting the evaluation in the field, the facilitators met with the *Synergy* members present at every location. The purpose of the project was repeated to the people, who were reminded of the main reasons for forage cultivation. Afterwards, about five women and five men were chosen randomly, each to form a team for the evaluation in the field. Before the scoring was started, the facilitator together with the groups went across the field to explain each kind of forage and have an overall appreciation by the group. Then, every person went individually to place a piece of paper on the plot of his/her choice. For scoring both trials, every person had 3 white papers for the most positive and 3 lined papers for the negative plots according to his/her choice. The preference indicated by papers was transformed into percentages adjusted to the number of evaluators in order to give equal weight to every location. To avoid any interaction during the scoring, one team assessed field replication 1 and the other replication 3. Finally, the plots were counted and each team was informed about their overall choice. When both teams had finalized their scoring, the results were compared between the men and women teams, and a common ranking was performed for every location. This participatory evaluation was performed both in the dry and the rainy season in each location.

Results and discussion

Agronomic evaluation – herbaceous and shrub/tree legumes. Regarding sites, Kamanyola offered the most productive environment, followed by Mulungu, Nyangezi and Tubimbi; however, the latter may be due to late establishment of the trial. Legumes showed differential adaptation and only *Canavalia brasiliensis* and *Desmodium uncinatum* appeared to be well adapted across all the four locations. Neither *Vigna unguiculata* nor *Lablab purpureus* showed particular good adaptation; they only produced biomass for one substantial cut. Both *Stylosanthes guinanensis* and *Centrosema molle* took time to establish well, i.e., biomass produced for the first cut was relatively low but later increased. *Clitoria ternatea* was not adapted except at Kamanyola. As expected, there were differences regarding persistence: some plants at some locations could be cut up to five times at 2-monthly intervals, whereas others only allowed two cuts. Overall, flowering time was slowest at Mulungu, but not substantially different at the other three locations. *Centrosema molle* and *Canavalia brasiliensis* were latest in starting to flower, whereas *Desmodium uncinatum*, *Macroptilium atropurpureum* and *Clitoria ternatea* were intermediate, and all the others rather early flowering. However, there was fair interaction between species/accessions and locations (Figure 35). The trial is being repeated at Nyangezi and Tubimbi during 2010/11.

Regarding shrub/tree legumes, they partly had been sown in January 2009 (Mulungu, Nyangezi). Apparently, the local check, *Calliandra calothyrsus*, is well adapted to the infertile soils and climate conditions of the trial sites. After a lag phase of initial slow growth, *Cratylia argentea*, *Desmodium velutinum* and *Leucaena diversifolia* accessions also started to continuously produce reasonable leaf biomass. This trial is continuing during 2010/11.

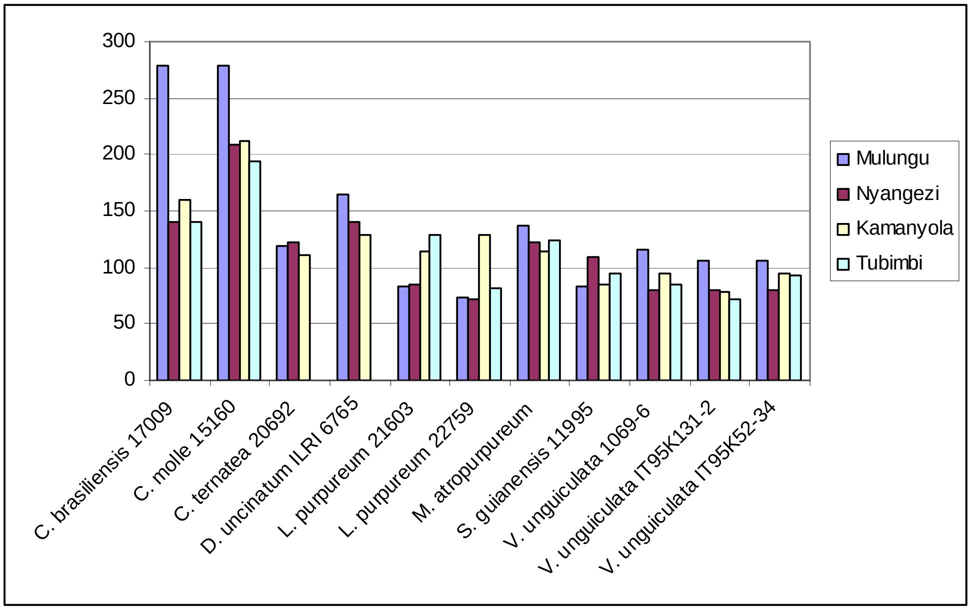


Figure 35. Beginning of flowering (50% of plants) of herbaceous forage legumes at four sites in South Kivu province of DR Congo.

Participatory evaluation – herbaceous legumes. People's criteria to chose forages differed slightly among locations, but stronger so between rainy and dry season (Table 32). The most important criteria, however, was always biomass production. Drought resistance was ranked either among the first five (during dry season) or not (rainy season) demonstrating, thus, how important the timing of participatory evaluation can be. Other criteria ranked very important were the nutritive value of forages and their acceptability to the animals, while their capacity to improve livestock production was not rated up front.

Table 32. Mean rank of top five evaluation criteria applied by farmers to various herbaceous legumes during the dry and rainy seasons in four locations of South Kivu province, DR Congo

Selection criteria identified by farmers	**Dry season (rank)** N = 21 women, 26 men	**Rainy season (rank)** N = 20 women, 14 men
High biomass production	1	1
Dry season tolerance	2	(6)*
High nutritive value	3	2
Well accepted/palatable	4	3
Disease resistant	5	(8)*
Improves soil fertility	(9)*	4
Serves for erosion control	n.m.	5
Promotes high milk production	(6)*	n.m.

* mentioned, but not among the top five; n.m., not mentioned.

The most preferred herbaceous species across all four sites and the two seasons were *Canavalia brasiliensis* and *Stylosanthes guianensis*, while *Centrosema molle* was highly chosen during the dry season, and *Lablab purpureus* and *Desmodium uncinatum* during the rainy season (Table 33). Least preferred were species/accessions that had already vanished during the dry season assessment, like all cowpea accessions. When comparing the different sites, *L. purpureus* CIAT 21603 received highest scores at Mulungu; *M. atropurpureum* cv. Siratro at Kamanyola and Mulungu; *Clitoria ternatea* CIAT 20692 was among the top five in Mulungu; whereas *Desmodium uncinatum* cv. Silverleaf (local check) was selected in Nyangezi.

Table 33. Participatory evaluation of different herbaceous legumes during dry and rainy seasons grown in four locations of South Kivu province, DR Congo

Species and accession ID	**Dry season** Overall choice (%)	**Rainy season** Overall choice (%)	**Dry season** preference
Canavalia brasiliensis CIAT 17009	78.7	61.8	+
Stylosanthes guianensis CIAT 11995	78.7	58.8	+
Centrosema molle CIAT 15160	55.3	5.9	++
Macroptilium atropurpureum cv. Siratro	34.0	0.0	++
Desmodium uncinatum ILRI 6765 (cv. Silverleaf)	24.3	44.1	
Lablab purpureus CIAT 21603	21.3	50.0	
Clitoria ternatea CIAT 20692	8.5	8.8	
Lablab purpureus CIAT 22759	2.1	32.4	
Vigna unguiculata IT95K131-2	2.1	8.8	
Vigna unguiculata 1069-6	0.0	20.6	
Vigna unguiculata IT95K52-34	0.0	11.8	

Participatory evaluation – shrub/tree legumes. Similar to herbaceous legumes, people's criteria to chose shrub legumes also differed slightly among locations, but again more strongly between rainy and dry seasons (Tables 34 and 35). Their most important criteria was biomass production, whereas nutrive value was second in both seasons. Drought tolerance was either ranked third (during dry season) or not among the top five (rainy season). Animal-related criteria of forages, like their acceptability/ palatability and their effect on animal health were ranked high during the dry season assessment, while soil-related criteria, such as improving soil fertility and controlling soil erosion, where ranked among the top five during the rainy season.

Table 34. Mean rank of top five evaluation criteria applied by farmers to various shrub legumes during dry and rainy seasons in four locations of South Kivu province, DR Congo

Selection criteria identified by farmers	**Dry season (rank)** N = 22 women, 27 men	**Rainy season (rank)** N = 20 women, 22 men
High biomass production	1	1
High nutritive value (improves animal/ milk production)	2	2
Tolerance to drought	3	(6)*
Well accepted/palatable	4	3
Provides good animal health	5	(10)*
Improves soil fertility	(11)*	4
Serves for erosion control	n.m.	5

* mentioned, but not among the top five; n.m., not mentioned.

Table 35. Participatory evaluation of different shrub/tree legumes during dry and rainy seasons grown in four locations of South Kivu province, DR Congo

Species and accession ID	**Dry season** Overall choice (%)	**Rainy season** Overall choice (%)	**Dry season** preference
Calliandra calothyrsus (local check)	54.8	73.8	
Cratylia argentea CIAT 18516*	42.7	28.3	+
Leucaena diversifolia ILRI 15551	36.0	39.2	
Flemingia macropylla CIAT 20618	34.7	26.3	
Leucaena leucocephala CIAT 17263	33.9	34.6	
Flemingia macrophylla CIAT 17403	22.0	8.8	+
Leucaena diversifolia K782	21.6	25.8	
Desmodium velutinum CIAT 13218	19.9	6.7	+
Desmodium velutinum CIAT 23982	17.0	0.0	+
Desmodium velutinum CIAT 23996*	16.1	5.0	+
Flemingia macrophylla CIAT 18438*	10.0	0.0	
Leucaena diversifolia CIAT 22192	7.5	22.9	
Leucaena diversifolia K780	6.6	34.2	
Leucaena diversifolia CIAT 17503	3.6	8.8	
Desmodium velutinum CIAT 33443	0.0	0.0	

* only evaluated in Mulungu and Nyangezi.

Except Kamanyola, where *Leucaena leucocephala* CIAT 17263 received high marks in the dry season, the most preferred shrub/tree legume species across all sites and the two seasons was the local check, *Calliandra calothyrsus*, while all others ranked much lower. During the dry season, there was slightly more preference for *Flemingia macrophylla* CIAT 20618 and the three *Desmodium velutinum* accessions, however, overall there was rather low preference for these species new to the farmers, while *C. calothyrsus* has been in the environment for a certain time and appears very well adapted to local conditions. Interestingly, *Cratylia argentea* CIAT 18516 – only grown in the two higher locations, Mulungu and Nyangezi due to lack of seed at sowing – was chosen immediately after *C. calothyrsus*. While it is known that *Cratylia* is sensitive to cooler temperatures in South America, it appears to be adapted to the South Kivu hillside locations; its drought tolerance was especially recognized by evaluators.

1.10 Agronomic evaluation of forages for monogastric animals, Colombia

Contributors: Muñoz, L.S.; Sarria, P.I. (UNAL-Palmira); Vivas, N. (Universidad del Cauca); N. Franco, L.H.; Hincapié, B.; Peters, M.; Holmann, F. (CIAT)

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 (Photos 14-15-16).

Photo 14. Planting and establishment of plots at La Sirena, Parraga, Cauca.

Photo 15. Planting and establishment of plots at El Peaje, El Bordo, Cauca.

Photo 16. Legumes at La Sirena, Parraga, Cauca.

At the site ‘Los Lagos’ accessions *Lablab purpureus* CIAT 22759, 21603, *Canavalia brasiliensis* CIAT 17009, *Vigna unguiculata* IT99K131-2, IT95K 52-34 and *Centrosema molle* established quickly with soil covers superior to 60% 3 months afterplanting; *Stylosantes guianensis* CIAT 11995 and *Desmodium heterocarpon* CIAT 13651 were slower (Table 36). At ‘La Sirena’ establishment was equally quick, with accessions *C. brasiliensis* CIAT 17009, *L. purpureus* CIAT 22759, 221603, V. *unguiculata* IT99K131-2, IT95K 52-34 and IT97K 1069-6 having soil covers above 70% 3 months after planting (Table 37). *Clitoria ternatea* CIAT 20692 and *D. heterocarpon* CIAT 13651 were the slowest to establish.

Table 36. Vigor, soil cover (%) during of establishment of legumes in Los Lagos, Cauca, Colombia 2010

Accessions	**8 Weeks**		**12 Weeks**	
	Vigor 1-5	**Soil cover %**	**Vigor 1-5**	**Soil cover %**
Lablab purpureus CIAT 22759	3.3	45	4.3	83
Lablab purpureus CIAT 21603	3	35	4	77
Canavalia brasiliensis CIAT 17009	3	33	4.3	77
Vigna unguiculata IT98K 131-2	2.3	30	3.6	63
Vigna unguiculata IT95K 52-34	3.6	47	3.6	63
Centrosema molle CIAT 15160	2.6	20	3.6	60
Vigna unguiculata IT97K 1069-6	3	32	3	43
Clitoria ternatea CIAT 20692	2.3	13	3.6	43
Stylosanthes guianensis CIAT 11995	1.6	13	2	15
Desmodium heterocarpon CIAT 13651	1.3	7	1.3	5
Mean	2.6	27.5	3.3	47.6

Table 37. Vigor, soil cover (%) during the establishment of legumes in La Sirena, Cauca, Colombia 2010

Accessions	8 Weeks		12 Weeks	
	Vigor 1-5	Soil cover %	Vigor 1-5	Soil cover %
Canavalia brasiliensis CIAT 17009	3	33	4	83
Lablab purpureus CIAT 22759	3.3	43	4.3	80
Lablab purpureus CIAT 21603	3.3	40	4	80
Vigna unguiculata IT98K 131-2	4	60	4	77
Vigna unguiculata IT95K 52-34	3.6	58	4	77
Vigna unguiculata IT97K 1069-6	3.6	53	4	70
Stylosanthes guianensis CIAT 11995	2.3	18	4	67
Centrosema molle CIAT 15160	3	23	3.6	62
Clitoria ternatea CIAT 20692	2	15	3.6	37
Desmodium heterocarpon CIAT 13651	1.6	2	3	10
Mean	3	35	3.8	64

Due to a different growth cycle, *Lablab purpureus* and *Vigna unguiculata* were harvested at different times after planting, both for dry matter and grain production; dry matter was harvested in pre-flowering stage and grain at ripening, the latter followed in different steps as grains ripened. Significant differences between accessions (P<0.05) were found for DM yields at 'La Sirena' but not for grain production in any of the locations. Biomass and grain yields were much lower at 'Los Lagos' (Table 38).

Table 38. Agronomic evaluation of *V. unguiculata* and *L. purpureus* in La Sirena and Los Lagos, Cauca. Data of one evaluation cut in the dry season

Accessions	La Sirena		Los Lagos	
	DM	Grain	DM	Grain
	(kg/ha)			
V. unguiculata IT95K52-34	3800	1286	953	1226
V. unguiculata IT98K 131-2	2169	1615	1512	526
V. u IT97K 1069-6	1952	1448	1377	864
L. p CIAT 21603	1694	1520	1187	-
L. p CIAT 22759	1213	1147	1226	-
Mean	2166	1403	1253	872
LSD (P<0.05)	4629		3001	

As in 'La Sirena' the dry period commenced at the end of establishment, the standardization cut for the 2nd year was done at the onset of the following rainy season. In the wet season there were significant (P<0.01) differences in DM yields between accessions, with highest yields measured for *Centrosema molle* CIAT 15160, *Stylosanthes guianensis* CIAT 11995 and *Canavalia brasiliensis* CIAT 17009, all yielding more 3.5 t DM/ha and soil covers above 95% (Table 39).

Table 39. Agronomic evaluation of Legumes in La Sirena, Cauca. Data of one evaluation cut in the wet season. DM yield after 8 weeks of regrowth

Accessions	Cov %	DM (kg/ha)
C. molle CIAT 15160	100	5004
S. guianensis CIAT 11995	95	4704
C. brasiliensis CIAT 17009	95	3510
D. heterocarpon CIAT 13651	80	2813
C. ternatea CIAT 20692	25	1060
Mean	79	3587
LSD (P<0.05)		2099

1.11 Agronomic evaluation of forages for monogastric animals, Nicaragua and Honduras

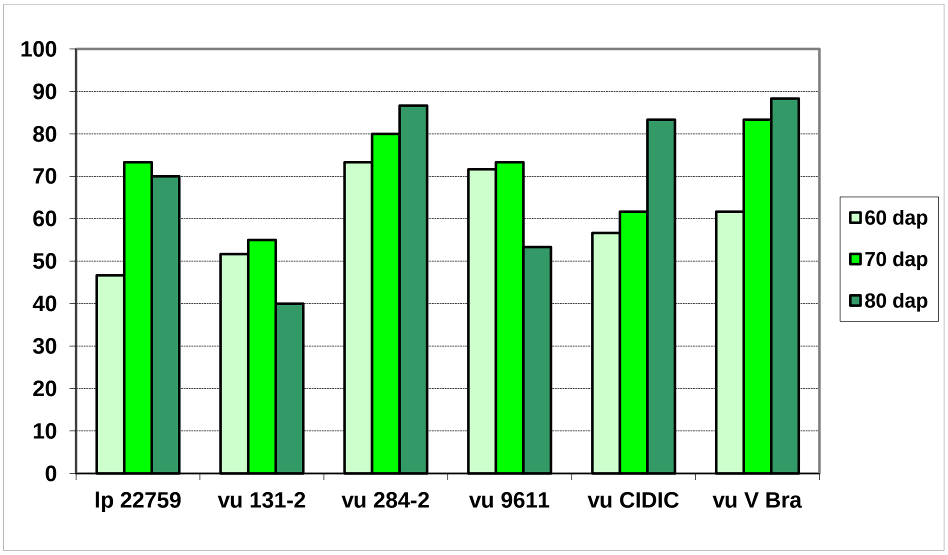
Contributors: Rodríguez, C.; van der Hoek, R.; Chavarría, E.; Peters, M. (CIAT); Mena, M.; Moreno, E.; Benavidez, A.; (INTA), Posas, M.; (SERTEDESO), Burgos, C. (consultant).

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.

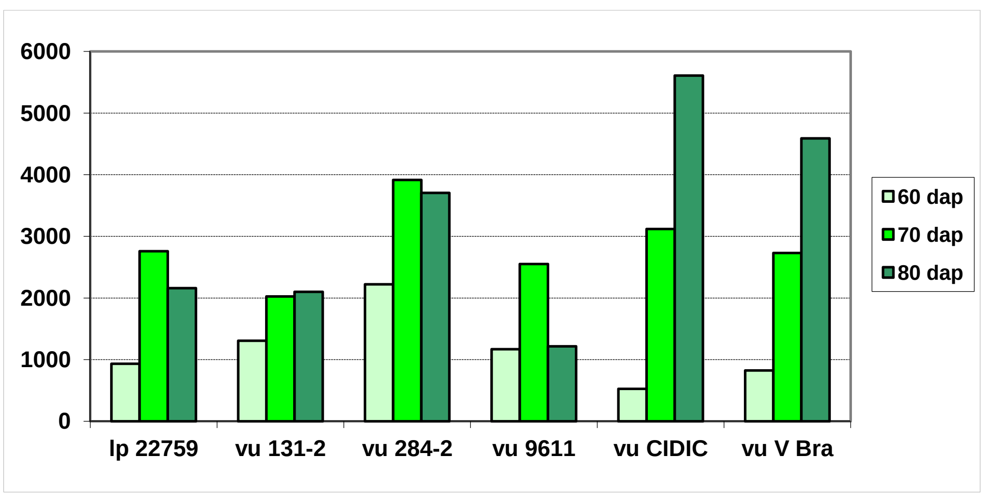
Agronomic trials

Complementary to similar trials in Nicaragua in 2009 (see CIAT annual report), in Yorito, Yoro, Honduras an on-farm experiment was implemented to determine agronomic characteristics of six promising forage legumes, five accessions of *Vigna unguiculata* and one of *Lablab purpureus* (Figures 36 and 37).



lp 22759: *Lablab purpureus* CIAT 22759; vu 131-2: *Vigna unguiculata* IT98K-131-2; vu 284-2: *Vigna unguiculata* IITA 284-2; vu 9611: *Vigna unguiculata* 9611; vu CIDIC: *Vigna unguiculata* CIDICCO; vu V Bra: *Vigna unguiculata* Verde Brasil

Figure 36. Cover (%) of herbaceous legumes at 60, 70 and 80 days after planting (dap), Yorito, Yoro, Honduras



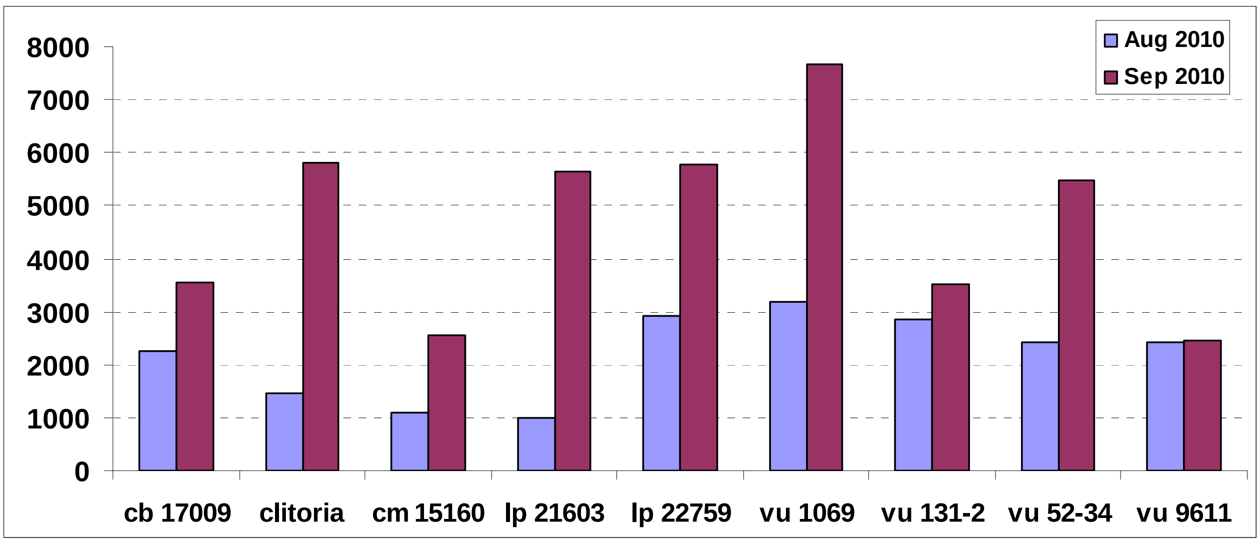
lp 22759: *Lablab purpureus* CIAT 22759; vu 131-2: *Vigna unguiculata* IT98K-131-2; vu 284-2: *Vigna unguiculata* IITA 284-2; vu 9611: *Vigna unguiculata* 9611; vu CIDIC: *Vigna unguiculata* CIDICCO; vu V Bra: *Vigna unguiculata* Verde Brasil

Figure 37. Biomass production (kg Dry Matter/hectare) of herbaceous legumes, at 60, 70 and 80 days after planting (dap), Yorito, Yoro, Honduras

The results show significant differences in cover and biomass production between accessions ($p<0.05$) and reflect the distinctive traits of the legumes, with marked differences in optimal harvesting moments, *Lablab purpureus* CIAT 22759 and *Vigna unguiculata* IITA 284-2 and 9611 at 70 days after planting and *Vigna unguiculata* CIDICCO and Verde Brasil at 80 days, the latter also producing more biomass ($p<0.05$) up to almost 6 t/ha.

Multilocational genotype-environment interaction trials

At two sites in the Pacific part of Nicaragua (Posoltega (Chinandega) and Palacaguïna (Madriz)) a genotype-environment interaction trial was established in which the agronomic characteristics of a range of herbaceous legumes, shrub legumes and grasses were evaluated, in plots of 25 m2 with three replicates. Due to problems with germination and drought with grasses and shrubs at both sites and animals at Palacaguïna, only the herbaceous legumes in Posoltega provided reliable results as presented in Figure 38.



cb 17009: *Canavalia brasiliensis* CIAT 17009; clitoria: *Clitoria ternatea* CIAT 20696; cm 15160: *Centrosema molle* CIAT 15160; lp 21603: *Lablab purpureus* CIAT 21603; lp 22759: *Lablab purpureus* CIAT 22759; vu 1069: *Vigna unguiculata* IT97K-1069; vu 131-2: *Vigna unguiculata* IT98K-131-2; vu 52-34: *Vigna unguiculata* IT95K-52-34; vu 9611: *Vigna unguiculata* 9611

Figure 38. Biomass production (kg DryMatter/hectare) of herbaceous legumes, Posoltega

Most promising in terms of biomass production and cover were some accessions of *Vigna unguiculata* (IT97K-1069, IT98K131-2), as well as *Lablab purpureus* CIAT 22759 and *Clitoria ternatea* CIAT 20696.

At the Palacaguïna site the four best performing herbaceous legumes in terms of biomass production were the accessions of *Vigna unguiculata* (ranging from 3700 to 9100 kg DM/ha for IT97K-1069), followed by *Stylosanthes guianensis* CIAT 11995 (3500 kg DM/ha) and *Canavalia brasiliensis* CIAT 17009 (3200 kg/ha).

1.12 Development of near infrared spectroscopy (NIRS) calibration equations for nutritional characterization of tropical forages

Objetive

Establish and validate NIRS calibration equations for predicting the nutritional quality parameters of tropical forages.

Contributors: Molano, M. L. (Universidad Nacional de Colombia, Sede Palmira); Ávila, P.; Martens, S. (CIAT)

Rationale

The nutritional value of forages is generally estimated based on their chemical constituents.

These values require many resources such as reagents, time and energy. The near infrared reflectance spectroscopy (NIRS), which is based on spectral measurements allows developing regression equations. Those relate the readings of the product spectrum in the near infrared area to the chemical composition and nutritional value of it. This method is fast and fairly accurate once generated a reliable equation.

In developing these equations, in the future we can evaluate the quality of tropical forages as animal feed in a cost and time efficient manner and environmentally friendly by increasing the throughput of samples for analysis.

Materials and Methods

Brachiaria hybrid samples were collected from plots which were planted on April 7, 2010. The first sampling was conducted in August 2010 where samples of 155 hybrids were harvested, and the second sampling was done at 5 weeks of regrowth in November 2010.

These samples were dried in an oven at 60 ° C and were ground to ensure a particle size of 1 mm in a Torrey mill type.

In addition to the grasses, we used a pool of different legume samples harvested between 2005 and 2010 to create a database and subsequent calibration equations: such as *Canavalia brasiliensis, Canavalia sp, Centrosema brasilianum, C. molle, Cratylia argentea, Cratylia sp, Desmodium velutinum, Dioclea guianensis, Flemingia macrophylla, Leucaena diversifolia, Leucaena trichandra, Tadehagi triquetrum, Vigna unguiculata, Clitoria ternatea* and *Stylosanthes guianensis.*

A database of all known agronomic and nutritional parameters was generated in MS Excel.
Once prepared, samples were scanned at the reflectance mode using quartz capsules with an internal diameter of 3.5 cm, using a NIRS-FOSS 6500 with ISIscan software. For managing the database of spectra, we used the software WinISI version 1.6.

In the calibration process these samples have been or will be analyzed by conventional wet chemistry depending on the goal of every plant investigated. Most common parameters are Crude Protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), *in-vitro* digestibility of dry matter (ruminants) (IVDMD) and neutral detergent fiber digestibility (NDFd).

These data will be related to data obtained from the NIRS through statistical models such as multiple regression, principal components analysis and partial least squares. After establishing a calibration equation, it will be validated. This is done with samples different to the calibration set. The composition of these samples shall be known first from wet chemistry data.

Results

A database of 1804 samples of different forage species has been developed, which contains information on CP, NDF, ADF, IVDMD and NDFd among others. These data have been obtained by wet chemistry.

Outlook

In 2011 we will continue to scan all samples and obtain wet chemistry data. We will define the statistical design, to create the nutritional prediction equations for each of the components evaluated in this study.

This project is part of an investigation co-financed by Embrapa "Identification of aluminum resistance genes in *Brachiaria* and phenotypic characterization of grass and legume germplasm for adaptation to and mitigation of climate change", as a high animal performance based on high nutritional quality will reduce greenhouse gases per unit animal product.

1.13 The pathogenic, molecular, and morphological characterization of *Rhizoctonia* isolates causing foliar blight in *Brachiaria*, Colombia

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Rationale

A member of the grass family Poaceae, *Brachiaria* is a genus of plants that includes about 100 species, some of which are economically significant (Kelemu et al. 1995; Miles *et* al 1996). The importance of this genus lies in its forage species being among the most economically valuable of the available sources of feed in the Tropics for cattle-raising, a key sector in the economies of Latin American countries (Rivas and Holmann *et* al. 2004).

Foliar blight is an invasive and destructive disease. It is caused by the pathogen *Rhizoctonia* spp., which devastates the susceptible genotypes of a wide range of hosts throughout the world, including *Brachiaria*, rice, potato, soybean, sorghum, sugarcane, strawberry, maize, tomato, common bean, canola, and ornamental plants (Parmeter Jr and Whitney 1970; Sneh et al. 1996; Dolores 2002). In Colombia, *Rhizoctonia* foliar blight is significant in cattle-raising areas such as the North Coast, the Amazonian Piedemonte, and particularly the Eastern Plains (Kelemu et al. 1995).

Materials and methods

Collecting, isolating, and storing *Rhizoctonia* spp.

To develop a collection of *Rhizoctonia* isolates, samples were collected from different *Brachiaria* accessions found in the Colombian Departments of Cauca, Meta, Casanare, Córdoba, and Caquetá. From 625 samples, isolates of the pathogen were prepared and stored, following the methodology of Aricapa and Correa (1994).

Morphological characterization of *Rhizoctonia* isolates

The morphology of 147 *Rhizoctonia* isolates was evaluated by establishing their nuclear condition and growth rate. Nuclear condition was determined by staining with 3% safranin "O"/KOH, as according to Bandoni (1979). Data of 20 individual cells per isolate were taken and averaged to estimate the nuclear condition.

To determine the growth rate, radial growth was evaluated, taking diameter data daily for 8 days and conducting an ANOVA, using a randomized complete block design with three replications per isolate. Statistical analyses were carried out with the Statistical Analysis System program, version 9. Qualitative characteristics such as color and sclerotium production were also recorded.

Pathogenicity tests

We used the 147 *Rhizoctonia* isolates collected from the field, mostly from *Brachiaria* hybrid cv. Mulato II, *B. brizantha*, and *B. decumbens.* The isolates were cultured on solid PDA medium with an antibiotic at 300 mg/L and incubated for 3–4 days.

The susceptible host was *Brachiaria* hybrid cv. Mulato (CIAT 36061). Inoculation was carried out on 40-day-old plants, using *Rhizoctonia* isolates in a randomized complete block experimental design, with five replications. To inoculate, we used the methodology suggested by Sotelo et al. (2007). Five plants per isolate were inoculated. The inoculum for the negative controls consisted of PDA agar discs. The inoculated plants were left at a temperature of 28°C and individually covered with 600 ml plastic drinking water bottles to create high relative humidity (80% to 100%) and physically to isolate individual plants from each other so as to avoid cross contamination.

Symptoms were evaluated against a visual scale of 0 to 11, estimating the percentage of affected leaf area as according to Horsfall and Barrat (1945). The plants were evaluated every 3 days after inoculation for 15–18 days to record the infectious process.

For statistical analyses, the variable used was the area under the disease progress curve (AUDPC). With this value, an ANOVA was carried out to determine statistically significant differences among isolates.

Molecular characterization

Extracting DNA from Rhizoctonia spp.

Extraction was carried out, according to the protocol reported by Álvarez et al. (2004), with some modifications, as follows: isolates were cultured into erlenmeyer flasks containing 100 mL of potato dextrose broth (PDB) and incubated at 30°C in the dark for 5–6 days on a shaker. Fungal mycelia were obtained and removed to filter paper (Whatman No. 2) placed in a funnel or ceramic filter (Büchner funnel), which was joined to an erlenmeyer flask and vacuum pump. The mycelia were washed three times with sterilized distilled water and filtered. The mycelia left on the filter paper were removed to labeled tubes that were then placed in a lyophilizer to extract moisture. The mycelia were then macerated with liquid nitrogen and placed into sterilized 2-mL eppendorf tubes, which were kept at -20°C.

Amplifying rDNA ITS regions
Universal primers were used: ITS1 and ITS4 (White et al. 1990), where:

ITS1 was 5′-TCCGTAGGTGAACCTGCGG-3′ and
ITS4 was 5′-TCCTCCGCTTATTGATATGC-3′

The PCR reactions were calculated for 30 **µL. The following amplification conditions were used**: 0.3 µL of each primer at a concentration of 50 µM; 0.25 µL of *Taq* polymerase at 5 U/µL; 2.4 µL of the dinucleotides dATP, dCTP, dGTP, and dTTP at a concentration of 2.5 mM each; 6 µL of buffer (5X; 10 mM Tris-HCl, pH 8.3, 50 mM KCl, and 15 mM $MgCl_2$); and 1.2 µL of fungal DNA at a concentration of 5 ng/µL.

The reaction was carried out in a thermal cycler (PTC-100 Peltier Thermal Cycler, MJ Research, Inc., Waltham, MA, USA), and amplification conditions were denaturation at 94°C for 3 min, followed by 30 cycles of denaturation at 94°C for 1 min, annealing at 59°C for 1 min, an extension of 72°C for 2 min, and a final extension at 72°C for 3 min.

The results were evaluated, using electrophoresis in 1.2% agarose gels, stained with GelRed™ (nucleic acid gel stain: 10,000X; Life Technologies (India) Pvt. Ltd, Delhi, India), on 1X TAE buffer and visualized under UV light. A DNA molecular-weight marker HyperLadder II (Bioline; Batch No.: H2K2-1008) was also used.

RFLPs and sequencing the rDNA ITS region
The amplified products were digested with restriction enzymes *Eco*RI, *Mbo*I, *Alu*I, and *Taq*I according to the conditions shown in Table 40.

Table 40. Conditions for digestion with restriction enzymes

	Volume (µL) with enzymes:	
Parameter	***Taq*I**	***Alu*I, *Eco*RI, or *Mbo*I**
Enzyme buffer	2.00	2.00
Enzyme	0.25	0.25
PCR product	5.00	5.00
Ultrapure water	7.55	7.75
Bovine serum albumin (BSA)	0.20	-
Final volume	15.00	15.00

The reagents were mixed and incubated for 16 h, with enzyme *Taq*I incubating at 65°C, and *Eco*RI, *Alu*I, and *Mbo*I at 37°C. Electrophoresis was carried out in 3% agarose gel with 1X TAE buffer. The results were stained with GelRed™ (nucleic acid gel stain: 10,000X) and the products visualized under UV light. To observe the fragments, a molecular-weight marker, the 50 bp DNA Ladder (New England BioLabs, Inc., Ipswich, MA, USA), was used.

From these data, the isolates were sequenced to determine their species. Sequencing was carried out in the laboratories of the Iowa State University DNA Facility (Molecular Biology Building, Ames, IA, USA).

A similarity analysis was carried out on the matrix data from the electrophoresis on the fragments obtained by the PCR–RFLP technique. This analysis grouped the population into genetic clusters according to their similarity of restriction bands. Comparisons were carried out on the basis of the presence or absence of RFLP bands. The dendrogram was made with the unweighted pair-group method arithmetic average (UPGMA) method and using the software NTSYS–pc, version 1.7.

With respect to the sequencing of the rDNA ITS region, data were examined with ChromasPro® software and the database of GenBank (National Center for Biotechnology Information or NCBI, Bethesda, MD, USA).

Results and discussion

Collecting plant materials and *Rhizoctonia* isolates

From samples of tissues exhibiting foliar blight symptoms caused by *Rhizoctonia* spp., we obtained 147 isolates belonging to the *Rhizoctonia* genus and which showed the characteristic features of this genus (González et al. 2006).

The pathogen was consistently isolated from samples of plant materials and from necrotic areas attacked by *Rhizoctonia.* The isolates were obtained from various geographic zones, and from eight *Brachiaria* genotypes from 10 sites (six municipalities in five departments) in Colombia. This type of collection enabled us to maximize the probability of obtaining isolates with significant genetic diversity. In addition, six isolates were collected from other species affected by *Rhizoctonia*: kenaf (*Hibiscus cannabinus)*, sugarcane (*Saccharum officinarum*), and sorghum (*Sorghum* sp.).

The methodology, as presented by Aricapa and Correa (1994), of isolating and storing the fungi on filter paper was simple and effective for the *Rhizoctonia* pathogen.

Morphological characterization

Morphological differences among *Rhizoctonia* isolates were observed for characteristics such as color of the colony, distribution, clumping of sclerotia, and number of nuclei per cell.

Mycelia of *Rhizoctonia* isolates cultured on PDA were white during the first 3 days of incubation, and then the color fluctuated between white and light brown. The 147 isolates separated into two groups or types: type 1 comprised 101 isolates that were light or dark brown; and type 2 comprised 46 isolates that were white. The mycelia of type 1 isolates grew over the agar's surface where they formed sclerotia that were initially white, becoming brown. The sclerotia of type 2 isolates remained white. However, the sclerotia of some isolates formed dark brown clumps that were 3 to 8 mm in diameter.

Isolates obtained from Cauca developed white colonies that produced few sclerotia, whereas those of Meta, Casanare, Córdoba, and Caquetá presented colonies that ranged from light to dark brown and produced abundant sclerotia.

With respect to the nuclear condition, of the 147 isolates obtained, 101 were multinucleate and 46 binucleate corresponding to the two color types dark brown and white color respectively.

For the variable "growth rate", significant differences were obtained (Table 41). Isolates from Cauca grew slowly (7 days to develop well), whereas those from Meta, Casanare, Córdoba, and Caquetá grew more rapidly (3 or 4 days).

Table 41. Analysis of variance for data on growth rates of *Rhizoctonia* isolates

Source of variation	df	Sum of squares	Mean of squares	*F* value	*P* > *F*
Replication	2	0.0430	0.0215	0.23	**0.7929**
Isolates	146	217804.4037	1491.8110	16099.70	**<0.0001**
Error	292	27.0570	0.0927		
Total	440	217831.5037			

According to the results obtained, the isolates analyzed separated into two biological species. The multinucleate *Rhizoctonia*, brown, with a fast growth rate were *R. solani* (sexual state *Thanatephorus cucumeris*). The smaller group of binucleate *Rhizoctonia*—white and growing slowly—were *Rhizoctonia* (sexual state *Ceratobasidium* sp.) that were pathogenic to plants of *Brachiaria* cv. Mulato. These characteristics corroborated reports by other researchers such as Carling and Summer (1992), Cedeño and Carrero (1996), Cardona et al. (1999), and da Silveira et al. (2000).

The binucleate *Rhizoctonia* isolates (sexual state *Ceratobasidium* sp.) were isolated from plant materials collected only from the Department of Cauca, whereas the *R. solani* isolates were collected from different sites in the Departments of Meta, Casanare, Córdoba, and Caquetá. This suggests that *R. solani* is the predominant species in Colombia and that, moreover, it is the principal species associated with foliar blight in *Brachiaria* spp.

Pathogenicity tests

In the susceptible cv. Mulato, the isolates caused symptoms that were typical of foliar blight caused by *Rhizoctonia* spp. The results were consistent, showing uniformity among replications with any one isolate.

The AUDPC showed differences in isolate pathogenicity, with three levels of pathogenicity (Photo 17 and Figure 39). The ANOVA resulted in statistically significant differences among isolates ($P < 0.0001$; Table 42). The isolates from Meta, Casanare, Córdoba, and Caquetá showed high pathogenicity, unlike those from Cauca, which had low pathogenicity.

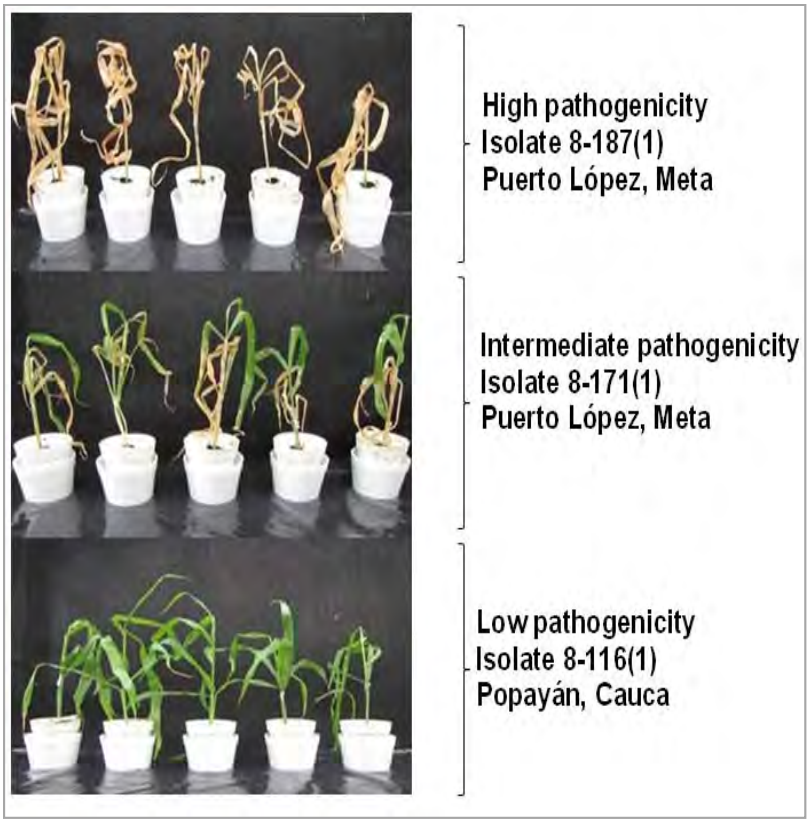

Photo 17. Reaction of *Brachiaria* hybrid cv. Mulato to *Rhizoctonia* isolates with high, intermediate, and low pathogenicity.

Duncan's multiple range test differentiated the isolates into three groups: (1) isolates from Cauca with low pathogenicity, (2) isolates from Meta, Casanare, Córdoba, and Caquetá with high pathogenicity, and (3) 13 isolates with intermediate values for AUDPC.

The most pathogenic isolates were 9-098(2), 9-111(2), 9-111(1), 9-114(1), 9-115(3), and 9-074(2) from the Department of Córdoba. These isolates are important for the selection of resistant materials and thus relevant to improvement programs.

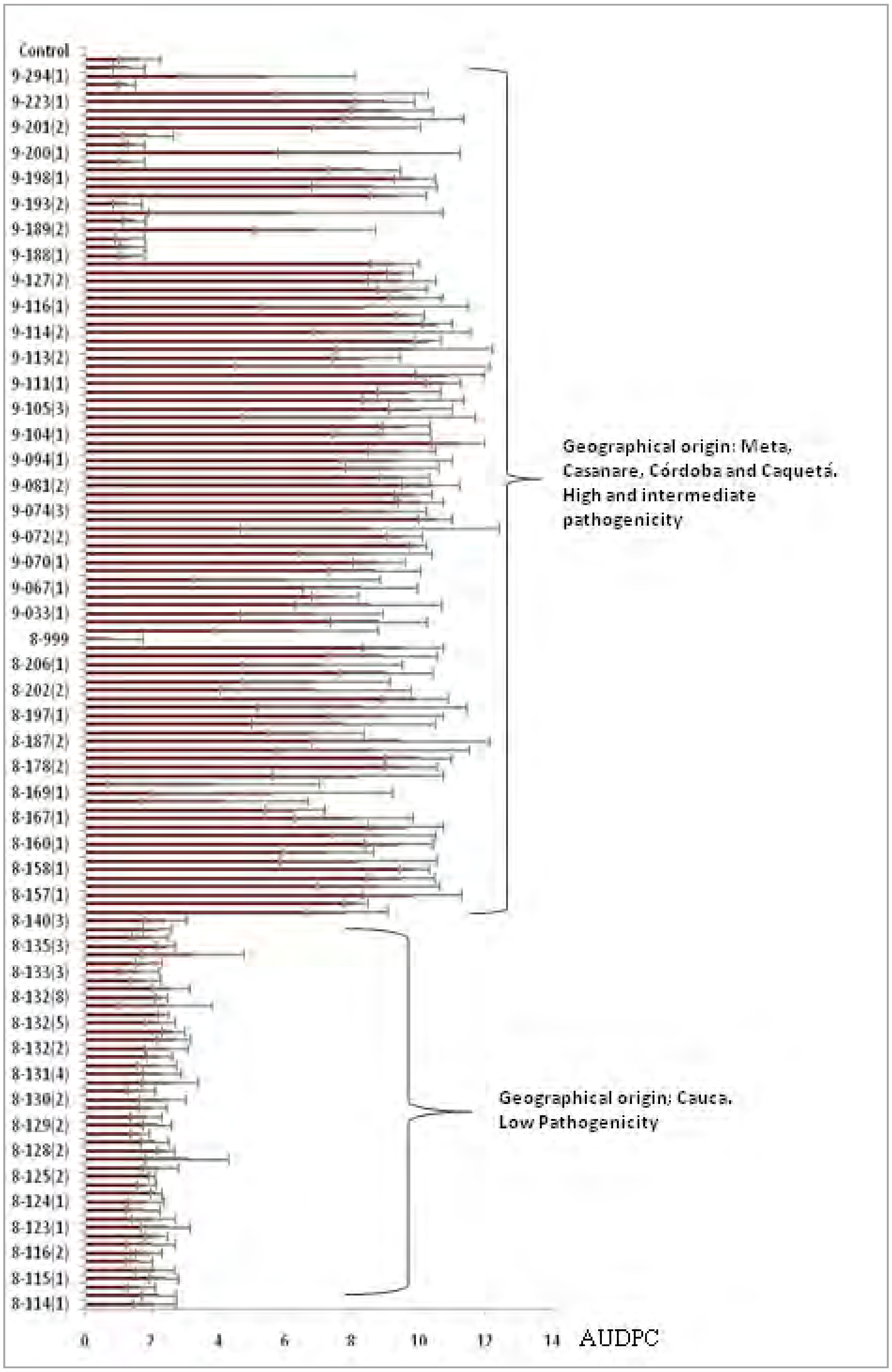

Figure 39. Pathogenicity of *Rhizoctonia* isolates expressed as the area under the disease progress curve (AUDPC). Control means uninoculated treatment.

Table 42. Analysis of variance of the pathogenicity of 147 *Rhizoctonia* isolates

Source of variation	df	Sum of squares	Mean of squares	*F* value	*P* > *F*
Model	147	292.4205712	1.9892556	36.48	<0.0001
Error	597	32.5572488	0.0545348		
Total	744	324.9778199			

Of the 147 isolates evaluated, 46 had low pathogenicity and belonged to the *Rhizoctonia* spp. from the Department of Cauca, 13 *R. solani* isolates had intermediate pathogenicity, and 88 *R. solani* isolates had high pathogenicity.

The group of isolates with intermediate pathogenicity was relatively small, compared with the other two groups, and performed more like the group with high pathogenicity. Evidence suggests that binucleate *Rhizoctonia* isolates are weak pathogens, with some being implicated in the repression of *R. solani*, reducing its pathogenicity (Burpee and Goulty 1984; Sneh et al. 1991; Tomaso-Peterson and Trevathan 2007).

According to the results, the *Rhizoctonia* genus in Colombia possesses significant diversity in terms of pathogenicity, with sufficient variation existing for the genus to present different species, races, or subraces. This variability of pathogenicity in the *Rhizoctonia* genus must be evaluated under greenhouse conditions with different genotypes of *Brachiaria*, and using a diverse and broad range of *Rhizoctonia* isolates that represent the pathogen's pathogenic and genetic variation.

In this study, we also used isolates collected from other crops of economic importance such as sugarcane, sorghum, and kenaf. Results suggested that they were also pathogenic to *Brachiaria*, except for the isolate collected from kenaf. Pathogens isolated from one host may be pathogens of other hosts. Because of this, where crop rotation occurs with rice, maize, wheat, cotton, soybean or rice (Tomaso-Peterson and Trevathan 2007), they could generate increased numbers of pathogen inocula. According to Grosh (2004), knowledge of the range of hosts for *Rhizoctonia* anastomosis groups (AGs) defined as the union of a hypha with another resulting in intercommunication of their contents, is fundamental for planning an effective strategy of crop rotation as part of an integrated control system, thus avoiding errors that would increase inocula and cause significant harvest losses.

Molecular characterization

DNA extraction and amplifying the rDNA ITS regions

For molecular characterization, the method used led to total extraction of DNA from 147 isolates collected from *Brachiaria* plant materials. The concentration and quality of the DNA obtained were sufficient to amplify the ITS region of rDNA and its later digestion with restriction enzymes, using the widely known polymerase chain reaction (PCR) technique. The amplified fragment had a molecular weight of 700 bp for all isolates (Figure 40), confirming their identity.

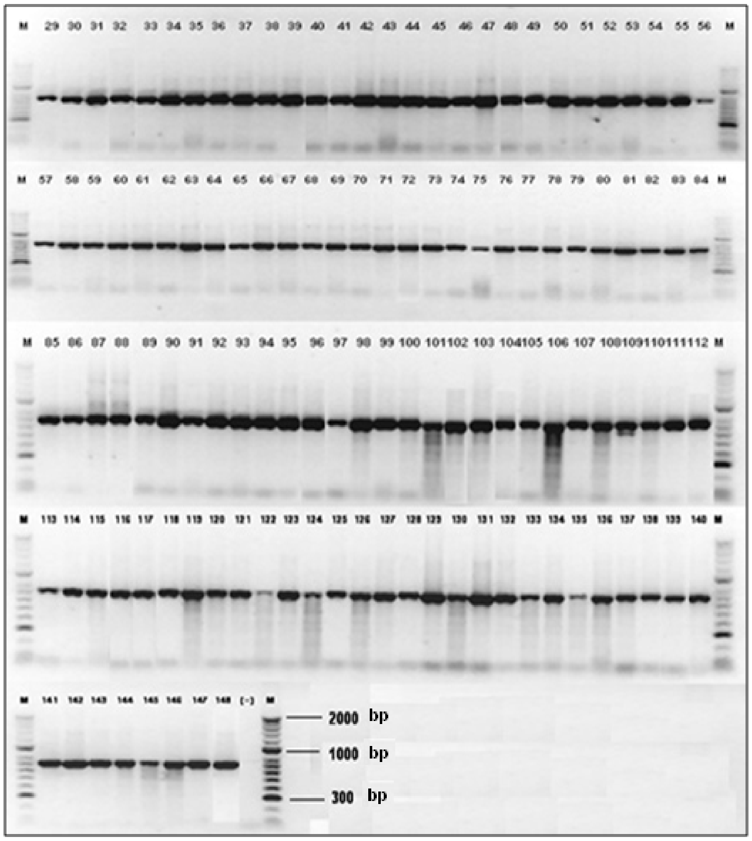

Figure 40. Amplification of the ITS region of the rDNA of 147 *Rhizoctonia* isolates.

Hayakawa et al. (2006) affirmed that analysis of the rDNA ITS region has been recognized as a useful method for identifying and grouping many fungal species. Analysis of ITS sequences is also useful for classifying intraspecific groups in *R. solani* (Boysen et al. 1996; Salazar et al. 2000).

Restriction fragment length polymorphisms (RFLPs) and sequencing of rDNA ITS regions

Results of RFLPs for the 147 isolates evaluated demonstrated six different restriction patterns with enzymes *Eco*RI, *Mbo*I, *Alu*I, and *Taq*I. The enzymes *Alu*I and *Taq*I showed the highest diversity of restriction patterns. Figures 41 and 42 show digestion in regions amplified from isolates previously selected, taking into account differences in their restriction patterns for enzymes *Alu*I and *Taq*I.

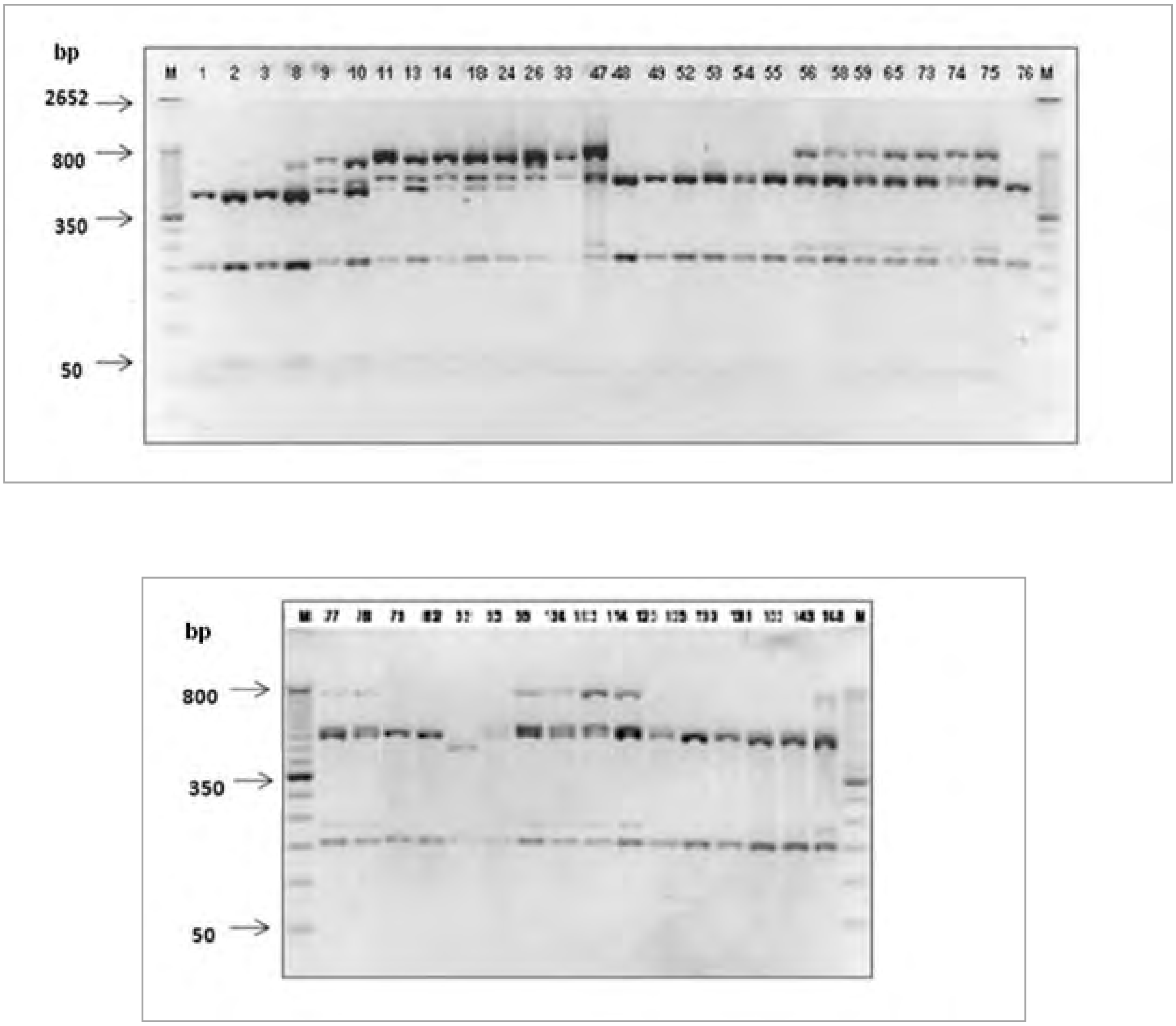

Figure 41. RFLPs of rDNA-ITS sequences digested with enzyme *Alu*I.

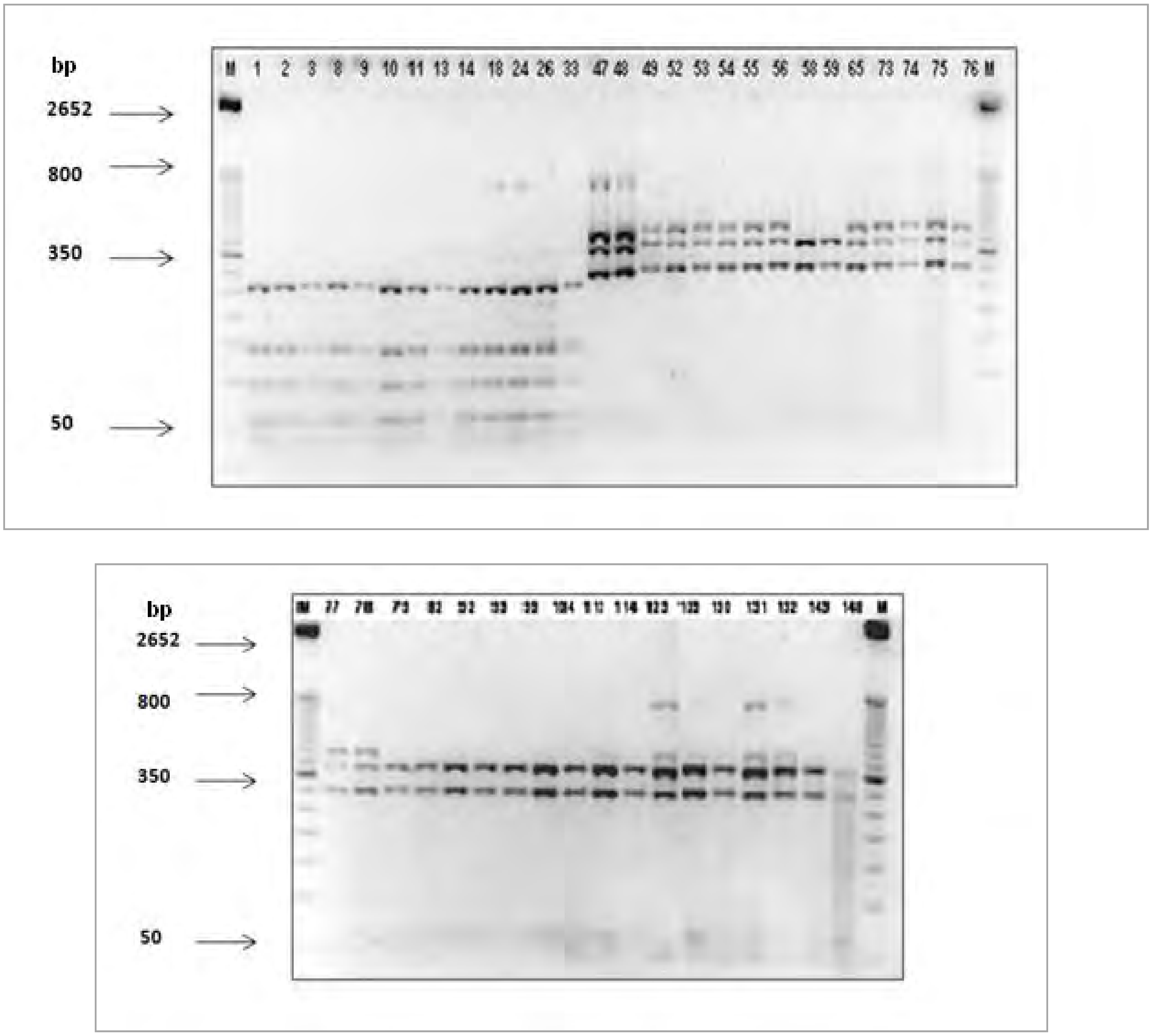

Figure 42. RFLPs of rDNA-ITS sequences digested with enzyme TaqI.

The result of sequencing the rDNA ITS regions indicated that the multinucleate *Rhizoctonia* isolates sequenced were *R. solani* of the anastomosis group AG-1 and the intraspecific group I-A (*R. solani* AG-1 I-A). The binucleate *Rhizoctonia* isolates were of the anastomosis group AG-D (*Rhizoctonia* spp. AG-D), with a similarity of 89% and 99% among nucleotide sequences (Table 43), these results agree with those proposed by other researchers such as Toda et al. (1999).

Table 43. Sequences of rDNA ITS regions from sampled fungal isolates compared with sequences stored at the GenBank database

Isolate	Identification	Origin	Result of ITS sequencing
2	8-114(2)	Popayán	*Ceratobasidium* sp. AG-D, 89%
9	8-121(2)	Popayán	*Ceratobasidium* sp. AG-D, 89%
10	8-123(1)	Popayán	*Ceratobasidium* sp. AG-D, 89%
11	8-123(3)	Popayán	*Ceratobasidium* sp. AG-D, 92%
18	8-128(1)	Popayán	*Ceratobasidium* sp. AG-D, 92%
24	8-129(4)	Popayán	*Ceratobasidium* sp. AG-D, 92%
33	8-132(4)	Popayán	*Ceratobasidium* sp. AG-D, 92%
47	8-153(1)	Puerto López, Meta	*Ceratobasidium* sp. AG-D, 92%
48	8-156(1)	Puerto López, Meta	*Thanatephorus cucumeris* 98%
49	8-157(1)	Puerto López, Meta	*Thanatephorus cucumeris* AG1-IA, 98%
56	8-160(2)	Puerto López, Meta	*Thanatephorus cucumeris* AG1-IA, 98%
58	8-167(1)	Puerto López, Meta	*Thanatephorus cucumeris* AG1-IA, 99%
73	8-202(2)	Yopal, Casanare	*Thanatephorus cucumeris* AG1-IA, 99%
74	8-202(3)	Yopal, Casanare	*Rhizoctonia solani* AG-1 1A, 92%
75	8-202(4)	Yopal, Casanare	*Rhizoctonia solani* AG-1 1A, 92%
76	8-206(1)	Yopal, Casanare	*Thanatephorus cucumeris* AG1-IA, 99%
82	9-033(1)	Sahagun, Córdoba	*Thanatephorus cucumeris* AG1-IA, 99%
99	9-083(1)	Sahagun, Córdoba	*Rhizoctonia solani* AG-1 1A, 99%
104	9-105(1)	Cereté, Córdoba	*Thanatephorus cucumeris* AG1-IA, 99%
113	9-113(1)	Cereté, Córdoba	*Thanatephorus cucumeris*, 88%
129	9-193(1)	Caquetá	*Rhizoctonia solani* AG-1 1A, 98%
131	9-197(1)	Caquetá	*Rhizoctonia solani* AG-1 1A, 98%
143	9-292(1)	Caquetá	*Thanatephorus cucumeris* AG1-IA, 99%
148	A-36061	Caquetá	*Thanatephorus cucumeris*, 95%

The dendrogram that includes all the *Rhizoctonia* isolates was obtained from data on digestion with enzyme *Taq*I, which resulted in the highest variability of restriction patterns (Figure 43).

With a Dice coefficient (similarity measure used for comparing the similarity and diversity of sample sets) of 0.75 (Rohlf, 1992), the RFLP molecular markers separated the Rhizoctonia isolates into two groups: R. solani AG-1 I-A and Rhizoctonia spp. AG-D. With a Dice coefficient of 0.88, all the isolates separated into five groups that represented evolutionary divergence within one anastomosis group, that is, isolates of R. solani AG-1 I-A were separated into three subgroups and, isolates of the Rhizoctonia spp. AG-D, into two subgroups. Separation at this level shows evolutionary divergence of the genus into subgroups, or intraspecific groups.

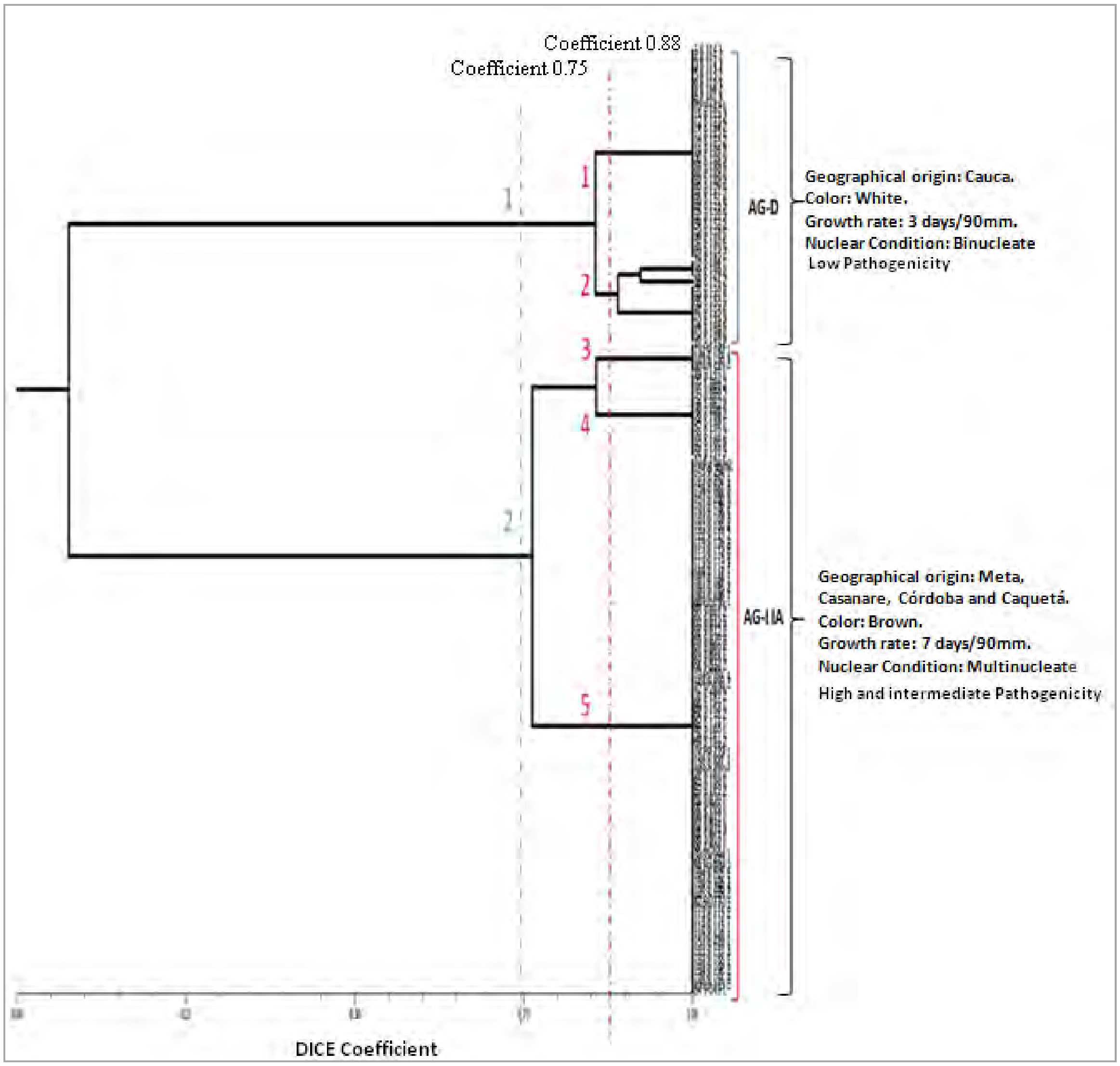

Figure 43. Dendrogram generated from data obtained, using RFLPs with enzyme *Taq*I.

Although the isolates obtained belonged to the intraspecific group I-A, these results show the genetic evolutionary divergence within this group. According to Vilgalys and Gonzales (1990), the variability of rDNA RFLPs among isolates within the same AG suggests the existence of subpopulations that are diverging genetically. For example, for *R. solani*, Liu and Sinclair (1993) showed the existence of six intraspecific subgroups in AG 1. In a similar fashion, Toda et al. (1999) separated binucleate isolates of *Rhizoctonia* spp. AG-D into two intraspecific subgroups.

The molecular results, together with the morphological and pathogenicity characteristics of the isolates, demonstrated that *Rhizoctonia* foliar blight in *Brachiaria* plants is caused by more than one *Rhizoctonia* species, and by several subgroups of *R. solani* (which proved to possess significant genetic diversity). For *Brachiaria* cultivars in Colombia, the groups causing foliar blight are *R. solani* AG-1 I-A and *Rhizoctonia* spp. AG-D.

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Output 2. Forages as high value products integrated into smallholder crop-livestock system to realize livelihood and environmental benefits

2.1 Forages for monogastric animals

2.1.1 Legume supplementation of village pigs in Lao PDR

2.1.1.1 Local pig breed weaner performance depends stronger on protein than on fiber content: An opportunity for improved forages

Highlight

- High fiber content inhibits local weaner pig growth less than expected if protein and essential amino acid levels are high. High quality forage legumes may therefore be suitable protein sources for recently weaned pigs and their use may help to overcome the severe production and health limitations faced currently in many smallholder pig systems in Laos and the region.

Contributors: Phengvilaysouk, A. (NAFRI); Stur, W.; Tiemann, T. (CIAT)

Rationale

In Laos and other south-east Asian countries recently weaned pigs suffer frequently from malnutrition, resulting in low growth performance and high mortality rates. This is not only the case in traditional feeding systems but also in improved forage based systems, employing Stylo 184 (CIAT) as protein source. The concrete reason for these nutritional deficiencies was unclear particularly as Stylo had proven excellent feed for older pigs. As it is known from high performing western breeds that high fiber contents are detrimental to animal performance, it was questioned if insufficient protein supply (particularly essential amino acids as lysine), unsuitably high fiber contents of green feeds or a combination both factors was the reason for the observed low animal performance.

Objective

The objective of this experiment was to determine the effect of protein and fiber content on the growth rate of weaned piglets.

Material and Methods

The experiment was conducted at the Livestock Research Centre (LRC), Nam Suang from March to June 2010. 24 Moolath male and female weaners weighing 6.5±2.1 kg were used for this experiment. To separate protein and fiber effects better, soy bean meal was used as protein source instead of Stylo, while rice bran was used as fiber source. Prior to the start of the experiment, the weaners were given access to creep-feed (rice bran, maize, soy bean; 45:45:10) to adapt weaners to solid feeds. Weaners were vaccinated (CSF), treated for internal parasites and given a vitamin injection. Six weaners (3 male and 3 female piglets) were randomly allocated to one of four diet treatments, and each treatment group was housed in a group pen. The four diet treatments consisted of combinations of high/low protein and high/low fiber content (Table 44).

Table 44. Weaner diets and projected[1] chemical composition[2]

Ingredients / parameters	Diet 1 High fibre / high protein	Diet 2 High fibre / low protein	Diet 3 Low fibre / high protein	Diet 4 Low fibre / low protein
	-------------------------------- Ratio, %			------------------------------
Rice bran,	65	70	20	25
Maize	10	30	60	75
Soy bean	25	0	20	0
	------------------- Chemical composition, %			-------------------
CP, %	15.7	7.3	15.3	8.5
Lysine, g/kg	7.5	2.0	6.5	2.1
Digestible Energy, Mcal	2.9	2.7	3.3	3.2
CF,%	20.6	20.5	8.5	8.7
Ca, %	0.14	0.07	0.09	0.03
P, %	0.36	0.29	0.35	0.29

[1] Chemical analysis results were not yet available at the time of writing, values are estimates
[2] Diets also contained approximately 20g salt per weaner per day.

The chemical analysis shown in Table 44 is based on results of similar samples in previous experiment. Representative samples of the actual ingredients were taken and sent for analysis, but results were not yet available at the time of writing. Rice bran, maize meal and soy bean meal were purchased from local markets. Feeding took place twice daily at a level close to ad libitum and water was provided at all times. Body weight gains and feed intake were measured during the experimental period of 12 weeks.

Results

Protein content had an overriding effect on growth of weaners (Table 45). Weaners on the high protein diets gained 100-120 g per day while those on the low protein diets grew only 3-10 g/day. Fiber level had no significant effect on growth, although the low fiber – high protein treatment group had consistently a slightly higher growth rate (10-20%) than the high fiber – high protein treatment throughout the experiment. Feed intake of weaners on the low protein diets was depressed, while high fiber appeared to stimulate intake of both the high and low protein diet.

Discussion

The results show that local weaner pigs cope surprisingly well with high fiber contents of about 20% in their diets if protein levels are appropriate. In this experiment the feed conversion ratios of the high protein diets were slightly higher than those recorded in a first experiment with commercial feeds, which may indicate that the level of essential amino acids supplied in the high protein diet treatment in this experiment may have been limiting to achieve maximum growth. Still growth rates were satisfactory and the difference in ADG between a low protein diet, as it may be found under village conditions and a high protein diet, is striking.

High protein diets containing soy bean meal as the main protein source resulted in high growth rate of Moolath weaners. There was an indication that the high fibre level of the high protein diet started to limit growth of weaners in this treatment and a slightly lower fibre level in weaner diets may be appropriate. This leads to the conclusion that fortification of village weaner diets using a highly digestible protein source, may be highly efficient in improving growth rates of weaners. Our results retrieve new challenges and opportunities for forage species with high protein and particularly lysine and low or moderate fiber content.

Table 45. Mean growth rate, feed intake and feed conversion ratio

	Diet 1 High fibre / high protein	Diet 2 High fibre / low protein	Diet 3 Low fibre / high protein	Diet 4 Low fibre / low protein
Initial weight, kg	6.3	6.7	7.1	6.1
Final weight, kg	14.8[a]	7.5[b]	17.3[a]	6.3[b]
Average daily gain, g/day	100.0[a]	10.0[b]	120.0[a]	3.0[b]
Feed intake, DM g/day	467	233	400	150
Feed intake, in % of body weight	5.0	3.2	3.7	2.4
FCR	5.3	20.9	4.1	22.3

2.1.1.2 Development of a diet calculator for formulating better diets and training of extension workers

Highlight

- The DIET CALCULATOR has been useful in formulating example diets, as a training tool for extension workers and in highlighting gaps in our knowledge to effectively formulate diets for native Lao pigs.

Contributors: Kopinski, J.S. (QDPI&F); Phengsavanh, P. (NAFRI); Stur, W.; Tiemann, T. (CIAT)

Rationale

The composition of appropriate pig diets for different classes of pigs fails often not only due to a lack of forage resources but due to a lack of knowledge about feed stuff chemical composition and animal needs at different life stages. Farmers as well as extension staff and even researchers have many times only a very vague idea, if any, about the quality of a given feed and recommendations regarding its use are therefore often difficult.

Objective

To assist in formulating diets using locally available feed ingredients to better provide the nutrients needed by the different classes of pigs (weaners, growers, etc.), a simple spreadsheet-based diet calculator was designed.

Material and Methods

The DIET CALCULATOR is a simple MS Excel based data collection and calculation program, which uses data (direct or derived) from proximate and amino acid analysis of commonly used feeds in northern Laos, forage legumes and other protein sources such as soy beans. Only a limited number of commonly available ingredients have been included in the calculator but more can be added as needed. The values in the diet calculator are based on an as-fed basis (i.e., air dry values not dry matter values). In this version, the diet calculator still works with many unknowns, which have had to be included as assumptions, based on our experience and published information from elsewhere.

These unknowns and assumptions are:

- Chemical analysis data of many of the local feeds. As many were based on only a few samples we know that there will be a lot more variation than documented here.
- Nutritional requirements of Moolath and other Lao native pig breeds at different stages of growth. We have some information from our experiments, field experience and feedback from project and Alliance partners, but there is a need for more accurate information on the energy and protein (lysine) requirements of these animals.
- Nutritive value (digestibility or availability) of the nutrients in the various feeds. Availability values currently included are based on published reports of related feed ingredients. Experimental data using Moolath pigs are needed to improve these values. The digestibility and availability values of ingredients have a big influence on the quality of the resulting diet.

Table 46 shows the types of recommended diets and specifications for Moolath pigs. The data and assumptions used in the diet calculator will need to be updated and improved as more information and results become available.

Table 46. Nutritive characteristics of diets and recommended specification for Lao native pigs

Diets	Used for	Diet description	Key nutrient composition			
			Crude protein	Available lysine	Digestible energy	Crude fibre
Weaner diet	1. Creep feeding piglets fror 2 weeks onwards. 2. Feed for piglets after weaning until they reach 20 kg.	• Very high protein • High energy • Low fibre	>18 %	>9.1 g/kg	>3.0 Mcal/kg (>12.5 MJ/kg)	<5 %
Grower diet	1. For growing and fattening pigs from 20 - 40 kg. 2. For lactating sows. 3. Boars used daily.	• High protein • Moderate energy • Moderate fibre	>14 %	>6.6 g/kg	>2.9 Mcal/kg (>12 MJ/kg)	<12 %
Finisher diet	1. Growing and fattening pigs from 40 kg until slaughter. 2. Dry sows (not suckling piglets). 3. Boars not used every day.	• Moderate protein • Moderate energy • High fibre	>10 %	>4.7 g/kg	>2.5 Mcal/kg (>10.5 MJ/kg)	<20 %

Results and Discussion

The DIET CALCULATOR includes several sheets including an ingredient list and a main page where the user can change the amount of different available ingredients in the diet until the desired specifications are satisfied. Examples of the program's main page and diets for Weaners and Growers are shown in Table 47 and Table 48.

Table 47. Diet calculator main page

Ingredient	Amount in diet (DM) %	Crude protein %	Available lysine g/kg	Digestible Energy Mcal	Crude Fibre %	Ca %	P %
Rice bran – poor quality	0	0.00	0.00	0.00	0.00	0.00	0.00
Rice bran – good quality	0	0.00	0.00	0.00	0.00	0.00	0.00
Maize grain	60	5.54	1.35	2.08	1.31	0.01	0.18
Soybean seed (not extruded)	20	8.48	4.84	0.78	1.59	0.06	0.11
Rice grain - broken	20	1.47	0.37	0.67	0.73	0.02	0.02
Cassava root	0	0.00	0.00	0.00	0.00	0.00	0.00
Stylo 184 – young	0	0.00	0.00	0.00	0.00	0.00	0.00
Stylo 184 – old	0	0.00	0.00	0.00	0.00	0.00	0.00
Paper mulberry - young	0	0.00	0.00	0.00	0.00	0.00	0.00
Banana stem	0	0.00	0.00	0.00	0.00	0.00	0.00
Pumpkin tops	0	0.00	0.00	0.00	0.00	0.00	0.00
Sweet potato vine - young	0	0.00	0.00	0.00	0.00	0.00	0.00
	100	**15.49**	**6.57**	**3.52**	**3.64**	**0.09**	**0.31**

Table 48. Examples of a Weaner (a) and Grower (b) diet

(a) Weaner Diet: cassava, maize and soy bean

Ingredient	Amount in diet (DM) %	Crude protein %	Available lysine g/kg	Digestible Energy Mcal	Crude Fibre %	Ca %	P %
Rice bran – poor quality	0	0.0	0.00	0.00	0.0	0.00	0.00
Rice bran – good quality	0	0.0	0.00	0.00	0.0	0.00	0.00
Maize grain	35	3.2	0.79	1.21	0.8	0.00	0.10
Soybean seed (not extruded)	35	14.8	8.47	1.36	2.8	0.11	0.20
Rice grain - broken	0	0.0	0.00	0.00	0.0	0.00	0.00
Cassava root	30	0.3	0.17	1.01	0.5	0.02	0.02
Stylo 184 – young	0	0.0	0.00	0.00	0.0	0.00	0.00
Stylo 184 – old	0	0.0	0.00	0.00	0.0	0.00	0.00
Paper mulberry - young	0	0.0	0.00	0.00	0.0	0.00	0.00
Banana stem	0	0.0	0.00	0.00	0.0	0.00	0.00
Pumpkin tops	0	0.0	0.00	0.00	0.0	0.00	0.00
Sweet potato vine - young	0	0.0	0.00	0.00	0.0	0.00	0.00
	100	**18.4**	**9.4**	**3.6**	**4.1**	**0.14**	**0.32**
Weaner diet specifications:		>18.0	>9.1	>3.0	<5.0		

(b) *Grower Diet: rice bran, cassava, maize, soy bean and Stylo*

Ingredient	**Amount in diet (DM) %**	**Crude protein %**	**Available lysine g/kg**	**Digestible Energy Mcal**	**Crude Fibre %**	**Ca %**	**P %**
Rice bran – poor quality	0	0.0	0.00	0.00	0.0	0.00	0.00
Rice bran – good quality	30	2.2	0.81	0.70	6.9	0.02	0.19
Maize grain	20	1.8	0.45	0.69	0.4	0.00	0.06
Soybean seed (not extruded)	20	8.5	4.84	0.78	1.6	0.06	0.11
Rice grain - broken	0	0.0	0.00	0.00	0.0	0.00	0.00
Cassava root	20	0.2	0.11	0.67	0.3	0.01	0.01
Stylo 184 – young	10	1.8	0.29	0.19	1.8	0.16	0.02
Stylo 184 – old	0	0.0	0.00	0.00	0.0	0.00	0.00
Paper mulberry - young	0	0.0	0.00	0.00	0.0	0.00	0.00
Banana stem	0	0.0	0.00	0.00	0.0	0.00	0.00
Pumpkin tops	0	0.0	0.00	0.00	0.0	0.00	0.00
Sweet potato vine - young	0	0.0	0.00	0.00	0.0	0.00	0.00
	100	**14.5**	**6.5**	**3.0**	**11.1**	**0.26**	**0.39**
Grower diet specifications:		>14.0	>6.6	>2.9	<12.0		

The DIET CALCULATOR has been useful in formulating example diets, as a training tool for extension workers and in highlighting gaps in our knowledge to effectively formulate diets for native Lao pigs. Several essential data are needed for diet formulation. These are: (1) The chemical composition of each feed ingredient, (2) the digestibility or availability of nutrients in each feed ingredient, and (3) the nutrient requirements of each type of pig, which depends on the breed (i.e. native, exotic) and the class of pig (i.e. weaner, grower, finisher, dry sows, lactating sows). The availability of ingredients in Laos for use in pig diets varies throughout the year which means that mixing balanced diets can sometimes be difficult. Using this tool it became also obvious that formulating diets with farm-grown ingredients is easier for older pigs than it is for Weaners as many of the commonly used ingredients contain a lot of fiber or are too low in protein (particularly the availability of lysine, the most limiting amino acid in pig diets). Some high-protein seeds such as soy bean are necessary to balance diets for piglets and young pigs. We used soy bean as it is used widely in commercial pig, poultry and fish diets but many other legume seeds, such as cowpea, contain similar amounts of protein and can also be used. A challenge of future projects will be to extend and improve the data base of this tool and to find viable options to overcome the limitations in weaner nutrition.

2.2 Nutritional value of tropical legumes as an alternative source of protein for pigs

Objective

The main objective of this first part of the investigations is to determine the nutritional composition of cowpea grain (*Vigna unguiculata*) in raw or heated form and cowpea and *Canavalia brasiliensis* herbage. In the second part, determination of *in-vitro* and *in-vivo* digestibilities will be performed.

Contributors: Torres Jaramillo, J.; Muñoz, L.S. (UNAL Palmira); Montoya, C.A. (Riddet Institute); Peters, M.; Martens, S.; Avila, P. (CIAT)

Materials and Methods

Samples

Vigna unguiculata (IITA 9611) grains, raw and heat-treated (boiled at 97°C for 5 min), and herbage meal of *Vigna unguiculata* (IITA 9611) and *Canavalia brasiliensis* (17009) were provided by the Tropical Forages Program of CIAT. They were compared with soybean meal purchased at the local market, which is a typical and high quality protein concentrate, a by-product from manufacturing soybean oil.

Determination of chemical composition

The legume samples were ground at 0.5 mm mesh-screen and analyzed for dry matter, ash crude protein, true protein, ether extract, neutral and acid detergent fibers (NDF and ADF) and, gross energy and total and soluble dietary fiber. The contents of Ca, P, Mg, K were determined after nitric-perchloric digestion with atom absorption spectroscopy. Further on, amino acid content and phytates were determined. The condensed tannins were analyzed by the butanol-HCl methodology and total phenols by the colorimetric method of Folin-Dennis. The total carotenoid content was determined by visible absorption spectrophotometry at an absorbance of 450 nm.

Results and discussion

The nutritional composition of the legume samples is detailed in Table 49. Little changes were observed in the composition of cowpea grain after the thermal treatment (e.g. protein content 240 and 234 g/kg DM). The heat treatment affects protein content by partial removal of certain amino acids. The content of true protein was lower than those reported in literature (210-270 g/kg DM). Similar protein content in cowpea and *canavalia* foliages were found (170-175 g/kg DM). In cowpea foliage the true protein was 52% of total N, which is similar to other reported results (50-67%). The fiber content of foliages was higher than in grains, *Canavalia* had the higher NDF content (361 g/kg DM).

Mineral composition

The slight decrease in ash content after thermal treatment of cowpea grain can be explained by the release of minerals (e.g. Mg from 2.05 to 1.82 g/kg DM) as reported elsewhere with autoclaved *Vigna catjan* (total minerals from 38 to 32 g/kg DM). In general, cowpea grain had a lower mineral content (except for P) as compared to the soybean meal concentrate and the foliages. The values found here are close to those reported elsewhere (K, Ca and Mg: 10-15, 0.6-2.0 and 1.6-5.2 g/kg DM, respectively).

Cowpea foliage had the highest content of K, Ca and Mg when compared to the other legume samples and the control soybean meal. Nielsen *et al*. (1997) found similar content of P and Ca for cowpea leaves (3.5 and 15.5 g/kg DM, respectively). All tested ingredients cover the requirements P (5-4); K (2.3-1.7);

Mg (0.4-0.4) g for different categories of Growing Pigs of (20-50) up to (80-120 kg) respectively, while only the leaves meet the needs of Ca (6-5-4.5), for this category (NRC, 1998).

Table 49. Nutritional composition of cowpea grain, cowpea and canavalia foliage and soybean meal

	VUR[a] grain		Foliages		
	Raw	**Heated[b]**	**VUR[a]**	**CB[a]**	**SB[a]**
***Composition* (g/kg DM)**					
Dry matter	915	916	880	921	914
Crude protein (N x 6.25)	240	234	170	175	454
True protein	180	171	99	84	334
Ether extract	298	280	270	240	279
Ash	47	44	98	120	60
NDF[c]	198	176	327	361	125
ADF[d]	62	65	214	180	47
Gross energy (MJ/kg DM)	16.4	16.7	14.5	14.2	16.6
***Minerals* (g/kg DM)**					
Phosphorus (P)	7.3	7.25	4.5	2.3	11.3
Potassium (K)	13.6	13.5	23.6	15.6	20.9
Calcium (Ca)	0.84	0.73	14.8	7.6	3.3
Magnesium (Mg)	2.1	1.8	6.7	1.9	3.1
***Anti-nutritional factors* (g/kg DM)**					
Total polyphenols	30	23	46	71	20
Condensed tannins	27.8	17.4	8.5	11.5	8.1
Phytate	2.2	2.0	6.0	7.4	2.4

[a] CB, *Canavalia brasiliensis*; VUR, *Vigna unguiculata*; SB, soybean meal ;. [b] Boiled for 5 min; [c]NDF: neutral detergent fiber [d]ADF: acid detergent fiber

Anti-nutritional factors

The thermal treatment slightly reduced the polyphenols and condensed tannins (CT) content. In *Vigna trilobata* and *Vigna unguiculata* subsp. *unguiculata* lower values were reported for total phenolic (13-21 g/kg DM) and CT (3.3-3.8 g/kg DM) (Arinathan *et al.*, 2003). However, the tannin content was similar to the ones reported for different cowpea varieties (17.9-29.2 g/kg DM). The CT has a negative effect on the digestion process, especially on protein.

Animals fed diets with a level of tannins over 5% showed depressed growth rates, decreasing the amino acids absorption, especially methionine and lysine. *Canavalia* and cowpea foliage had higher content of polyphenols and phytates than the cowpea grain and the soybean meal. Between foliages, *Canavalia* had the highest content of the antinutritional factors measured here. However, CT was lower than those reported in forage legumes such as *Desmodium ovalifolium*, *Gliricidia sepium*, *Cratylia argentea* (76-299; 21-121; not detected-19) g/kg DM, respectively) (Barahona, 1999; Shofield, 2001). Phytic acid is the major source of P in legume seeds (62-73% of total P). The phytate content of grains was only a third of that in foliages, and slightly lower than those reported (2.5-3.1 g/kg DM) for *Vigna unguiculata* (D'Mello, 1995). The phytate binds to proteins and chelate minerals, such as zinc, iron, calcium, reducing its bioavailability (Martinez-Herrera *et al*., 2006).

Amino acids composition

The amino acid profile of the tropical legume samples as well as of the soybean meal is shown in Table 50. In general, the cowpea grain had higher content of some essential amino acids such as arginine and lysine (20-37% higher) when compared to the cowpea and canavalia foliage and similar content when compared to soybean meal. The arginine content in the samples covers the requirements for higher performance for growing pigs from 3-5 to 80-120 kg (5.4-1.6 g) respectively (NRC, 1998).

In % of the DM, cowpea grains are about 27-11% higher in lysine than soybean meal. While the foliages are 7.84% more lower than soybean meal. However, lysine content of cowpea grain (7.0 g/16 g N) is just enough to cover the requirements of growing pigs of 50-80 and 80-120 kg live weight (NRC, 1998). The values obtained here are close to those reported elsewhere for cowpea grain. The concentration of the sulfur-containing amino acids (methionine and cysteine) was lower for all samples.

Table 50. Amino acid composition (g/16 g N) of cowpea grain, cowpea and canavalia foliage and soybean meal

	Grains	**Foliages**		
Legumen	**VUR[a]**	**VUR[a]**	**CB[a]**	**SB[a]**
Essentials				
Arginine	7.1	5.9	6.1	6.9 - 7.4
Histidine	3.4	2.6	2.8	2.8 - 2.6
Isoleucine	4.2	4.4	4.7	4.2 - 4.6
Leucine	8.2	8.4	8.8	7.1 - 7.7
Lysine	7.0	5.1	5.1	5.5 - 6.3
Methionine	1.5	1.5	1.8	1.3 - 1.4
phenylalanine	5.9	5.7	5.6	4.9 - 5.2
Threonine	4.0	5.0	4.8	3.7 - 4.0
Tryptophan	ND	ND	ND	3.7 - 4.0
Valine	5.3	6.1	6.1	4.5 - 4.8
No essentials				
Alanine	4.5	6.5	5.8	4.9 - 5.8
Aspartic acid	11.9	13.7	15.1	8.5 - 12
Cysteine	1.2	1.4	1.4	1.4 - 1.5
Glutamic acid	19.5	12.2	12.5	13 - 14
Glycine	4.4	5.6	5.4	4.1 - 4.4
Proline	3.9	8.5	6.5	5.2 - 5.7
Tyrosine	2.7	2.7	2.8	3.5 - 4.0
Serine	5.3	4.8	4.7	5.2 - 5.7

[a] CB, *Canavalia brasiliensis*; VUR, *Vigna unguiculata* (only raw cowpea was analyzed); SB, soybean meal; range of samples from Argentina, Brazil, Spain and the U.S. (Coca-Sinova *et al.,* 2008); ND, not determined.

Carotenoids composition

The content of betacarotene of the tropical legume samples is shown in Table 51. In the present study, low total carotenoid content was obtained for cowpea grain and soybean meal as compared to previously reported data (6.3-6.8-28.8 mg/100g). As was expected, the total carotenoid content was higher for the cowpea foliage when compared to cowpea grain. The thermal treatment did not affect the content of carotenoids. The carotenoids are source of precursors for vitamin A and play a role as antioxidant. Nielsen *et al*. (1997) have reported 0.01-0.02 mg/100 g of β-carotene for cooked and raw cowpea grain respectively.

Table 51. Carotenoid content (mg/100 g) of grain and foliage legumes and soybean meals

	Grains		**Foliage**	
Legume	**VUR**[a]		**VUR**[a]	**SB**[a]
	Raw	**heated**[b]		
All β-carotene	Nd	Nd	4.4	0.033
α-carotene	Nd	Nd	0.17	Nd
B-criptoxanthin	Nd	Nd	0.07	0.01
9-cis- β-carotene	Nd	Nd	0.63	Nd
13-cis-β-carotene	Nd	Nd	0.14	Nd
Lutein	0.002	0.002	0.036	0.005
Violaxanthin	Nd	Nd	0.272	Nd
Zeaxanthin	0.047	0.048	15.4	0.39
Xanthophyll	0.002	0.002	0.44	0.02
Total carotenoids	0.5	0.51	27.2	0.5

[a]CB, *Canavalia brasiliensis*; VUR, *Vigna unguiculata*; TS, Soybean meal; [b]Boiled for 5 min; Nd, no detectable. (CB) *Canavalia brasiliensis* (was not analyzed)

Conclusion

According to the chemical composition, cowpea (mainly grain) could be an alternative protein source, explained by its protein content and its amino acid composition. The thermal treatment of cowpea grains affects slightly the composition. The foliage of cowpea had better protein, amino acid composition and mineral content as well as less fiber content than Canavalia foliage.

2.3 Improving forages for monogastric animals with low-income farmers in Nicaragua and Honduras

Contributors: Rodríguez, C.; van der Hoek, R.; Chavarría, E.; Peters, M. (CIAT); Mena, M.; Moreno, E.; Benavidez, A. (INTA); Posas, M. (SERTEDESO); Burgos, C. (consultant)

Feeding trials with pigs

In three regions in Nicaragua (León, Chinandega, Quilalí: total 15 farmers) and one region in Honduras (Yoro: 5 farmers) trials were implemented with 19 pig farmers (both women and men), in which the effect was assessed of substituting 25% and 50% of sorghum (Nicaragua) and maize (Honduras) by fresh foliage of forage legumes (*Vigna unguiculata* and *Lablab purpureus*) to improve animal production, food security, decrease costs and diversify the farming system. At each farm three pigs (all of them either male or female) of the same litter were used, at an age of 75 days onwards. The animals were housed in a pigpen in individual compartments, each receiving one of the three treatments (0% (control), 25% and 50% substitution of sorghum/maize by forage). The quantity of sorghum/maize administered was based on the metabolic live weight of the pigs (estimated dry matter daily intake: 100%, 75% and 50%, respectively, of 85 g per $kg^{0.75}$), and modified on a weekly basis after weighing the animals.
The forage, harvested daily at flowering stage whereas fresh supply was guaranteed by planting small plots (100 m^2) at weekly intervals, was given to the animals ad lib.

Results showed a daily average live weight gain of 140 g per animal without significant differences between the treatments ($p>0.05$; Figure 44).

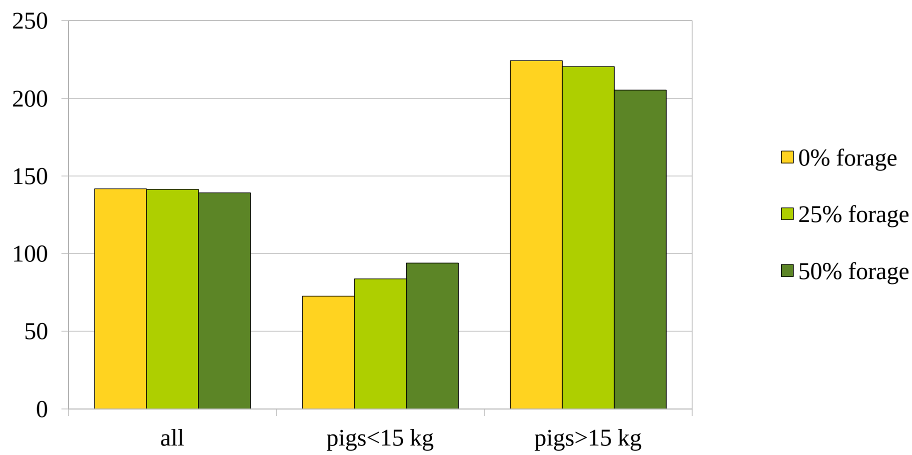

Figure 44. Daily live weight gain (g) of pigs with increasing proportions of substituting cereals by fresh forage legumes

No significant differences between sex or basic ration (sorghum and maize) were found neither. However, initial live weight proved to significantly influence ($p<0.05$) performance.
Animals over 15 kg grew 220 g/day, in comparison to less than 100 g for smaller pigs.

In general, results are promising, showing a mean daily live weight gain of up to 300 g without differences between the rations, implying that at typical on-farm performance levels the substitution of up to 50% of the cereal by forages does not affect productivity and leading to a considerable decrease in costs when the extra labor needed for forage production (less than an hour per day) is not taken into consideration. For further experiments it is recommended to include only animals over 15 kg, as smaller pigs do not have sufficient capacity to utilize forage material with a relatively high fiber content.

Seed production

To secure seed availability for future experiments, forage seed was produced both at the CIAT seed production unit, especially of *Vigna unguiculata* 9611, *Lablab purpureus* CIAT 22759, *Vigna unguiculata* IITA 284-2, *Vigna unguiculata* Verde Brasil, *Vigna unguiculata* FHIA and *Clitoria ternatea* CIAT 20696. Participating farmers in the feeding trials produced also considerable quantities of *Vigna unguiculata* 9611 and *Lablab purpureus* CIAT 22759.

Outlook

Work with smallholder farmers will continue in Nicaragua and Honduras. Apart from new experiments with pigs in which 30% of the ration will be substituted by different forage legumes (both fresh and as silage) we intend also to perform trials with poultry comparing expensive soya with a high-grain yielding accession of *Vigna unguiculata* (FHIA). Furthermore, an on-station experiment in Nicaragua will be conducted in collaboration with the Cuban University "Universidad Central Marta Abreu de las Villas" and the University of Rostock, in which different fresh and ensiled forages will be tested with pigs. In both the on-station and on-farm work we intend to also include shrubs (*Cajanus cajan*), to diversify the feed offer and decrease labor requirements.

2.4 Developing a tropical silage inoculant: Cryoprotectants and storage

Contributors: Martens, S. and M. Peters (CIAT)

Rationale

Forage conservation plays an important role in eco-efficient agriculture as it allows maximum use of limited land. Excess forage can be harvested at the optimum vegetative stage of nutritive value x yield and regrowth is allowed. With correct management the forage can be stored without major losses in quality and quantity. In a (sub)humid context, where high dry matter for hay can hardly be achieved, ensiling is a good option to preserve forage which cannot be consumed at once in its favorable stage, either for times of scarcity (e.g. drought, inundation) or increased demand (e.g., offspring) or for sale. Ensiling requires good management to minimize losses. As it is a natural fermentation with little control, different microorganisms are competing for available carbohydrates until oxygen is used up and the pH is sufficiently low. To shorten this period and reduce losses, the application of a high number of efficient homofermentative lactic acid bacteria ($\geq 10^5$ cfu/g FM) has been shown effective.

These biological silage additives are commonly used in temperate zones for forages with high and moderate ensilability as fermentation stimulants. However, this practice is yet barely implemented in tropical countries. One reason is the little awareness of farmers and extensionists of the additive, second its availability and third doubtful suitability and adaptation of additives developed in temperate climates to tropical conditions.

Thus, the objective of this research is to facilitate the use of an inoculant, which was isolated and tested (Heinritz et al., this volume and 2009) at CIAT Palmira from 2008-2010.

A lyophilized preparation is the most common condition for trading biological silage additives. This requires a careful evaluation of different cryoprotectants to ensure survival and preservation of acidification ability throughout lyophilization and subsequent storage. As storage conditions may vary widely from the place of production to the farmer, their effect on product viability has to be considered.

Photo 18: Lyophilization of bacteria samples

Materials and Methods

The *Lactobacillus* strain was inoculated in MRS broth in 15 ml plastic tubes for proliferation one day prior to lyophilization and incubated at 37 °C for 24 h. The number of colony forming units (cfu) was determined from two tubes by serial dilutions and plating on MRS agar (37 °C, 3 d). The other tubes were centrifuged and the supernatant discarded. The bacteria cells were resuspended in 1 ml of cryoprotectant solution.Two series of experiments were evaluated. In the first, the following 8 cryoprotectants were tested: Ringer solution as control, inulin, oligofructose, maltose, sucrose, PEG 8000, glycerol, all at 5% w/v and a conservation medium for freeze storage based on glycerol, Tris-HCl and $MgSO_4$.
The tubes were freezed at -80 °C before lyophilizing them starting at -20 °C at 45 mbar and ending at 24 °C after 28 h (Photo 18). All tubes were stored in a vacuum sealed bag for 60 d, one half at 4 °C, the other at ambient temperature (~25 °C). The number of cfu was determined and one of each replicate which survived with > 7×10^7 cfu/ml was inoculated in chopped *Cratylia argentea* forage for ensiling at lab scale in duplicate. Freshly cultured *Lactobacillus* was used as reference. The silage pH was determined after 3 d of anaerobic storage at ambient temperature.

In the second experiment, the following 10 cryoprotectants/ cryoprotectant combinations were tested (Table 52).

Table 52. Cryoprotectants (% w/v) in 2nd experiment

No.	Cryoprotectant	%	Combined with	%
1	CMC	0.50%		
2	Trehalose	5.00%		
3	Trehalose	5.00%	+ PEG 8000	5.00%
4	Trehalose	5.00%	+CMC	0.50%
5	Maltose	5.00%		
6	Maltose	5.00%	+ PEG 8000	5.00%
7	Maltose	5.00%	+CMC	0.50%
8	Sucrose	5.00%		
9	Sucrose	5.00%	+ PEG 8000	5.00%
10	Sucrose	5.00%	+CMC	0.50%

CMC: Sodiumcarboxymethylcellulose

After lyophilization the tubes were stored in vacuum sealed bags with silica beads at ambient temperature (24-27 °C) for 60 days. The number of cfu was determined and single colonies from surviving lyophilized treatments as well as from fresh strain were cultivated in MRS broth for inoculation in minced *Canavalia brasiliensis* for the *in-vitro* Rostock Fermentation Test.

Results and Discussion

Trial 1:
Ringer solution and conservation medium resulted in lower cfu numbers, about 1 log unit below the other treatments after lyophilization. None of the treatments stored at ambient temperature survived. While PEG seemed to be a good cryoprotectant, in the ensiling trial forage inoculated with either PEG or glycerol treated bacteria resulted in the highest pH after 3 days (pH 5.0), while the reference of freshly cultured bacteria had a pH of 4.7. The best fermentation results gave the sucrose and maltose treatments with pH 4.7 and 4.6, although the inoculation rate was significantly lower (2 log units) than with the freshly cultured bacteria.

From this first trial it was concluded that the disaccharides best preserve acidification ability. As PEG guaranteed a high viability and additionally provided a desirable powdery texture, but could not well preserve acidification ability, the combination of disaccharides with PEG was evaluated in the second trial.

Trial 2:

The second trial should verify whether a better control of relative humidity (immediate vacuum sealing and silica beads) during storage together with a combination of the best treatments of trial 1 could improve storage life at ambient temperature.

As a third disaccharide trehalose was included in the evaluation, as it is involved in anhydrobiosis, the ability of plants and animals to withstand prolonged periods of desiccation. Sodiumcarboxymethylcellulose was included as a rather economic cryoprotectant reported in literature.

After 60 d of storage at ambient temperature the number of cfu had decreased significantly. No growth at all was observed in treatment 1, 2, 6, 7 and 10, very poor growth in treatments 4, 5 and 8 (order of 10^1 cfu/ml) and poor growth in treatment 9 and 3 (order of 10^2-10^3 cfu/ml), with 3 being better. Because of the very poor survival, single colonies were cultivated in MRS broth prior to inoculation for the fermentation test. In the test the fermentation rate measured by pH drop was equally good with all of the 5 treatments and the control.

Outlook

To ensure whether the water activity in the second trial was optimal ($a_w \leq 0.3$) this will be measured in the remaining replicates to draw conclusions on temperature and humidity effect on the lyophilized *Lactobacillus* strain.

In any case it can be concluded that the optimum cryoprotectant for conditions where a constant cooling chain cannot be assured, from those evaluated, is a combination of trehalose+PEG 8000. Furthermore, a culture medium is being developed based on easily available ingredients such as sugar cane molasses and yeast extract. This will allow the farmer a self-cultivation of the inoculant with low input need one day prior to ensiling. The outcome of the lab investigation will be evaluated in-situ in Nicaragua.

2.5 Forages for cattle

2.5.1 System change catalyzed by the introduction of forage species

2.5.1.1 Forage as entry point for economic and social shifts in Vietnam

Highlight

- The introduction of forages for cattle fattening permitted farmers to access higher value beef markets and was the impetus for a profound system change in smallholder cattle production in the project area in Vietnam.

Contributors: Dr Nguyen Ngoc Anh (NIAS); Dr Truong Tan Khanh (TNU); W. Stur; T. Tiemann (CIAT)

Rationale

Many smallholder farmers in south-east Asia perceive themselves as animal keepers rather than as animal producers. Animals (in this case beef cattle) are kept as assets not as commodities and seen as additional activity with certain benefits, often others then purely economic ones. This is often related to tight time commitments not allowing farmers to invest more time to feed and manage their animals more intensively, resulting in low growth and reproduction performance. The introduction of forages to these smallholder groups was identified as an important step forward towards more productive and product oriented animal systems. They were later also found to foster social shifts related to a change in perception of the own opportunities and role within the market chain.

Objective
Assessing the social and economic effects of forage adoption at our project sites in Vietnam.

Material and Methods

To assess the effects of forage adoption on social and economic changes four studies have been carried out and compared: a rapid market appraisal in 2004 and 2009 and a forage adoption survey in 2007 and 2010. In In the fodder adoption surveys, livestock chain stakeholders in 255 villages were interviewed to identify reasons for forage adoption or non-adoption, and the perception of farmers as livestock keepers or producers. To relate these farmer statements also to market information in 2009, 30 farmers and 20 traders have been interviewed about their experience with the recent market situation in the region. This information has been compared with the information of a former RMA in 2004 to identify changes in the market environment.

Results and Discussion

The traditional attitude of smallholders towards animal production has undergone a profound change. This is related to the opportunity to access new markets with better revenues and to produce more and more reliable with less effort. Both are directly linked to the introduction of improved forage options to feed cattle. While in 2004, before forage adoption took place all sales went to local markets, which accept meat regardless of quality at low prices, in 2009 mainly urban markets were delivered, which require high quality standards but pay up to 25% more than local markets. To enter these markets new product criteria had to be adopted: From the concept of a cow is a cow it had to shift to the urban market requirements which require animals of more than 300kg live weight with a condition score of $>4<5$ and not more than 36 months of age. Tethering or free scavenging systems made complying with these conditions impossible. However, the introduction of forage based feeding systems to supplement or fully feed their cattle provided an efficient and - most important to many farmers - little time consuming technology. While tethering or free scavenging systems require children or women to take care of the animals for several hours a day, this time could be spent more productively with confined systems, which became viable with forage based feeding. Keeping animals in pens or other confined systems, additionally prevented them from damaging neighboring fields, which frequently leads to conflicts and makes compensation payments necessary. The aggregated advantage of all these system related changes was reflected in the success the introduction of forages had: By 2007, more than 2400 smallholders had adopted cultivated forages to feed their animals on an average area of 750m^2 per household. By 2010, more than 3100 farmers had adopted forage based feeding systems on an average area of 1309m^2. From 3 farmers fattening cattle for beef production in 2005, in 2010, 525 smallholders produce beef while 800 practiced intensive or semi-intensive cow-calf production. At the same time, the number of farmers fattening cattle has increased little between 2008 and 2010, while the number of cattle per household has more than doubled. This shows a clear change towards a production oriented system: While the cattle population has remained stable the number of animals sold by farmers has increased from 8000 animals in 2005 to 15,000 animals in 2008.

With these new opportunities opened up through the introduction of forages a completely new way of thinking and planning established leading also to further livelihood opportunities. Farmers started to think about breeding to improve the productivity of their cattle. Bull selection and keeping bulls as business as well as the increased demand for artificial insemination are strongly approached fields by smallholders. While in 2004 70 % of animals were native breeds, this ratio had dropped by 2010 to 40% with an increase of Laisind and particularly Laisind x exotic crossbreds to 37 and 23%, respectively. But farmers also started to create “farmer clubs” to exchange on technologies and discuss common problems. These clubs also empower farmers to negotiate better prices with traders and recently first contract farming agreements between farmers and traders and a meat company in the next urban center were established.

In conclusion the introduction of forages permitted in the case of our study in Vietnam a profound system change: Naturally available feed resources were replaced by planted forages, free grazing by penned or confined animal keeping, extensive production by defined production, production not linked to markets and market demand by market oriented production, no breeding concept by the intention to improve breeds, natural fertilization by artificial insemination and the perception of cattle as an asset has changed to perceive cattle as a commodity leading to higher incomes and improved livelihoods.

2.5.1.2 Improved cow calf production through forage based feeding systems in Cambodia

Highlight

- The adoption of forages in cow-calf systems helps to improve the system productivity and has potential to increase animal welfare and social compliance between livestock owners and crop farmers.

Contributors: Dr. Sorn San (DAHP); Sar Chetra (DAPH); W. Stur; T. Tiemann (CIAT)

Rationale

Cow-calf production is a common livestock activity of smallholders in Cambodia and other countries in the region. Cows are kept for multiple reasons most commonly as draught animals and assets. Calf production is often practiced as an added value but the focus on this activity is often low. The reason is the common perception that cow-calf production cannot be accelerated as calves grow slowly and cannot be separated from the mother too early without putting at risk their lives and health. This perception is based on very poor feeding and management leading to high weight losses of the cow, very low milk production and low growth performance of the calf. Forages were considered to be key to improve animal nutrition and the overall performance of the production system. To demonstrate and assess the impact of forage adoption on cow-calf production, an on-farm survey was carried out.

Materials and Methods

A 5-months on-farm survey was carried out in two districts in Cambodia (Prey Chor and Tbong Khmum). In both districts farmers were divided in forage adopters and non-adopters with the following characteristics:

Traditional cow-calf producers	Improved cow-calf producers
Forage non-adopter	Forage adopter
Free grazing practiced	*Ad libitum* feeding and water
	Penning
No/spontaneous weaning	Weaning

The survey included measurements on the involved animals at the beginning and end of a 3 months pre-weaning period. Life weight and condition score (BCS, on a 1-5 scale) of cows and calves were assessed. Also, the period from weaning to the next estrus of the cows was recorded.

Results

Life weight loss of cows in the adopter group was as expected clearly lower than in the non-adopter group (13-36 kg vs. 41 to 60 kg loss in 3 months). This was also reflected in the body condition where cows from forage adopters lost about 0.5 units while those of non-adopters lost 1-1.5 points. The calves showed higher variability in performance: Those of forage adopters showed growth rates of 40 to 45kg within the 3 months period while those of non-adopters gained between 27.5kg and 49kg. In the adopter group calves were weaned and separated from the cows at the age of 3.5 months. Cows in this group returned into heat 22 days after the separation from the calf.

Discussion

In traditional smallholder cow-calf production systems, protein deficient, rice straw based feeds are the common diet provided to cattle. Particularly at the end of the dry season this feed has turned very poor and fibrous and cannot supply adequate nutrient levels for lactating cows. Additional free-grazing to improve the diet of the animals brings often other problems such as increased disease risk for the animals or conflicts with neighbors due to damage. As a consequence of poor nutrition, cows produce generally low amounts of milk and lose massively weight. Additionally, farmers do often not dare to separate their calves early and weaning takes often place only after 8-10 months. By then cows are so haggard that it takes them often several weeks to months to get into heat again. The calves at the same time show often low weights and BCS and are more prone to diseases.

The adoption of forages has proven to be an effective means to improve the nutritional status of cows and by that to improve the total productivity of the system. The cows lose less weight during lactation and calves show better growths performance, allowing early weaning and faster selling. This together with the faster return into estrus due to a better BCS, results in a shorter production cycle from >18 months to about 13 months. It also permits a year round confinement reducing the risk of highly infectious diseases such as FMD and reduces conflicts between livestock owners and crop farmers. Increasing adoption of forage for cow calf production reflects the recognition of these positive effects by farmers.

In conclusion the introduction of forages is an apt entry point to improve the productivity of cow-calf systems and offers solutions to change them towards a more species-appropriate and socially reconcilable livestock management for greater animal welfare and higher economic benefit.

2.6 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.

Contributors: Holmann, F. (CIAT); and Burkart, S. (CIAT /University of Hohenheim)

Introduction

Poultry and swine production in smallholder farms in Colombia is based on the backyard production system (Mora, 2004). This system is very flexible but low productive. 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 (ie., seeds, insects, worms, etc).

Colombia slaughters about 2 million pigs a year for a per capita annual consumption of about 3 kg (Velasco, 2010). 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 (Velasco, 2010). 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 the 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 (Espinal, 2005). 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.

The pig sector in this regards has to improve its health and food safety standards. There are about 10,000 clandestine slaughterhouses in Colombia, most of them used for small scale pig slaughtering (MAVDT, 2004). 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. No middlemen were found in the area.

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 53 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 cassave, all basic staple food crops of rural families in Colombia.

Table 53. 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 54 shows the herd structure found in the sample farms. Only one farm had cattle (18 heads). Thus, the great majority of sample farms did not have cattle, mostly due to the small mean farm size of 3.4 ha.

Table 54. 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 55 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 55. 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 56 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 56. 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 57 contains 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 little because most farms do not have cattle. Thus, most of the animal protein comes from the consumption of eggs and chicken.

Table 57. 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 is performed by solely the owner of the farm. No involvement of other 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 (Table 58).

Table 58. 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. Nevertheless they would like to receive one as well for buying fattening pigs. On average, the amount of credit of the receiving farmers is US$10,520/farmer, and the average of all farmers is US$ 9,205/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 used for purchasing livestock, especially swine, labor, equipment and infrastructure. Credit institutes are Finagro, Banco Agrario, Caja Agraria, Banco Caja Social, and Mundo Mujer.

Feeding Strategy for Chicken and Pigs

Table 59 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 tows. 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 59. Amounts of feed supplements offered to chicken and pigs in smallholder farms in Cauca

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

Table 60 contains 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 cocentrate 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 compliment protein intake can significantly raise the food security, nutritional benefits, and additional income.

Table 60. 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 (gr/d)	20	15	280
• Dry Matter Consumption (gr/d)	135	73	2000
Offer of nutrients of current diet			
• Maize [4]			
- Metabolizable energy (kcal/d)	130	130	NA
- Crude Protein (gr/d)	4.1	4.1	NA
• Concentrate [5]	84	84	3,287
- Metabolizable energy (kcal/d)	4.5	4.5	135
- Crude Protein (gr/d)			
• Cassava Starch[6]	NA	NA	2,213
- Metabolizable energy (kcal/d)	NA	NA	19
- Crude Protein (gr/d)			
Total nutrients offered	214	214	5,500
- Metabolizable energy (kcal/d)	8.6	8.6	154
- Crude Protein (gr/d)	79	79	1,749
- Dry Matter Consumption (gr/d)			

1 2.5 kg of body weight, 60% production
2 750 gr 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 and3,250 kcal ME for poultry and 2,830 kcal ME for pigs
7 NRC (1977)
8 NRC (1979)

Marketing Strategy

Although the participating smallholders produce a variety of different products related to the livestock production (swine, chicken, eggs, milk) almost the only product they sell out of this range are pigs. Merely one producer (the female producer) is selling chicken as well. The chicken are sold not from the farm but from the house 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.

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. In all cases the head of the household is the male part of the family. 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 90 kg. Table 61 shows the prices for the products of one of the local butchers.

Table 61. 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

The 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 62).

This information supports other source (Asoporcicultores, 2000), which reports that from a 100 kg (live weight) pig, about 24 kg is viscerae 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 63 contains a list of consumer prices in two of the largest supermarket chains in the country and from the street markets of Popayán, 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 is a 27% to 37% higher price.

Table 62. 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
Viscerae (17 kg)	17.27
Blood (8 kg)	6.50
Total revenue/pig of 100kg	358.10
Turnover/pig of 100kg	**110.27**

Comparing the prices at the supermarket with those sold in the street market, in general, the prices for the best cuts are cheaper 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 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 damages.

Table 63. 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
Viscerae	1.22	NA	1.02

Conclussions

Pig production in smallholder farms is an alternative 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. No middlemen were found in the area surveyed.

Most farmers have pigs year round but all of them have pigs which are sold during the 2 peak demand season: Christmas (December) and June. The average weight of a swine (fattener) at farm sale is 89 kg. 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. Pigs are sold directly to local butchers or slaughtered and marketed directly through restaurants.

However, the nutritional balance for both poultry and pig production shows they are receiving a diet deficiency 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.

The use of microcredit is very important because it facilitates the acquisition of pigs for fattening. However, it is currently not enough to meet the demand that exists in the region. Both producers and small butchers need an improved access to credit.

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. In the street markets it is 7% more expensive and in the supermarkets it is a 27% to 37% higher price.

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. 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 pig sector in this regards has to improve its health and food safety standards. There are about 10,000 clandestine slaughterhouses in Colombia, most of them used for small scale pig slaughtering (MAVDT, 2004). 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.

Acknowledgements

The authors wish to acknowledge the effort of Luis Horacio Franco and Belisario Hincapie from CIAT and to Nelson Vivas, Elkin Rendón, and Sandra Morales from Universidad del Cauca for the organization and logistics of the interviews, and for accompaining us during the 3-day survey process and who were key in facilitating the interview process with farmers.

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2.6.1 The consumption of meat in Colombia and Nicaragua: A consumer analysis

Highlight

- The study shows that consumers in both countries prefer chicken and beef over pork. This results from the lower price, the availability, and the higher quality/hygiene. Smallholder producers have limited distribution channels for their meat (especially pork). They mainly act in rural markets. This is due to lower quantity, lower quality, and limited infrastructure.

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Rationale and background

The livestock sector in Colombia and Nicaragua is a rapidly growing sector. Due to a rising meat consumption of 24% in Colombia between 2000 and 2007, and 61% in Nicaragua (2000-2007), respectively the livestock production is also increasing. The largest growth in both countries happens in chicken production. In Colombia, this subsector grew by 102% between 2000 and 2009 to 1020299 tons/year. The Nicaraguan chicken production increased by 92% from 2000 till 2008 to 90950 tons/year. The second highest growth rate in Colombia shows the pig subsector (71% between 2000 and 2009 to 179465 tons/year), and in Nicaragua cattle (83% between 2000 and 2008 to 96080 tons/year). In Colombia, the cattle subsector increased production by 26% between 2000 and 2009 to 936302 tons/year, while the pig subsector in Nicaragua grew by 21% from 2000 till 2008 to 7091 tons/year.

Concerning the consumption of the different meat types, in both countries chicken is the most preferrred meat (Colombia: 23.21 kg/capita in 2008, Nicaragua: 16.32 kg/capita in 2007). The chicken consumption showed a growth rate of 61% in Colombia (2000 to 2007) and replaced beef as most consumed meat type. In Nicaragua, the chicken consumption grew by 69% between 2000 and 2007. The second most important meat type in both countries is beef with an annual per capita consumption (2007) of 17.09 kg in Colombia (negative growth rate 2000-2007: -7%), respectively 6.91 kg in Nicaragua (growth rate 2000-2007: 39%). In both countries, pork is the third most consumed type of meat and shows high growth rates. The pork consumption in Colombia in 2007 was 4.21 kg/capita (growth rate 2000-2007: 50%), respectively 2.28 kg/capita in Nicaragua (growth rate 2000-2007: 104%).

The rapid growth of the chicken sector is considered as result of two main reasons: the high price of other meat types such as beef and pork, and the higher accessibility of chicken in regions where poorer consumers live. Reasons for the increase in pork consumption might be: (a) the growing per capita income; (b) the shift of nutrition preferences towards meat; and (c) the interest in a variation of alimentation. The increases in the chicken and pork consumption might explain the decrease in beef consumption in Colombia. This leads to the assumption, that chicken and pork are gaining and beef is loosing in importance for consumers. The producers are the first stakeholders of the meat value chain, the consumers the last ones. To make their products accessible to consumers, producers mostly use intermediaries such as,

supermarkets, traders, slaughterhouses, butcheries and restaurants. The intermediary process leads to benefits for producers (e.g., access to markets) but also to difficulties (e.g., fulfillment of quality requirements), which not all producers can overcome. This results in different types of production: artesanal production, semi-technical production, and technical production. The artesanal production is characterized by: (a) a smaller animal inventory, (b) less market access, and (c) lower hygienical standards. The technical production (also called industrialized production) is characterized by: (a) larger animal inventories, (b) higher market connectivity, and (c) higher hygienical standards. In Colombia and

Nicaragua, large parts of the pork production are of artesanal character. This means that animals are produced by smallholder producers and commercialized directly at the farms or in local markets. Quality standards are low, and clandestine slaughtering occurs, which poses a risk especially for rural consumers without a possibility of buying meat from more developed markets with higher food safety standards. The meat (especially chicken) for the higher developed markets (e.g., supermarkets) comes from large scale producers (industrialized production), mostly vertically integrated farms (production, slaughtering, and marketing done by the same company), which fulfill high quality requirements. This puts chicken in advantage over pork as quality standards are higher and the producers have more market access.

Objectives

Objectives of this study were (all with special relevance of pork and chicken):

- to analyze consumer preferences concerning meat
- to detect the main reasons for the consumption of different meat types (e.g., price, accessibility)
- to detect the main reasons for meat purchase in the different locations (e.g., supermarket chains, Mercados, Pulperías)
- to analyze the weekly personal expenses for meat as well as the amount of consumption of the different meat types
- to analyze differences in consumption and purchase issues concerning e.g., country, origin (village, city), or gender
- to analyze consumers information status on quality standards and meat origin
- to obtain a reputation index for the different locations of meat sales
- to evaluate chances and restrictions for smallholder products

Material and Methods

The data for this study was gathered by using a semi-quantitive questionnaire for meat consumers. The objective of the study was to get an insight in the consumption of meat, the status of information of consumers concerning food security, and their attitude towards smallholder producers with a special emphasis on the pork and chicken consumption. The research was conducted in Colombia (April 2010) and Nicaragua (July 2010). Research area in Colombia was Popayán (city consumers) and its surrounding villages (rural consumers); in Nicaragua research took place in Chinandega (city consumers) and its surrounding villages (rural consumers). Students from the Universidad del Cauca in Popayán (Colombia) and from the Universidad Nacional Agraria in Managua (Nicaragua) were trained and asssisted in the surveys. Moreover, two M.Sc. students from the University of Hohenheim contibuted to the research. One interview took on average 30 minutes. In total, 450 consumers were interviewed; 238 consumers in Colombia (Popayán: 133, surrounding villages: 105), and 212 in Nicaragua (Chinandega: 114, surrounding villages: 98). Furthermore, secondary data mainly from the Food and Agricultural Organization of the United Nations (FAO) was used.

Results

General sample information

Out of the 450 interviewed consumers, 203 come from villages around the two centers of the research area (Popayán, Chinandega) which connotes a total percentage of 45.11%. 247 interviewees come either directly from Popayán or from Chinandega, which is a total percentage of 54.89%. The villages inluded in the survey in Colombia were Cajete, Cajibio, El Tambo, Morales, Piendamo, San Piedro, Silvia/Ucenda/La Estrella, and Timbío.. The villages in Nicaragua included San Francisco del Norte, El Realejo, Corinto, Chichigalpa, Posoltega, El Viejo, Cinco Pino, and Villa 15 de Julio. The interviewed consumers were on average 37.1 years old, with 37.9 years in the villages, and 36.5 years in the cities. In

Colombia the average age of the interviewees was 38.6 years, with 40.7 in the villages and 36.9 years and in Popayán, respectively. With an average age of 35.6 years, interviewees in Nicaragua were slighly younger than the ones in Colombia, with an average of 34.9 years in the villages and 36.1 years in Chinandega, respectively. Concerning the gender distribution, 40.22% of the interviewees were male, and 59.78% female, which means a higher share of female interviewees. In the villages, the share of male interviewees was 39.9%, and 60.1% female, and in the cities 40.40% male, respectively 59.51% female. Table 64 shows the gender distribution of the sample split up for both countries.

Table 64. Gender distribution of the interviewed consumers

Country	**Colombia**			**Nicaragua**		
Gender	Male %	Female %	n	Male %	Female %	n
Villages	30.48	69.52	105	50.00	50.00	98
Cities (Popayán, Chinandega)	43.61	56.39	133	35.71	64.29	114
Total	37.82	62.18	238	42.38	57.62	212

The average household size of the interviewees was 4.65 persons in total, respectively 4.63 persons in the villages and 4.66 persons in the cities. Referring to meat consumption, an average household includes 4.53 meat consumers in total, respectively 4.52 meat consumers in the villages and 4.54 in the cities. The split up information for both countries is shown in table 65.

Table 65. Average household size of the interviewed consumers

Country	**Colombia**			**Nicaragua**		
Household size	In Persons	In meat consumers	n	In Persons	In meat consumers	N
Villages	4.44	4.38	105	4.83	4.67	98
Cities (Popayán, Chinandega)	4.47	4.36	133	4.89	4.75	114
Total	4.45	4.37	238	4.86	4.71	212

The table shows, that on average, the household size is bigger in Nicaragua than in Colombia. Moreover, the number of meat consumers per household is larger in Nicaragua. In both countries, the most interviewed household member was the mother (Colombia: 43.7%, Nicaragua: 41.4%), followed by the father (Colombia: 20.59%, Nicaragua: 28.77%). The share of the fathers was significantly higher in Nicaragua than in Colombia (*0.05, 2-sided). Also interviewed household members were the son(s) (Colombia: 12.18%, Nicaragua: 15.57%), the daughter(s) (Colombia: 13.45%, Nicaragua: 9.91%), and other household members, e.g., grandparents, cousins (Colombia: 10.08%, Nicaragua: 4.72%).

Meat purchase and meat consumption

Regarding the responsibility of purchasing the meat for the household, the most important role in both countries plays the mother (Colombia: 46.77%, Nicaragua: 69.23%). The second most important is the father (Colombia: 32.7%, Nicaragua: 17.65%). Other household members play a minor role. In total, the responsibility for purchasing meat for the household tends to be more a task for female household members (Colombia: 55.88%, Nicaragua: 76.47%) than for male household members (Colombia: 44.12%, Nicaragua: 23.53%). In Nicaragua, the responsibility of female household members to purchase meat is more marked than in Colombia (**0.01, 2-sided). In Colombia, there is moreover a significantly higher share of responsibility for the meat purchase jointly by female and male family members (**0.01, 2-sided). Table 66 shows the differences in the responsabilities between the rural areas and the cities for both countries.

Table 66. Responsibility for meat purchase in the interviewees households

	Origin	Father %	Mother %	Son %	Daughter %	Whole family %	Other %	n
COL	Village	31.03	49.14	3.45	2.59	1.72	12.07	105
	City	34.48	45.52	4.14	4.14	3.45	8.28	133
	Total	32.70	46.77	3.80	3.42	3.42	10.89	238
NIC	Village	24.51	61.76	4.90	4.90	0.00	3.92	98
	City	11.76	75.63	5.88	2.52	0.00	4.20	114
	Total	17.65	69.23	5.43	3.62	0.00	4.07	212

The household member who decides in the majority of the cases the type of meat consumed by the family is the mother (Colombia: 59.18%, Nicaragua: 70.48%). The second most important household member in this case is the father with 22.1% in Colombia, respectively 18.06% in Nicaragua. The other household members play a minor role. In general, like the responsibility for the meat purchase, the decision on the type of meat consumed tends more to be a task for female household members (Colombia: 67.65%, Nicaragua: 75%) than a task for male household members (Colombia: 32.35%, Nicaragua: 25%). This tendency is significantly stronger in Nicaragua than in Colombia (**0.01, 2-sided). The differences between rural areas and the cities concerning this issue are displayed in table 67.

Table 67. Decision-maker on type of meat for household consumption

	Origin	Father %	Mother %	Son %	Daughter %	Whole family %	Other %	n
COL	Village	17.50	62.50	4.17	0.83	3.33	11.67	105
	City	25.85	56.46	3.40	4.08	1.36	8.84	133
	Total	22.10	59.18	3.75	2.62	2.25	10.11	238
NIC	Village	21.15	65.38	2.88	3.85	1.92	4.81	98
	City	15.45	74.80	4.88	2.44	0.81	1.63	114
	Total	18.06	70.48	3.96	3.08	1.32	3.08	212

The preferred type of meat of all interviewed consumers in both countries together is beef with 33.29%, followed by chicken (28.30%), pork (19.72%), fish (15.27%), and meat types of minor importance (lamb: 2.78%, rabbitt: 0.61%, guinea pig: 0.03%). Nevertheless, there are differences between the countries. Both together derive the fact that beef is the most important meat. But having a closer look on each country shows, that in Nicaragua chicken is the meat type with the largest importance for the consumers (**0.01, 2-sided), whereas in Colombia, beef stays the most important type of meat for the consumers (**0.01, 2-sided). Consumers living in the villages significantly rank beef higher than consumers living in the city (**0.01, 2-sided). Consumers of an age of 47 years or more significantly rank pork worse than younger consumers (*0.05, 2-sided). If the person of meat purchase is female, the preferred type of meat is significantly more often chicken (**0.01, 2-sided), respectively significantly less often if male (**0.01, 2-sided), whereas the opposite situation occurs for beef (**0.01, 2-sided). Households with weekly meat expenses of less than US$ 2.30/person significantly tend to rank pork lower and chicken higher (*0.05, 2-sided). Households with weekly meat expenses of more than US$ 5.51/person significantly tend to rank beef and pork higher and chicken lower than consumers of households with lower personal meat expenses (*0.05, 2-sided). Table 68 gives an overview on the importance of the different meat types for the two countries and divides them into rural areas and cities.

Table 68. Preferred meat type per country

	Origin	Beef %	Pork %	Chicken %	Fish %	Lamb %	Rabbit %	Guinea pig %	n
COL	Village	36.08	18.76	27.91	14.45	2.72	0.00	0.08	105
	City	31.24	20.42	28.58	15.87	2.83	1.05	0.00	133
	Total	33.29	19.72	28.30	15.27	2.78	0.61	0.03	238
NIC	Village	30.06	21.56	31.92	16.15	0.31	0.00	0.00	98
	City	28.47	19.21	31.85	20.20	0.00	0.00	0.00	114
	Total	29.35	20.29	31.88	18.33	0.14	0.00	0.00	212

This gives the following rankings of meat types per country:

Colombia
1. Beef
2. Chicken
3. Pork
4. Fish
5. Lamb
6. Rabbit
7. Guinea Pig

Nicaragua
1. Chicken
2. Beef
3. Pork
4. Fish
5. Lamb

For the consumers in both countries, the most important reason for buying beef is its taste (Colombia: 39.59%, Nicaragua: 48.25%), followed in Colombia by its economic price (20.81%) and in Nicaragua by its nutritive value (17.54%). Other important reasons for purchasing beef in Colombia are the tradition of beef in the culture (18.78%), the good quality of the meat (7.61%), its nutritive value (6.60%), the accessibility (4.06%), and the variety of preparation possibilities (2.54%). In Nicaragua, the taste and the nutritive value of the beef are followed by the variety of preparation possibilities (11.40%), the economic price and the tradition of beef in the culture (both 7,89%), and the good quality of the meat and its accessibility (both 3.51%).

Concerning pork, the most important reason for its purchase in both countries is its taste (Colombia: 73.24%, Nicaragua: 57.14%). Second most important reason in Colombia is to use pork as variation possibility (11.27%), and in Nicaragua its quality/tenderness (28.57%). Other important reasons in Colombia are the tradition of pork in the culture (5.63%), its economic price (4.23%), its nutritive value (2.82%), and its quality/tenderness as well as its easy preparation (both 1.41%). In Nicaragua, the taste and the quality/tenderness of pork is followed by the facility of using pork as variation possibility (7.14%), its economic price (4.76%), and its easy preparation (2.38%).

The consumers in Colombia see the taste (28.49%) as the most important reason for buying chicken, followed by its economic price (24.02%), to use it as variation possibility (20.11%), its nutritive value (13.41%), its easy preparation (5.59%), its quality/tenderness (5.03%), and the tradition of chicken in the culture (3.35%). In Nicaragua, the economic price of chicken (44.89%) is the most important reason for its purchase, followed by its nutritive value (25.00%), its taste (15.34%), its quality/tenderness (7.95%), its accessibility (2.84%), to use it as variation possibility (2.27%), and its easy preparation (1.70%).

Having a look at fish, its nutritive value, its taste, and the use as variation possibility (all 28.16%) are the most important reasons for Colombian consumers to buy it. These reasons are followed by the economic price (8.74%), the quality and the tradition of fish in the culture (both 2.91%), and its accessibility (0.97%). In Nicaragua, the nutritive value of fish (63.46%) is the main reason for the consumers to purchase it, followed by the tradition of fish in the culture (12.50%), its taste (11.54%), its economic price (7.69%), the use as variation possibility (2.88%), and its accessibility (1.92%).

Table 69 gives an overview on the main reasons for the purchase of the different meat types in both coutries, split up by local and city consumers.

Table 69. Reasons for purchasing different meat types

	Meat type	Origin Consumer	Economic Price %	Nutritive value %	Tradition %	Taste %	Preparation possibilities %	Quality %	Accessibility %	n*
COL	Beef	Village	25.53	4.26	21.28	31.91	4.26	6.38	6.38	94
		City	16.50	8.74	16.50	46.60	0.97	8.74	1.94	103
		Total	20.81	6.60	18.78	39.59	2.54	7.61	4.06	197
NIC		Village	14.29	19.64	7.14	41.07	12.50	0.00	5.36	56
		City	1.72	15.52	8.62	55.17	10.34	6.90	1.72	58
		Total	7.89	17.54	7.89	48.25	11.40	3.51	3.51	114
COL	Fish	Village	7.32	36.59	4.88	21.95	21.95	7.32	0.00	41
		City	9.68	22.58	1.61	32.26	32.26	0.00	1.61	62
		Total	8.74	28.16	2.91	28.16	28.16	2.91	0.97	103
NIC		Village	7.50	55.00	17.50	12.50	5.00	0.00	2.50	40
		City	7.81	68.75	9.38	10.04	1.56	0.00	1.56	64
		Total	7.69	63.46	12.50	11.54	2.88	0.00	1.92	104
	Meat type	Origin Consumer	Economic Price %	Nutritive value %	Tradition %	Taste %	For variation %	Quality %	Easy preparation %	
COL	Pork	Village	7.41	3.70	7.41	62.96	14.81	0.00	3.70	27
		City	2.27	2.27	4.55	79.55	9.09	2.27	0.00	44
		Total	4.23	2.82	5.63	73.24	11.27	1.41	1.41	71
NIC		Village	0.00	0.00	0.00	47.06	5.88	41.18	5.88	17
		City	8.00	0.00	0.00	64.00	8.00	20.00	0.00	25
		Total	4.76	0.00	0.00	57.14	7.14	28.57	2.38	42
COL	Chicken	Village	24.64	13.04	2.90	27.54	27.54	1.45	2.90	69
		City	23.64	13.64	3.64	29.09	15.45	7.27	7.27	110
		Total	24.02	13.41	3.35	28.49	20.11	5.03	5.59	179
NIC		Village	40.00	25.00	5.00	18.75	3.75	6.25	1.25	80
		City	48.96	25.00	1.04	12.50	1.04	9.38	2.08	96
		Total	44.89	25.00	2.84	15.34	2.27	7.95	1.70	176

*Captions: multiple answers were possible

The consumers in both countries also named reasons for not buying pork. The Colombian consumers do not buy pork because of its bad taste (31.82%), its high price (24.24%), the fear of sicknesses (22.73%), its bad quality (9.09%), its high fat content (6.06%), its limited accessibility (4.55%), and its lower availability of preparation varieties (1.52%). In Nicaragua the most important reason for not buying pork is the fear of sicknesses (49.14%), followed by its bad taste (21.55%), its high fat content (14.66%), its high price (6.90%), its limited accessibilitiy (5.17%), its lower availability of preparation varieties (1.72%), and its bad quality (0.86%). The main sickness the consumers are afraid of is called Cysticircosis, a sickness wich is passed on to humans by pigs. The differences between village and city consumers regarding this issue are displayed in table 70.

Table 70. Reasons for not buying pork

	Origin Consumer	High Price %	High fat content %	Sick-nesses %	Bad taste %	Less prepara-tion varieties %	Bad quality %	Limited accessibility %	n
COL	Village	24.14	3.45	24.14	27.59	0.00	13.79	6.90	29
	City	24.32	8.11	21.62	35.14	2.70	5.41	2.70	37
	Total	24.24	6.06	22.73	31.82	1.52	9.09	4.55	66
NIC	Village	7.14	14.29	39.29	26.79	3.57	1.79	7.14	56
	City	6.67	15.00	58.33	16.67	0.00	0.00	3.33	60
	Total	6.90	14.66	49.14	21.55	1.72	0.86	5.17	116

According to their answers, the Colombian consumers eat meat six days per week on average, respectively the Nicaraguan consumers five days per week. Setting the focus on the consumption of the different meat types (in days/week), it seems that in both countries the consumers eat different types of meat within one day of consumption, with a stronger tendency in Colombia. This is shown in table 71. The days of consumption of each meat type match with the meat ranking presented in table 68.

Table 71. Average amount of days of consumption of the different meat types per household

	Origin Consumer	Beef	Pork	Chicken	Fish	n
COL	Village	3.97	0.89	2.33	0.65	105
	City	3.14	1.24	2.92	0.65	133
	Total	3.51	1.08	2.66	0.65	238
NIC	Village	1.52	0.98	2.55	0.68	98
	City	1.59	0.80	2.56	0.85	114
	Total	1.56	0.89	2.56	0.77	212

The meat consumption per interviewed household in Colombia is on average 4.82 kg per week, which means a consumption of 1.09 kg per week per household member, and 1.10 kg per week per meat consuming household member. In Nicaragua, the average weekly amount per household is 5.09 kg, which is a weekly consumption of 1.05 kg per household member, and 1.08 kg per meat consuming household member. This leads to the following average amounts spent on meat weekly per household: Colombia 21.71 US$ and Nicaragua 13.79 US$. Thus, each household member spends on average 4.88 US$ weekly on meat in Colombia, respectively 3.10 US$ in Nicaragua. Only considering the meat consuming household members, each spends 4.97 US$ weekly in Colombia, respectively 3.16 US$ in Nicaragua. Consumers in Nicaragua define a significantly larger part of the consumers consuming meat for <3.50 US$/week, whereas Colombian consumers define a significantly larger part of the consumers consuming meat for >3.50 US$/week (**0.01, 2-sided). People living in villages define a significantly larger part of the people consuming meat for <2.30 US$/week than people living in the cities (**0.01, 2-sided). Small households (1-3 household members) make up a significantly smaller part of the consumers consuming meat <3.50 US$/week, whereas big households (6 and more household members) make up a significantly larger part of this group (**0.01, 2-sided). On the other hand, medium (5 household members) and large households define a significantly smaller part of the consumers with weekly meat expenses of more than 5.51 US$/person, whereas small households define a significantly larger part of that group (**0.01, 2-sided). In households with weekly meat expenses of >US$ 5.51/person, the decision on the bought type of meat is significantly more often taken by male household members than by female ones (**0.01, 2-sided).

Moreover, in these households the decision on which type of meat is getting bought is significantly less often taken by female household members than by male ones (**0.01, 2-sided). Table 72 shows the weekly amounts of meat consumed per household/household member and the amount spent in total/per lb for each meat type.

Table 72. Weekly meat consumption and amount spent on the different meat types

	Meat type	Origin Consumer	kg/household (HH)	kg/HHmember	kg/meat consumer in HH	US$/kg	US$/week/HH	n
COL	Beef	Village	1.85	0.42	0.42	4.98	9.20	105
		City	1.72	0.39	0.39	5.20	8.91	133
		Total	1.78	0.40	0.41	5.10	9.07	238
NIC		Village	1.32	0.27	0.28	3.24	4.25	98
		City	1.36	0.28	0.28	3.42	4.64	114
		Total	1.34	0.28	0.28	3.34	4.45	212
COL	Pork	Village	0.67	0.15	0.16	5.24	3.52	105
		City	0.72	0.16	0.17	5.68	4.10	133
		Total	0.70	0.16	0.16	5.52	3.86	238
NIC		Village	0.87	0.18	0.19	3.96	3.43	98
		City	0.78	0.16	0.17	3.74	2.93	114
		Total	0.82	0.17	0.18	3.84	3.16	212
COL	Chicken	Village	1.60	0.36	0.37	3.18	5.08	105
		City	2.00	0.45	0.46	3.40	6.80	133
		Total	1.82	0.41	0.42	3.30	6.02	238
NIC		Village	2.20	0.46	0.47	2.12	4.63	98
		City	2.32	0.48	0.49	2.12	4.91	114
		Total	2.27	0.47	0.48	2.12	4.79	212
COL	Fish	Village	0.47	0.11	0.11	4.50	2.10	105
		City	0.52	0.12	0.12	5.60	2.91	133
		Total	0.50	0.11	0.12	5.16	2.56	238
NIC		Village	0.49	0.10	0.11	1.92	0.94	98
		City	0.82	0.17	0.18	2.12	1.74	114
		Total	0.67	0.14	0.15	2.08	1.39	212

Because of the special relevance for pork and chicken in this study, consumers were asked to name the most important attributes for purchasing meat. In Colombia, the most important attribute for buying pork is the visual appearance of the meat (24.94%), followed by meat color (23.52%), texture (19.75%), price (15.98%), expiry date (14.62%), and other characteristics of minor importance (1.63%) e.g., the location, or trust in the seller. The situation in Nicaragua is different from the one in Colombia. There, the most important attribute for buying pork is the price (27.11%), followed by the visual appearance of the meat (20.96%), its color (19.95%), its texture (15.14%), its expiry date (13.44%), and other characteristics of minor importance (3.39%).

For Colombian consumers, the most important attribute for buying chicken is its color (23.63%), followed by its appearance (22.70%), its expiry date (20.51%), its texture (15.80%), its price (15.11%), and other characteristics of minor importance (2.25%) like e.g., the smell, or the refirgeration system of the location. In Nicaragua, like for pork, the price for the meat is the most important attribute for the consumers (30.70%). Rank two is meat color (19.64%), followed by its appearance (18.89%), its texture (14.94%), the expiry date (11.74%), and other characteristics of minor importance (4.09%). Table 73 lists the attributes for meat purchase, differentiated by rural and city consumers in both countries.

Table 73. Most important attributes for the purchase of pork and chicken

	Meat type	Origin Consumer	Price %	Color %	Expiry date %	Appear-ance %	Texture %	Other %	n
COL	Pork	Village	16.17	26.03	16.17	21.72	18.56	1.34	105
		City	15.85	21.81	13.56	26.39	20.56	1.83	133
		Total	15.98	23.52	14.62	24.49	19.75	1.63	238
NIC		Village	26.60	20.50	14.20	19.92	14.68	4.10	98
		City	27.59	19.45	12.73	21.93	15.56	2.74	114
		Total	27.11	19.95	13.44	20.96	15.14	3.39	212
COL	Chicken	Village	15.42	24.50	21.76	21.37	15.04	1.91	105
		City	14.90	23.03	19.65	23.61	16.32	2.48	133
		Total	15.11	23.63	20.51	22.70	15.80	2.25	238
NIC		Village	31.25	19.42	12.15	17.60	14.05	5.52	98
		City	30.25	19.82	11.40	19.95	15.67	2.91	114
		Total	30.70	19.64	11.74	18.89	14.94	4.09	212

This leads to the following rankings of attributes for pork and chicken purchase in both countries:

Colombia pork	*Colombia chicken*	*Nicaragua pork*	*Nicaragua chicken*
1. Appearance	1. Color	1. Price	1. Price
2. Color	2. Appearance	2. Appearance	2. Color
3. Texture	3. Expiry date	3. Color	3. Appearance
4. Price	4. Texture	4. Texture	4. Texture
5. Expiry date	5. Price	5. Expiry date	5. Expiry date
6. Other	6. Other	6. Other	6. Other

Regarding pork purchase, the price is of significantly higher importance for the Nicaraguan consumers (**0.01, 2-sided), whereas the quality issues “appearance” (**0.01, 2-sided), “color” (*0.05, 2-sided), “texture” (*0.05, 2-sided), and “expiry date” (*0.05, 2-sided) are of significantly higher importance for Colombian consumers. For the chicken purchase too, the price is of significantly higher importance for the consumers in Nicaragua (**0.01, 2-sided), and for consumers in Colombia the quality issues “color” (**0.01, 2-sided), “appearance” (**0.01, 2-sided), and “expiry date (**0.01, 2-sided) play a significantly more important role.

The appearance of pork significantly plays a higher role for young consumers (<27 years) than for older consumers (*0.05, 2-sided). For small households (1-3 household members), the price of pork and chicken is of significantly lower importance than for larger households (>3 household members) (**0.01, 2-sided). If the meat purchasing person is female, the price of the meat (pork and chicken) is significantly more important than if the person is male (**0.01, 2-sided). For consumers with preferred meat type beef, the price of chicken is significantly less important than for other consumers, whereas for those with preferred meat type chicken, it is significantly more important (**0.01, 2-sided).

For consumers from households with meat weekly expenses of >5.51 US$/person, the price of pork and chicken is of less importance than for consumers with lower weekly meat expenses (**0.01, 2-sided). Quality issues concerning pork and chicken (e.g., texture, expiry date, appearance, color) are of significantly higher importance for consumers from households with weekly meat expenses of >5.51 US$/person (**0.01, 2-sided).

For the people from the villages in Colombia, the main locations for purchasing meat are the Galerías/Mercados, which are the market places in the village centers, and the Tiendas/Pulperías (for chicken and fish), which are small local shops for the everyday needs. Some of the consumers also buy in other locations like e.g., the Galerías/Mercados in Popayán, the supermarkets in Popayán, or private sellers (smallholder producers). Nevertheless, these options only play a minor role. The main locations for purchasing meat in Popayán are supermarkets, the Galerías/Mercados in the city, and the Tiendas/Pulperías (mainly for chicken and fish). Private sellers (smallholder producers) and the Galerías/Mercados in the villages only play a minor role for the city consumers. In Nicaragua, consumers from the villages have three main locations for buying meat: the Galerías/Mercados of the villages, the Pulperías of the villages (mainly for chicken), and the supermarkets who almost exist in all village centers. Of minor importance are private sellers (smallholder producers). People from Chinandega mainly buy in the central Galería/Mercado, in Pulperías in the city (for chicken), and in the supermarkets. Like in the villages, private sellers are of minor importance. Table 74 shows the reasons of the consumers for buying meat in the different locations. The table shows that in Colombia, the main reason for buying in a Galería/Mercado or a Tienda/Pulpería is the accessibility. The places are near to peoples houses which saves transport costs and time. Main reason for buying in the supermarket is product quality followed by hygiene. In Nicaragua, the main reason for buying in a Galería/Mercado is the price, followed by the accessibility and the hygiene. The main reason for buying in the Tienda/Pulpería is the accessibility, followed by the quality and the price. Meat in supermarkets is mostly purchased because of the price, followed by hygiene and quality.

In total, table 74 delivers the following ranking of most important characteristics for a meat selling location:

Colombia

1. Accessibility of the location
2. Quality of the product
3. Hygiene of the product/location
4. Economic price
5. Tradition of the location
6. Trust in the seller
7. Service in the location
8. Friendship to the seller/personell
9. Taste of the product

Nicaragua

1. Economic Price
2. Accessibility of the location
3. Hygiene of the product/location
4. Quality of the product
5. Service in the location
6. Tradition of the location
7. Trust in the seller
8. Friendship to the seller/personell

Table 74. Reasons of the consumers for buying meat in the different locations

	Meat type	Location	Access-ibility %	Hygiene %	Quality %	Taste %	Price %	Tradition %	Trust %	Service %	Friendship %	n*
COL	Beef	Galería rural	41.11	11.11	16.67	1.11	13.33	4.44	7.78	1.11	3.33	90
		Galería city	35.63	9.20	13.79	1.15	13.79	13.79	8.05	2.30	2.30	87
		Supermarket	4.17	16.67	58.33	0.00	8.33	0.00	4.17	8.33	0.00	48
NIC		Galería rural	21.62	29.73	0.00	0.00	37.84	2.70	0.00	5.41	2.70	37
		Galería city	17.50	22.50	5.00	0.00	47.50	2.50	0.00	5.00	0.00	40
		Supermarket	4.81	27.88	25.96	0.00	27.88	1.92	1.92	9.62	0.00	104
COL	Pork	Galería rural	36.36	5.45	20.00	0.00	16.36	7.27	10.91	0.00	3.64	55
		Galería city	25.71	11.43	15.71	1.43	15.71	15.71	11.43	0.00	2.86	70
		Supermarket	4.55	18.18	52.27	4.55	6.82	0.00	4.55	9.09	0.00	44
NIC		Galería rural	22.86	20.00	0.00	0.00	45.71	2.86	0.00	5.71	2.86	35
		Galería city	32.14	14.29	0.00	0.00	42.86	0.00	0.00	7.14	3.57	28
		Supermarket	4.05	28.38	20.27	0.00	28.38	1.35	2.70	14.86	0.00	74
COL	Chicken	Galería rural	45.28	5.66	7.55	1.89	15.09	11.32	7.55	3.77	1.89	53
		Pulpería rural	26.47	14.71	38.24	0.00	11.76	2.94	2.94	0.00	2.94	34
		Galería city	41.38	10.34	6.90	1.72	15.52	17.24	3.45	0.00	3.45	58
		Pulpería city	25.00	8.33	22.92	2.08	22.92	10.42	4.17	4.17	0.00	45
		Supermarket	4.44	20.00	51.11	2.22	8.89	0.00	4.44	8.89	0.00	48
NIC		Galería rural	30.77	7.69	0.00	0.00	46.15	3.85	0.00	11.54	0.00	26
		Pulpería rural	56.10	12.20	14.63	0.00	14.63	0.00	0.00	2.44	0.00	41
		Galería city	17.74	32.26	11.29	0.00	32.26	3.23	0.00	3.23	0.00	62
		Pulpería city	61.11	0.00	11.11	0.00	22.22	5.56	0.00	0.00	0.00	18
		Supermarket	9.30	25.58	24.42	0.00	27.91	0.00	2.33	10.47	0.00	86
COL	Fish	Galería rural	37.50	9.38	6.25	3.13	9.38	9.38	18.75	6.25	0.00	32
		Pulpería rural	31.25	18.75	31.25	0.00	6.25	0.00	12.50	0.00	0.00	16
		Galería city	36.17	8.51	10.64	0.00	10.64	17.02	14.89	0.00	2.13	47
		Pulpería city	10.00	30.00	20.00	0.00	10.00	0.00	20.00	10.00	0.00	10
		Supermarket	0.00	21.43	57.14	0.00	3.57	0.00	10.71	7.14	0.00	28
NIC		Galería rural	31.58	10.53	0.00	0.00	47.37	5.26	0.00	5.26	0.00	19
		Galería city	22.50	17.50	5.00	0.00	40.00	7.50	0.00	7.50	0.00	40
		Supermarket	8.33	26.67	25.00	0.00	25.00	0.00	1.67	11.67	1.67	60
COL	Total	Galería rural	42.39	7.82	13.17	1.23	13.17	7.82	9.88	2.06	2.47	243
		Pulpería rural	25.40	17.46	33.33	0.00	7.94	4.76	4.76	0.00	6.35	63
		Galería city	34.93	11.03	12.13	1.10	13.60	15.07	8.82	0.74	2.57	272
		Pulpería city	24.64	15.94	21.74	1.45	17.39	7.25	7.25	4.35	0.00	69
		Supermarket	3.83	22.95	52.46	1.64	6.56	0.00	4.92	7.65	0.00	183
NIC		Galería rural	25.64	18.80	0.00	0.00	43.59	3.42	0.00	6.84	1.71	117
		Pulpería rural	66.22	9.46	8.11	0.00	9.46	0.00	2.70	2.70	1.35	74
		Galería city	21.18	23.53	6.47	0.00	39.41	3.53	0.00	5.29	0.59	170
		Pulpería city	64.10	2.56	12.82	0.00	10.26	10.26	0.00	0.00	0.00	39
		Supermarket	6.48	27.16	24.07	0.00	27.47	0.93	2.16	11.43	0.31	324
Col	Total	All locations	29.11	13.37	23.55	1.42	11.72	8.05	7.69	2.84	2.25	845
Nic		All locations	23.60	21.60	13.47	0.00	29.47	2.27	1.33	7.47	0.80	750

*Captions: multiple answers were possible

Information status of the consumers on meat

Information on the location of meat purchase

Colombian consumers mostly get informed by friends (37.64%), followed by family members (26.94%), the shops (11.07%), television (9.23%), personal experience (made with locations; 7.01%), magazines/newspapers (3.69%), radio (2.58%), and tradition (1.85%). The Nicaraguan consumers mainly get informed by friends (51.25%), family (31.25%), television (5.42%), radio (4.17%), personal experience (3.75%), magazines/newspapers (2.08%), the shops (1.25%), and tradition (0.83%). This data shows that in Nicaragua, family and friends play a significantly more important role (**0.01, 2-sided) concerning identifying locations for meat purchase than in Colombia, whereas in Colombia, the information given by the shops is of significantly greater importance (**0.01, 2-sided). In the cities the media (TV, radio, magazines) play a significantly higher role as an information source on meat selling locations than in villages (**0.01, 2-sided). Radio and television play both a significantly more important role for small and medium scaled households (1-4 household members), than for larger households (*0.05, 2-sided), and the shops as information source are more important for small households (1-3 household members) than for larger ones (*0.05, 2-sided). Consumers from households with weekly meat expenses of >5.51 US$/person significantly tend to receive more information on meat selling locations by television (*0,05, 2-sided) and shops (*0.05, 2-sided), and less information by friends (**0.01, 2-sided) than consumers from households with lower weekly personal meat expenses. Table 75 shows the differences between rural and city consumers concerning this issue.

Table 75. Information source for meat-selling locations

	Origin	Friends %	Family %	TV %	Radio %	Magazine/ Newspaper %	Personal experience %	Tradition %	Shops %	n*
COL	Village	44.83	23.28	4.31	0.86	1.72	12.07	2.59	10.34	116
	City	32.26	29.68	12.90	3.87	5.16	3.23	1.29	11.61	155
	Total	37.64	26.94	9.23	2.58	3.69	7.01	1.85	11.07	271
NIC	Village	55.66	30.19	3.77	0.94	1.89	3.77	1.89	1.89	106
	City	47.76	32.09	6.72	6.72	2.24	3.73	0.00	0.75	134
	Total	51.25	31.25	5.42	4.17	2.08	3.75	0.83	1.25	240

*Captions: multiple answers were possible

Meat prices and discounts

With regard to the information sources for meat prices and discounts, Colombian consumers get large parts of their information from friends (28.76%) and from the shops (27.42%). Other important roles play the family (18.73%), television (11.04%), magazines/newspapers (6.35%), radio (4.01%), and personal experience (3.68%). Nicaraguan consumers obtain this type of information mostly from friends (43.17%) and the family (26.20%). Additional information is received from the shops (8.86%), television (7.01%), radio (6.64%), magazines/newspapers (6.27%), personal experience (1.48%), and tradition (0.37%). Again, the data shows that, in Nicaragua, friends and family play a significantly more important source of information (**0.01, 2-sided) than in Colombia, whereas in Colombia the information given by shops is of significantly higher importance (**0.01, 2-sided). Table 76 shows the differences between rural and city consumers in both countries.

Table 76. Information source for meat prices and discounts

	Origin	Friends %	Family %	TV %	Radio %	Magazine/ Newspaper %	Personal experience %	Tradition %	Shops %	n*
COL	Village	40.00	16.92	10.00	0.77	0.77	5.38	0.00	26.15	130
	City	20.12	20.12	11.83	6.51	10.65	2.37	0.00	28.40	169
	Total	28.76	18.73	11.04	4.01	6.35	3.68	0.00	27.42	299
NIC	Village	50.85	23.73	5.08	5.93	3.39	2.54	0.85	7.63	118
	City	37.25	28.10	8.50	7.19	8.50	0.65	0.00	9.80	153
	Total	43.17	26.20	7.01	6.64	6.27	1.48	0.37	8.86	271

*Captions: multiple answers were possible

The table shows, that friends play a significantly more important role in the villages concerning the aquisition of information on meat prices and discounts than in the cities (**0.01, 2-sided), whereas in the cities magazines and newspapers are of significantly more important meaning (**0.01, 2-sided). Television and radio tend to be more important information sources in cities than in rural areas. Female consumers significantly use television more often for obtaining information of meat prices as male consumers (*0.05, 2-sided), whereas for male consumers shops are a significantly more important information source (*0.05, 2-sided). The family as source of information on meat prices plays a significantly less important role for consumers of an age of 47 years or more than for younger consumers (*0.05, 2-sided). For small households (1-3 members), family plays a significantly less important role as information source for meat prices than for larger households (*0.05, 2-sided), whereas for big households (6 and more members) friends are significantly less important than for smaller households (*0.05, 2-sided). Consumers from households with weekly meat expenses of >5.51 US$/person significantly tend to receive more information on meat prices by shops (*0,05, 2-sided) than consumers from households with lower weekly personal meat expenses.

Sources of information about meat attributes

In matters of information acquisition on meat attributes and risks, the most important source of information for the Colombian consumers is television (42.05%), followed by friends (16.23%) and family (13.25%). Of minor importance as information sources are magazines/newspapers (8.28%), radio (7.62%), personal experience (6.29%), shops (4.30%), and doctors (1.99%). In Nicaragua the three most important information sources are friends (26.09%), family and television (both 21.38%). Other important sources are radio (12.68%) and magazines/newspapers (10.14%). Of minor importance as information sources are shops (5.43%), personal experience and doctors (both 1.45%). The table 77 shows, that in Nicaragua, family and friends are of significantly greater importance concerning this issue than in Colombia (**0.01, 2-sided). In Colombia, television is significantly used more for obtaining this information than in Nicaragua (**0.01, 2-sided), whereas there, radio is used more (*0.05, 2-sided).

The table shows, that television and magazines/newspapers tend to be a more common information source in the cities than in the rural areas. This might be due to the availability of these media or the high costs a televison means for rural people. Radios are a significantly more common source of information in the rural areas (**0.01, 2-sided), which might be a result of the lower purchase price. Moreover, female consumers tend to get their information on meat attributes significantly more often from magazines than male consumers (*0.05, 2-sided). Friends and meat selling locations as information source on meat attributes are significantly more important for younger consumers (<27 years) than for older consumers (*0.05, 2-sided). Television plays a significantly more important role for small households (1-3 members; *0.05, 2-sided), and a significantly less important role for big households (6 and more members; **0.01, 2-sided). If the meat is bought by a female household member, television plays a significantly less important information source (**0.01, 2-sided), respectively a significantly more important one if male (*0.05, 2-sided).

Table 77. Information source for meat attributes and risks

	Origin	Friends %	Family %	TV %	Radio %	Magazine/ Newspaper %	Personal experience %	Doctor %	Shops %	n*
COL	Village	20.42	13.38	37.32	8.45	4.23	9.86	1.41	4.93	142
	City	12.50	13.13	46.25	6.88	11.88	3.13	2.50	3.75	160
	Total	16.23	13.25	42.05	7.62	8.28	6.29	1.99	4.30	302
NIC	Village	25.38	16.92	19.23	17.69	10.00	2.31	1.54	6.92	130
	City	26.71	25.34	23.29	8.22	10.27	0.68	1.37	4.11	146
	Total	26.09	21.38	21.38	12.68	10.14	1.45	1.45	5.43	276

*Captions: multiple answers were possible

Consumers from households with weekly meat expenses of <2.30 US$/person significantly tend to receive more information on meat attributes by friends (*0.05, 2-sided) than consumers from households with higher weekly personal meat expenses. On the other hand, consumers from households with weekly meat expenses of >5.51 US$/person significantly tend to receive more information on meat attributes by television (**0.01, 2-sided) than consumers from households with lower weekly personal meat expenses.

In both countries, the consumers were also asked if they inform other people (like family members or friends) on e.g., meat prices and discounts, locations for meat purchase, meat characteristics, or meat risks. 65.13% of the Colombian consumers do so, 34.87% not (n=238). In Nicaragua, 70.28% of the interviewees inform other people and 29.72% do not (n=212). Smaller households (up to 4 members) significantly tend to inform more on meat than larger households (*0.01, 2-sided). The Colombian as well as the Nicaraguan interviewees answered to inform mainly on prices and discounts (Colombia: 50.21%, Nicaragua: 55.14%), followed by quality (Colombia: 33.33%, Nicaragua: 29.44%), and location (Colombia: 11.11%, Nicaragua: 7.94%).

In Nicaragua the consumers moreover inform on problems with the concerning meat (6.07%), and in a little way on preparation/weight of the meat, weight/size of the meat and the service (all 0.47%). Of minor relevance in Colombia are preparation/consumption issues (2.06%), weight/size of the meat (1.65%), problems with the shop/meat (1.23%), and the service (0.41%). This indicates, that in both countries the meat price is the most important criteria for consumption. In both countries, there are no big differences between rural and city consumers, besides that city consumers tend to inform more on the problems with the shops/meat than rural consumers. The most common reason for not informing other people on meat issues is in both countries the missing interest in informing other people (Colombia (n=83): 39.47%, Nicaragua (n=63): 56.86%), followed by the belief that other people already possess sufficient information (Colombia: 26.32%, Nicaragua: 19.61%), and little communication between the people (Colombia: 14.47%, Nicaragua: 23.53%). In Colombia two minor reasons additionally occur: people themselves do not know a lot about this issue and cannot advise others (10.53%), and for others it is difficult to advise, as other persons might feel themselves being taught (9.21%).

Origin of Meat

Concerning information on the meat origin, 40.76% the Colombian consumers told to know where it comes from, 59.24% answered to be uninformed. In Nicaragua, the consumers are even less informed – only 24.06% state to know the origin, 75.94% do not. Colombian consumers are significantly more informed on this topic than Nicaraguan consumers (**0.01, 2-sided). Rural consumers significantly tell to be more informed on the meat origin than city consumers (**0.01, 2-sided). Consumers from households with weekly meat expenses of >5.51 US$/person significantly tend to have more information on meat origin (*0.05, 2-sided) than consumers from households with lower weekly personal meat expenses.

Moreover, consumers who obtain their information on meat prices, meat characteristics, and meat selling locations by shops significantly tend to have more information on meat origin than consumers who receive their information from other sources (*0.05, 2-sided). Where in the opinion of the consumers the meat comes from is shown in table 78.

Table 78. Opinion of the consumers on meat origin

	Origin	Distributors %	Villages of the region %	Super-markets %	Slaughterhouses in other departments %	Imported from other countries %	Municipal slaughterhouses %	n
COL	Village	1.75	50.88	0.00	1.75	0.00	45.61	57
	City	35.00	20.00	2.50	10.00	2.50	30.00	40
	Total	15.46	38.14	1.03	5.15	1.03	39.18	97
NIC	Village	22.22	33.33	0.00	14.81	0.00	29.63	27
	City	43.33	6.67	0.00	16.67	0.00	33.33	30
	Total	33.33	19.30	0.00	15.79	0.00	31.58	57

In Colombia, large parts of the rural consumers who state to know the meat origin seem to be wrongly informed. They assume that the meat they purchase comes from municipal slaughterhouses, which is only true for beef in most of the cases (other parts come from other departments, or big producers). Pork does normally not come from the municipal slaughterhouses as there are in the whole region only two which slaughter pigs (Popayán, Timbío). The pigs in other villages than Timbío usually get slaughtered in private households or in the butcheries themselves. In matters of chicken, almost all chicken products come from big distributors, even in the villages. Chicken products sold in the Galerías and in the Tiendas normally do not have their origin in private households. Chicken which comes from private households is normally sold directly from household to household, but only plays a minor role in the total chicken purchase. City consumers seem better informed.

They state, that 35% of their meat comes from distributors. This is true for chicken – independent from the shopping location. Moreover, also parts of the pork and the beef come from distributors (the meat sold in supermarkets and partly in the Galerías). They are also right that large parts come from the villages in the region, and from the municipal slaughterhouse (large parts of the meat which is sold in the Galerías). In Nicaragua, rural consumers seem to be better informed on meat origin. They state, that parts of it comes from distributors, which is true as most of the chicken sold in the Meracdos and Pulperías comes from distributors. Chicken is also sold privately, but this occurs directly from household to household and not in the open market. Furthermore, it is not the common way of purchasing chicken. The consumers are also right that large parts of the meat comes from villages in the region as all pork sold in the Mercados has this origin. Pigs for the rural market normally do not get slaughtered in municipal slaughterhouses, as the only licensed slaughterhouse for pig slaughtering is in Chinandega. Pigs are slaughtered in private households and either sold there or in the Mercados. Other parts of the pork are sold in the supermarket chains which are located in many of the villages. This meat comes from licensed slaughterhouses in Chinandega or in cities in other departments (e.g., Léon, Managua), and from distributors.

Concerning the beef sold in Mercados, most of it comes from the municipal slaughterhouses or private slaughterings in households. The beef sold in supermarkets comes from the municipal slaughterhouses in the department or in other departments, and from distributors. The city consumers in Nicaragua, who stated to know about the meat origin, also seem to be well informed. They state that most of the meat comes from distributors which is true for almost all chicken sold in the city. Also parts of the pork and the beef come from distributors (especially the meat sold in supermarkets). They also state that the meat comes from municipal slaughterhouses from the department and from other departments which is true for large parts of the pork and the beef (especially the parts sold in the Mercados). In Colombia (n=97), consumers who know about meat origin do not buy directly from there because the amount purchased is too little (36.08%), it is impossible to buy from there as a normal household (23.71%), it is too far away and costs time and money to get there which makes it more expensive (21.65%), because it is easier to buy in the shops (17.53%), or because of tradition (1.03%). The Nicaraguan (n=40) consumers do not purchase their meat directly from the origin because of the distance and the involved costs for transport (47.50%), the purchased amount is too little (37.50%), it is easier to buy in the shops (10.00%), and it is impossible to buy from there as a normal household (5.00%). In both countries, the purchased amount is more an issue for the rural consumers than the city consumers, whereas the distance is considered as a higher burden for the city consumers. The consumers name two different reasons for not knowing the meat origin: no information available (Colombia: 29.79%, Nicaragua: 50.31%), and no interest in the topic (Colombia: 61.70%, Nicaragua: 22.36%). 8.51% of the Colombian consumers did not give an answer, respectively 27.33% of the Nicaraguan consumers. It seems, that there is more information available on this topic in Colombia than in Nicaragua which might explain the higher percentage of knowledge of the consumers. Nevertheless, the interest of the consumers in this topic is higher in Nicaragua than in Colombia, which might result from the missing information available.

Quality Standards

Consumers were asked if they know about the adhernce to quality standards by their suppliers. In Colombia (n=238), 86.55% believe that they are fulfilled, 13.45% do not. The Nicaraguan consumers (n=212) do not seem to be that well informed, as only 56.60% believe in the fulfillment and 43.40% do not. Colombian consumers believe significantly more in the fulfillment of quality standards than Nicaraguan consumers (**0.01, 2-sided). If the meat is bought by a male household member, the interviewee significantly believes to be more informed on quality standards (*0.05, 2-sided). Consumers from households with weekly meat expenses of >5.51 US$/person significantly tend to be more informed on quality standards (**0.01, 2-sided) than consumers from households with lower weekly personal meat expenses. Consumers who see the pork and chicken price as most important criteria significantly tend to be less informed on quality standards (**0.01, 2-sided), and consumers who see quality issues (e.g., appearance, color) as most important criteria for buying pork or chicken, significantly tend to be more informed on quality standards (**0.01, 2-sided). Knowledge on quality standards is significantly more widespread amongst consumers who receive their information on meat prices and characteristics by shops (**0.01, 2-sided) or by television (*0.05, 2-sided). Consumers who know about the meat origin significantly tend to be better informed on quality standards than those who do not know (**0.01, 2-sided). 25.91% of the Colombian consumers who seem to know about the quality standards receive their information from Governmental Institutions (e.g., town hall, regulation authorities). The rest of their information they receive by the media (23.88%), word of mouth (e.g., friends, family, 19.43%), the visible product quality/hygiene (14.57%), information in shops (8.10%), certifications (5.67%), and other sources (e.g., slaughterhouse, university, in total 2.43%). In Nicaragua, the consumers receive their information from Governmental Institutions (33.61%), the media (22.95%), the visible product quality/hygiene (14.75%), word of mouth (13.93%), information in shops (11.48%), certifications (1.64%), and other sources (e.g., slaughterhouse, university, in total 1.64%).

Sources of information about quality standards

Table 79 shows the information sources for the knowledge on the fulfillment of quality standards by the suppliers divided into rural and city consumers for both countries.

Table 79. Information source for knowledge on the fulfillment of quality standards by suppliers

	Origin	Governmental Institutions %	Shops %	Word of mouth %	Quality/ hygiene %	Certifications %	Media %	Other %	n*
COL	Village	28.43	7.84	25.49	15.69	5.88	14.71	1.96	102
	City	24.14	8.28	15.17	13.79	5.52	30.34	2.76	145
	Total	25.91	8.10	19.43	14.57	5.67	23.89	2.43	247
NIC	Village	36.84	10.53	7.02	12.28	0.00	33.33	0.00	57
	City	30.77	12.31	20.00	16.92	3.08	13.85	3.08	65
	Total	33.61	11.48	13.93	14.75	1.64	22.95	1.64	122

*Captions: multiple answers were possible

The table shows, that for rural consumers the Governmental Institutions play a more important role than for consumers in the city. Word of mouth is more an information source for rural consumers in Colombia than for city consumers, whereas in Nicaragua the situation is vice versa. Colombian city consumers receive more of their information from the media than local consumers, in Nicaragua it is vice versa again. Concerning the fulfillment of the quality standards, 77.18% of the Colombian consumers (n=206) trust their suppliers and 22.82% do not. Colombian city consumers tend to have more trust than local consumer, which might be explained by the higher food security standards in the city. In Nicaragua (n=120), 85.83% of the consumers have trust in their suppliers, 14.17% do not. Again, there is a slightly higher trust level in the city than in rural areas. As reasons for trust consumers (Colombia: n=159, Nicaragua: n=103, multiple answers were possible) mention the product quality/hygiene (Colombia: 55.76%, Nicaragua: 70.19%), the control system by the government (Colombia: 26.67%, Nicaragua: 21.15%), and the attention of the personnel (Colombia: 17.58%, Nicaragua: 8.65%). In Colombia, there exist differences between rural and city consumers. City consumers trust more in the product quality/hygiene and in the control system by the government than local consumers, whereas they have more trust in the personnel. This might be caused by the general higher product quality and control in the city than in the rural areas and by the higher personal connections between rural consumers and their suppliers (tradition). In Nicaragua, rural and city consumers have the same trust level in the product quality, which might be due to the existence of supermarket chains in rural areas which have the same product quality in all their locations. The trust in the personnel is higher by city consumers than by local consumers, whereas local consumers have more trust in the control system by the government. As reasons for not having trust in the quality standards, Colombian (n=50) and Nicaraguan (n=17) consumers named general mistrust (Colombia: 50.00%, Nicaragua: 41.18%), manipulations by the shop/control institution (Colombia: 32.00%, Nicaragua: 35.29%), and inadequate product quality/shop hygiene (Colombia: 18.00%, Nicaragua: 23.53%). The consumers in Colombia who do not know about quality standards (n=32), have the following explications: no information available (41.94%), no interest (35.48%), and never asked anybody (22.58%). There exist differences between the rural and city consumers in all points. Rural consumers tend to have less information than city consumers, but at the same time more interst in getting the information. Nevertheless, the rural consumers tend to ask less about quality standards than the city consumers. In Nicaragua (n=63), no information available (80,95%) was the main reason for not having knowledge, followed by never asked anybody (12.70%), and no interest (6.35%). There are no differences between rural and city consumers.

Consumer opinion on smallholder products and on the meat suppliers

Concerning the opinion on smallholder products, the consumers commonly think that the products are of the same quality as those of big producers (Colombia: 26.23%, Nicaragua: 20.85%). In Colombia this is followed by the opinion that smallholder products are healthier, more nutritive, or cleaner than from big producers because of the used feed (18.14%), and in Nicaragua by the lack of control (13.60%). Table 80 gives an overview over all opinions on smallholder products divided by rural and city consumers for both countries.

Table 80. Opinion of the consumers on meat origin

	COL			NIC		
	Village (n=175)*	City (n=233)*	Total (n=408)*	Village (n=155)*	City (n=176)*	Total (n=331)*
Meat worse quality	4.57	5.58	5.15	6.45	11.36	9.06
Meat better quality	7.43	8.15	7.84	2.58	2.27	2.42
Meat same quality	32.57	21.46	26.23	22.58	19.32	20.85
Eggs worse quality	1.14	2.58	1.96	4.52	8.52	6.65
Eggs better quality	12.00	16.74	14.71	9.03	9.66	9.37
Healthier products	18.29	18.03	18.14	14.84	7.95	11.18
Access difficult	4.00	4.72	4.41	5.16	2.84	3.93
No quality control	0.57	9.44	5.64	8.39	18.18	13.60
Better taste	6.86	4.72	5.64	5.81	6.82	6.34
More expensive	2.86	3.43	3.19	0.65	1.14	0.91
Cheaper	5.14	1.72	3.19	9.03	4.55	6.65
No trust	0.57	0.43	0.49	3.23	2.84	3.02
Need help	0.57	0.86	0.74	1.94	1.70	1.81
Doesn't buy/know	3.43	2.15	2.70	5.81	2.84	4.23

*Captions: multiple answers were possible

The table shows, that in the villages in both countries more consumers think of a better/same quality of smallholder meat than in the cities. Especially in Nicaragua, more city consumers think of a worse quality of the smallholder meat than rural consumers. Rural consumers in Nicaragua rather believe that smallholder products are healthier products (due to feeding differences) than products of large scale producers. City consumers rather think that they are lacking quality control and that they are not always fulfilling the quality requirements of the state. In total, it seems that smallholder products enjoy a better reputation in the villages than in the cities.

To get a reputation index for the different shopping locations for meat, the consumers in both countries were asked 23 different questions dealing with different topics concerning the locations like e.g., product quality, employees, environment protection, retability, or trust. They were asked to rank each of the 23 questions from 1 to 7 (1 = very bad; 4 = neutral; 7 = very good). Nevertheless, it seems that the consumers rated their locations mostly from neutral to very good. Ratings less than neutral have not been done very often. This could have been caused by two different reasons: first, the consumers are very satisfied with their shopping locations and second, they were afraid of being asked by a governmental institution which tries to improve food safety in the meat market (and therefore shuts down or fines locations which have low standards or possess a risk for the consumers). Due to many bad comments of the consumers about the shopping locations, the second option seems rather reasonable.

Small Supermarkets reputation

In Colombia, the Tiendas/Local Supermarkets in the rural areas were rated with an average reputation of 5.88 (n=39, only rural consumers). The three lowest ratings were on average made on “the assistance to good causes” e.g., assistance for help projects, schools, poor people (4.67), “the product price” (5.28), and “the payment of the employees” (5.32). The three highest ratings were on average made on “the importance for the community” (6.54), “the respect for the supplier” (6.41), and “the acceptance by the community” (6.37). The first thoughts of the consumers when listening the name of their Tienda/Local Supermarket were on “product quality” (either good or bad, 62.16%), “product hygiene” (either high or low, 16.22%), “service” like e.g., accessibility, product variety, friendliness of the personell (either good or bad, 13.51%), “trust” (either high or low, 5.41%), and “price” (either high or low, 2.70%). In Nicaragua, the Pulperías/Local Supermarkets in the rural areas were on average rated with 5.31 (n=49, only rural consumers). The three lowest ratings were on average made on “the assistance of good causes” (2.69), “the protection of the environment” (4.08), and “the organization of the business” (4.56). Consumers rated the three following indicators the highest: “The respect for the supplier” (6.22), “location hygiene” (6.00), and “trust” (5.92).When listening the name of their Pulpería/Local Supermarkets, the consumers first think in “service” (either good or bad, 43.75%), followed by “product quality” (either good or bad, 27.08%), “price” (either high or low, 12.50%), “product hygiene” (either high or low, 10.42%), and “trust” (either high or low, 6.25%).

The Tiendas/Local Supermarkets in Popayán (Colombia) were rated with an average reputation of 5.00 (n=56, only city consumers). The three lowest ratings were on average made on “the assistance of good causes” (3.80), “the transparency of the suppliers business” (4.35), and “the payment of the employees” (4.58). The three highest ratings were on average made on “the respect for the supplier” (5.49), “the importance for the community” (5.35), and “the locations hygiene” (5.29). The first thoughts of the consumers when listening the name of their Tienda/Local Supermarket were on “product quality” (46.30%), “service” (14.81%), “product hygiene”, “trust”, and “price” (all 12.96%). In Nicaragua, the Pulperías/Local Supermarkets in Chinandega were on average rated with 5.17 (n=27, only city consumers). The three lowest ratings were on average made on “the assistance of good causes” (3.39), “the payment of the employees” (4.48), and “the protection of the environment” (4.72). Consumers rated the three following indicators the highest: “The future growth of the business” (5.96), “the respect for the supplier” (5.72), and “the product quality” (5.70).When listening the name of their Pulpería/Local Supermarkets, the consumers first think in “service” (40.74%), followed by “product quality” (29.63%), “trust” (14.81%), “price” (11.11%), and “product hygiene” (3.70%).

Galerias reputation

The Colombian consumers evaluated the rural Galerías in the villages with an average reputation of 5.44 (n=98, rural consumers: 94, city consumers: 4). In general, local consumers (5.46) tend to give a higher rating for the Galerías than city consumers (4.92). Lowest ratings were made on “the assistance to good causes” (3.95), “the protection of the environment” (4.35), and “the payment of the employees” (4.98) – highest ratings were made on “the respect for the supplier” (6.34), “the acceptance by the community” (6.24), and “the importance for the community” (6.07). When listening the name of their rural Galería, consumers first think in “product quality” (56.84%), followed by “trust” (18.95%), “product hygiene” (11.58%), “price” (7.37%), and “service” (5.26%). In Nicaragua, the rural Mercados in the villages were on average rated with 4.86 (n=42, only rural consumers). The lowest ratings were given on “the assistance of good causes” (3.29), “the protection of the environment” (3.81), and “the payment of the employees” (4.17). Highest ratings were made on “product variety” (5.76), “the future growth of the business” (5.52), and “the product price” (5.50). Consumers first thoughts about the rural Mercados are “price” and “service” (both 35.71%), followed by “product hygiene” (16.67%), “product quality” (9.52%), and “trust” (2.38%).

The Galerías in Popayán were on average rated with 5.27 by the Colombian consumers (n=100, city consumers: 93, rural consumers: 7). As for the rural Galerías too, the city consumers tend to evaluate the city Galerías worse (5.21) than the rural consumers (6.06). The lowest rating was given for “the assistance of good causes” (3.62), followed by “the protection of the environment” (4.43), and “the transparency of the suppliers business” (4.46). Highest ratings were given on “respect for the supplier” (6.14), ”the importance for the community” (5.93), and “the acceptance by the community” (5.92). Colombian consumers first think in “product quality” (36.17%) when listening the name of the Galería where they purchase meat, followed by “product hygiene” (20.21%), “price” (18.09%), “trust” (13.83%), and “service” (11.70%). Nicaraguan consumers rated the city Mercado in Chinandega on average with 4.93 (n=64, only city consumers). The lowest ratings were given on “the assistance of good causes” (3.82), “the payment of the employees” (4.25), and “the protection of the environment” (4.34) – consumers rated the highest on “product variety” (5.73), “the acceptance by the community” (5.61), and “the respect for the supplier” (5.58). First thoughts on the Mercado in Chinandega are “service” (37.70%), “price” (26.23%), “product quality” (24.59%), and “product hygiene” (11.48%).

Large Supermarkets reputation

The supermarket chains in Popayán were on average assessed with 6.30 by the Colombian consumers (n=103, city consumers: 68, rural consumers: 35). The lowest ratings were given on “the transparency of the suppliers business” (4.85), “the assistance of good causes” (5.24), and “the product prices” (5.52). Consumers evaluated the best the following issues: “the location hygiene” (6.79), “the locations order” (6.78), and “the organization of the supplier” (6.77). First thoughts when listening the supermarkets names are “product quality” (56.31%), “price” (19.42%), “service” (13.59%), “product hygiene” (6.80%), and “trust” (3.88%). In Nicaragua, the supermarkets were on average rated with 5.83 (n=149, city consumers: 102, rural consumers: 47).

The lowest number of points was on average given to “the assistance to good causes” (4.37), “the payment of the employees” (4.75), and “the happiness of the employees” (4.84). Highest ratings were made on “the future growth of the business” and “the locations order” (both 6.39), “the locations hygiene” and “the rentability of the business” (both 6.37). The Nicaraguan consumers first think in “product quality” (25.57%) when listening the name of the supermarket, followed by “price” (29.53%), “service” (16.78%), “product hygiene” (16.11%), and “trust” (2.01%).

Smallholder producers reputation

The private (smallholder) producers were on average rated with 5.76 by Colombian consumers (n=16, city consumers: 9, rural consumers: 7). There is a tendency that rural consumers give the smallholder producers a higher reputation (5.99) than city consumers (5.58) which might be caused by the stronger relation to the producers. Lowest rates were given for “the assistance of good causes” (4.06), “the protection of the environment”, “the future plans of the supplier”, and “the future grwoth of the business” (all 5.25). Consumers gave most points on “the respect for the supplier” (6.63), “trust” (6.31), and “the communication with the supplier” (6.25). When hearing the name of their smallholder supplier, people first think in “product quality” (37.50%), “trust” (25.00%), “price” (18.75%), “service” (12.50%), and “product hygiene” (6.25%). In Nicaragua, the consumer rating for the private (smallholder) producers was on average 4.64 (n=15, city consumers: 3, rural consumers: 15).

Like in Colombia too, the rural consumers tend to rate the smallholder producers higher (4.70) than the city consumers (4.39). Lowest rates were given on “the assistance of good causes” (2.74), “the transparency of the suppliers business” (3.86), and “the protection of the environment” (3.93). Consumers gave the highest rating on “the product price” (5.46), “the acceptance by the community”, and “the rentability of the business” (both 5.33). First thoughts of the consumers, concerning their supplier are about “service” (46.67%), “product quality” (26.67%), “product hygiene”, and “trust” (both 13.33%).

Conclusions on reputation index

Calculating all reputations for the different meat suppliers together, gives an overall reputation for meat suppliers in Colombia of 5.61 (n=412, city consumers: 230, rural consumers: 182). Rural consumers tend to be more satisfied with their meat suppliers (5.76) than city consumers (5.49). In total, the three lowest ratings were on “the assistance of good causes” (4.24), “the protection of the environment” (4.94), and “the transparency of the suppliers business” (4.99). Highest ratings were given on “the respect for the supplier” (6.27), “the acceptance by the community” (6.11), and “the importance for the community” (6.03). When listening the name of their supplier, Colombian consumers first think in “product quality” (50.13%), “price” (13.78%), “product hygiene” (12.78%), “trust” (12.03%), and “service” (11.28%). In Nicaragua, the overall reputation of the meat suppliers is 5.37 (n=346, city consumers: 196, local consumers: 150). Lowest ratings were given on “the assistance of good causes” (3.75), “the payment of the employees” (4.53), and “the happiness of the employees” (4.69). Highest ratings were made on “the respect for the supplier (5.95), “the future growth of the business” (5.94), and “the rentability of the business” (5.90). Nicaraguan consumers first thoughts when listening the name of their meat supplier are “service” (29.82%), “product quality” (28.36%), “price” (24.56%), “product hygiene” (13.45%), and “trust” (3.80%).

Table 81 gives an overview on the ratings for each indicator for all different meat suppliers in Colombia. Table 82 shows the same for Nicaragua.

This gives the following ranking for meat selling locations:

Colombia	*Nicaragua*
1. Supermarket chains Popayán	1. Supermarket chains
2. Tiendas/Local Supermarkets villages	2. Pulperías/Local Supermarkets villages
3. Private (Smallholder) producers	3. Pulperías/Local Supermarkets Chinandega
4. Galerías villages	4. Mercado Chinandega
5. Galerías Popayán	5. Mercados villages
6. Tiendas/Local Supermarkets Popayán	6. Private (Smallholder) producers

Table 81. Reputation index for meat suppliers in Colombia

Indicator	Tiendas/Local Supermarkets villages	Galerías villages	Galerías Popayán	Supermarket chains Popayán	Tiendas/Local Supermarkets Popayán	Private (smallholder) producers	Total
n	39	98	100	103	56	16	412
Product quality	6.04	5.68	5.69	6.68	5.17	6.12	5.92
Product price	5.28	5.52	5.81	5.52	5.15	6.12	5.54
Product variety	5.41	5.76	5.77	6.56	5.11	5.50	5.83
Employees happiness	5.82	5.30	5.26	5.87	4.80	5.81	5.43
Employees payment	5.33	4.98	4.93	5.92	4.58	5.63	5.21
Location order	6.08	5.11	5.10	6.78	5.23	5.82	5.66
Location hygiene	6.13	5.08	5.10	6.79	5.29	5.69	5.66
Location ambience	5.90	5.07	4.96	6.73	5.15	5.69	5.57
Transparency	5.97	5.47	4.46	4.85	4.35	6.00	4.99
Acceptance by community	6.37	6.24	5.92	6.50	5.28	6.19	6.11
Fulfillment of laws	6.31	5.49	5.19	6.68	5.03	5.31	5.72
Environment protection	5.67	4.35	4.43	5.86	4.60	5.25	4.94
Importance for community	6.54	6.07	5.93	6.31	5.35	5.81	6.03
Assistance to good causes	4.67	3.95	3.62	5.24	3.80	4.06	4.24
Organization	6.05	5.37	5.14	6.77	5.22	5.75	5.72
Future plans	5.54	5.10	4.90	6.61	4.95	5.25	5.46
Communication with supplier	5.90	5.80	5.53	6.07	5.15	6.25	5.74
Rentability	6.10	5.78	5.72	6.66	5.18	5.88	5.94
Future growth	5.79	5.22	5.10	6.56	4.85	5.25	5.53
Feeling about supplier	5.85	5.59	5.17	6.35	5.03	6.09	5.65
Trust in supplier	5.87	5.79	5.51	6.46	5.12	6.31	5.82
Respect for supplier	6.41	6.34	6.14	6.66	5.49	6.63	6.27
Image others have of supplier	6.15	6.00	5.79	6.45	5.20	6.06	5.97
Total reputation index	5.88	5.44	5.27	6.30	5.00	5.76	5.61

Table 82. Reputation index for meat suppliers in Nicaragua

Indicator	Pulperías/Local Supermarkets villages	Mercados villages	Mercado Chinandega	Supermarket chains Chinandega	Pulperías/Local Supermarkets Chinandega	Private (smallholder) producers	Total
n	49	42	64	149	27	15	346
Product quality	5.84	5.40	5.14	6.22	5.70	5.20	5.78
Product price	5.65	5.50	5.23	5.64	5.31	5.46	5.51
Product variety	5.31	5.76	5.73	6.10	5.37	4.73	5.76
Employees happiness	4.90	4.29	4.41	4.84	4.85	4.40	4.69
Employees payment	4.73	4.17	4.25	4.75	4.48	4.06	4.53
Location order	5.76	4.57	4.46	6.39	5.46	4.26	5.56
Location hygiene	6.00	4.52	4.55	6.37	5.50	4.47	5.60
Location ambience	5.69	4.79	4.54	6.11	5.13	4.46	5.45
Transparency	5.44	4.86	4.59	5.56	4.87	3.86	5.15
Acceptance by community	5.82	5.24	5.61	6.07	5.50	5.33	5.77
Fulfillment of laws	5.43	4.62	4.63	5.99	4.81	5.00	5.36
Environment protection	4.08	3.81	4.34	5.40	4.72	3.93	4.71
Importance for community	4.57	4.62	5.02	5.71	5.11	4.06	5.17
Assistance to good causes	2.69	3.29	3.82	4.37	3.39	2.74	3.75
Organization	4.56	4.69	4.95	5.80	4.91	4.40	5.20
Future plans	5.41	5.33	4.91	5.98	5.19	4.73	5.51
Communication with supplier	5.57	5.19	5.07	5.77	5.35	4.54	5.45
Rentability	5.78	5.29	5.50	6.37	5.67	5.33	5.90
Future growth	5.88	5.52	5.42	6.39	5.96	5.00	5.94
Feeling about supplier	5.33	4.86	5.08	5.74	5.26	5.07	5.39
Trust in supplier	5.92	5.19	5.14	6.03	5.20	5.20	5.65
Respect for supplier	6.22	5.26	5.58	6.33	5.72	5.27	5.95
Image others have of supplier	5.63	5.02	5.41	6.05	5.52	5.20	5.67
Total reputation index	5.31	4.86	4.93	5.83	5.17	4.64	5.37

Conclusions

Consumers in Colombia prefer beef over other meat types which results from the beef tradition in the country. This is because people like the taste, the accessibility is high (even in remote rural areas), the quality is good compared with other meat types, and it is cheaper than e.g., pork or lamb. Nevertheless, chicken is the type of meat with the highest consumption, which results from its economic prices throughout the country and its high nutritive value. Moreover, the quality of chicken is high, as large parts come from certified, vertically oriented, large scaled producers, and it is easily accessible in remote areas. Pork plays a less important role for Colombian consumers, but is growing in importance. Compared to other meat types it is more expensive which is one reason for the lower consumption. Another important reason is the fear of consumers of diseases resulting from bad quality and low hygiene standards in production. Fish is of less importance than pork and mainly consumed because of its nutritive value and for variation. Concerning the consumption of meat, the Colombian consumer has two main points of interest: quality and price. Quality is the most important characteristic, but price also plays an important role (high amount of chicken consumption).

In Nicaragua, consumers prefer chicken over other meat types. This is due to its low price and its nutritive value as well as to its higher quality in comparison to other meat types (like in Colombia, most of the chicken sold comes from vertically integrated producers). Moreover, it is easily accessible in remote rural areas. Beef plays an important role, too, even if its consumption is by far not as high as the chicken consumption. This results, like in Colombia, from the fact that beef is very traditional in Nicaragua. Pork is of minor relevance than chicken and beef, which results from the fear of diseases (mainly Cysticercosis), its high fat content, and the high price. Fish is mainly bought because of its high nutritive value and because of tradition (easy access to the sea, lakes, and rivers). Generally, the price is the most important characteristic for the Nicaraguan meat consumer, the quality plays a minor role.

Concerning the meat consumption in both countries, beef is more important in rural areas than in the cities, which derives from the tradition, the accessibility and the quality of beef in rural areas (higher than other types of meat, e.g., pork). In poorer households (with lower meat expenses), consumers preferrably buy chicken, resulting from its more economic price. Consumers from richer households prefer beef or pork, the more expensive meat types and also do care more about meat quality. Female consumers like chicken more than other meat types and male consumers prefer beef. This might be caused by the fact that female household members have more responsibility for the meat purchase (decision on meat type, conducting of meat purchase) and therefore are more in charge of the household budget, which makes them rather buy the cheaper meat types like chicken. Caused by the same reason is the greater importance of the meat price for female household members. For larger households, the meat price is of higher importance than for smaller households, resulting from the fact that the household budget has to be shared with more household members.

Referring to the meat selling locations, Colombian consumers have two main reasons for choosing a location: quality/hygiene of the products and the location, and accessibility (nearby to save time and costs, meat type available). They choose supermarket chains for buying meat mainly beacause of the quality, whereas Tiendas and Galerías are chosen for their accessibility. Tiendas are located in most neighborhoods, Galerías offer a wide range of products at economic prices. In Nicaragua, consumers choose their locations beacause of: price, accessibility, and quality/hygiene. Supermarket chains are chosen for their economic prices and their high quality/hygiene, Mercados for their economic prices and their accessibility, and Pulperías for their accessibility, their quality, and their economic prices. Like the Tiendas in Colombia, the Pulperías in Nicaragua are located in most neighborhoods, and the Mercados offer a large variety of products at economic prices.

Because of the special relevance of chicken and pork for this study, it can be concluded from this part that the chicken production is on a successful way in both countries and mostly fulfills the consumer preferences. Quality standards are mostly guaranteed, even in remote rural areas, and the products are available at economic prices. The pig production could gain in importance but is currently not always meeting the consumer preferences. A lack of quality fears the consumers, high prices makes pork often unattractive, and the access for the consumers is not always guaranteed.

Concerning the consumer information on meat selling locations, prices/discounts, and on meat attributes, the most important source of information are friends/family. The media and the information given by shops (e.g., flyers) are also of importance. In Colombia, shops play a more important role, which might be caused by the higher investments in publicity. In Nicaragua in total and in the villages in both countries, friends and family are of larger importance, due to the lower availability of information by shops and the higher remoteness of many villages. The shops and the media play a more important for smaller households and richer households and for city consumers, which results from higher availability of both in cities and the higher distribution of media in smaller/richer households. Television is more important for Colombian consumers, and radio for Nicaraguan consumers, as the availability of media and electronic articles as well as the financial resources of the consumers are higher in Colombia.

Large parts of the consumers in both countries inform other people on meat issues. Mostly they give information on prices and discounts which again shows the importance of this issue in the meat consumption. Quality and hygiene of the meat and the location are communicated more infrequently but play a more important role in Colombia than in Nicaragua.

Referring to the origin of the meat, the level of knowledge is in Colombia low and in Nicaragua very low. This can be explained by the missing information given by shops and by the missing interest of the consumers on this topic. This underlines again the great importance of the price in both countries. Richer households show a higher level of knowledge concerning this issue, which leads to the conclusion that consumers start to get interested in that topic when they do not have to worry too much anymore about the price of the meat. If the consumers show knowledge on the meat origin, their knowledge is very often not correct (especially in Colombia), which might be explained by the modification/loss of information by word of mouth. With regard to the information on quality standards for meat, there is a high level of knowledge in both countries. Richer households and consumers who care more about quality than price tend to be better informed on this issue. Consumers who care more about price than quality tend to have less information. This shows, that consumers start to care about quality standards when they do not have to worry too much about the price anymore. Most important source of information on quality standards are in both countries the governmental institutions, the media, and friends/family. In both countries, the level of trust in quality standards is high, nevertheless there are consumers without any trust. This results from the fear of manipulations, a lack of control, or an insufficient product quality.

Concluding the information part, it can be said, that the most important role on consumer information about meat are friends/family, the media, the shops, and governmental institutions (for quality standards). Nevertheless, there are still large parts of uninformed or wrongly informed consumers (especially on meat origin). This leads to mistrust and fear in the meat purchase. The consumer prefers to buy the meat type in which he has more trust (beef, chicken) and neglects meat types with a higher rist level (pork). The data also leads to the conclusion, that price is the most important information criteria. People seek and communicate price information the most, and inform less on quality issues. This changes, when consumers do not have to worry about meat prices anymore. Quality and hygiene become important issues then.

Smallholder producers enjoy a higher reputation in Colombia than in Nicaragua. The mistrust in Nicaragua is generally higher and the people have more fear of meat diseases. City consumers rate smallholder products worse than village consumers (higher relatedness). Smallholder production is restricted in the following issues: quality/hygiene control, fulfillment of laws/requirements (manipulations), protection of the environment, transparency of the production, accessibility of the products, and future plans/visions. Especially the missing quality/hygiene control and the lack in the fulfillment of laws/requirements cause fear for the consumers which makes them avoid to buy their products directly from the smallholder producers. Nevertheless, large parts of the products sold in Galerías/Mercados come from smallholder producers, and consumers buy them indirectly without knowing the origin. This results from their lower price, their regional relevance (relatedness), and the fact that they are sometimes the only option for the shop owners.

2.6.2 The importance of networking for smallholder swine and chicken producers in Colombia: A Social Network Analysis

Highlight

- The study shows that social networking helps smallholder producers in obtaining credits and trainings. Therefore, social behavior seems to be essential for development.

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Rationale and background

Social networks are an important strategy in helping people to cope with challenging conditions such as a lack of basic services or inputs. The worse the conditions and the poorer the people, the more they will protect themselves by forming social networks. In many cases, social networks replace formal service and input providers relying on the delivery of informal financial services, extension and problem solving assistance. Smallholder swine and chicken producers in Colombia are facing difficult production and market conditions. For example, the limited access to credit and extension or the availability of affordable feeds are major constraints.

Objectives

- To show the monogastric production network with a focus on the smallholder produers
- To present individual monogastric production networks by describing exemplary villages
- To analyze and evaluate the impact of social networks on the monogastric production of smallholder producers in the Popayán Region
- To identify gender roles in the production activities and network
- To identify the most important actors for the social network and the reasons for their importance

Material and Methods

In March and April 2010, a Social Network Analysis (SNA) for smallholder monogastric production (swine and chicken) was conducted using a semi-quantitative survey. The research area was the Popayán Region in Cauca, Colombia.

The main objective was to get an overview on the social network in the swine and chicken production of the region and to analyze how networking affects the access to formal and informal credits and services, respectively. Students from the Universidad del Cauca in Popayán were trained and assisted in the surveys. Moreover, two M.Sc. students from the University of Hohenheim contributed to the research and used this data as main input for their theses.

Results

General sample information

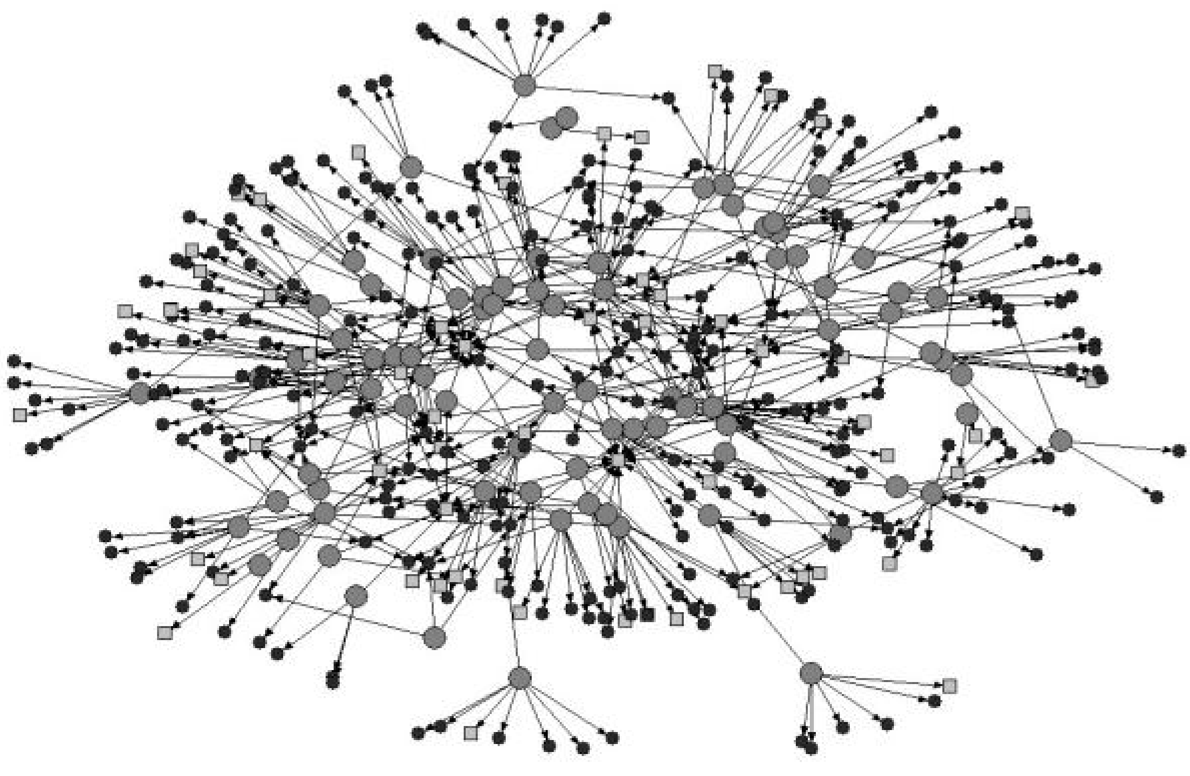
The 84 interviewed smallholder producers are on average 46.8 years old and the gender ratio is 60% male to 40% female. Not all interviewees produce either swine or chicken, some of them produce both. Of the focus group 83% hold swine (32.4 animals on average per household) and 50% chicken (56.3 animals on average per household). The gender ratio of the swine producers is 66% male to 34% female and of the chicken producers 53% male to 47% female. On the question if they could produce more 73% of the producers answered yes, 27% no. Their reasons for not producing more are lack of money (54%), lack of space (18%), lack of clients (13%), missing resources (5%), lack of infrastructure (5%) and limited market access (5%).

Concerning the access to formal credit, 47% of the producers have or had access (in the moment receiving: 32%; already received in the past: 15%), while 53% never received formal credit. 61% of the producers already applied for credits, 39% never did. Producers named two main reasons for not applying for formal credit: either they are afraid of the constraints/conditions like e.g., fear of having debts/losing property (53%), or they do not need credit (47%). Of the 61% who applied for a formal credit, 22% were rejected. Reasons for rejection were the lack of necessary documents (56%) and the unavailability of credit in general (no more funds, 11%). 33% do not know the reasons for rejection. Of the producers, 48% already used informal sources for lending money (e.g., family members, neighbors, and friends). The two most important credit institutions for the producers in Colombia are Banco Agrario and Fundación Mundo Mujer. Informal credits were mentioned as an important way of access to money. 48% of the producers already received types of informal credit. Major informal money sources are family members, neighbors, and friends.

With regard to training and extension, 45% of the interviewed smallholder producers had received formal training (held by a Non-Governmental Organization (NGO), a Governmental Organization (GO), or by a feed supplier), while 55% did not. 58% of the interviewees would like to receive training in the future, 18% do not need training and 24% did not answer. Training is needed on proper feeding of the animals (26%), farm management (23%), animal health (14%), animal breeding (13%), animal management/production (11%), new technologies (4%) and the use of animal products as fertilizer (1%). In terms of gender labor division, women are more likely to do household activities (e.g., cooking, cleaning) and to help in basic agricultural activities (e.g., taking care of the chicken, assistance in pig feeding). In general their activities do not require much physical strength. Men, on the other hand, are in most cases the farm managers who are responsible for all activities related to animal production, especially if they require physical strength (e.g., swine castration, slaughtering, animal feeding) and if the animal is big (e.g., swine, cattle). Moreover, they are also dominating the external activities (e.g., commercialization of the animals, purchasing inputs). Generally it can be stated that chicken production is more a female task whereas swine production is usually dominated by male actors.
This basic information shows that the most limiting factors for the smallholder swine and chicken producers are the access to credit and training. Both factors are prerequisites to producing a higher quantity and quality of livestock products and linking to more developed markets.

Social Network information

The social network of the focus group shows the connections of the interviewed smallholder producers to the institutions, family members, friends and neighbors they use for obtaining formal/informal credit and extension/training (Figure 45). In general, the network displays 397 nodes (actors) and 552 ties (relations). The density is 0.35% which means a low connectivity within the network. The low connectivity results of the fact that the region of Popayán is composed of sub-regions (e.g., Silvia, Piendamó, Timbío). People from one sub-region are not highly connected to people from other sub-regions, but they have contacts to people from their own region or to institutions in Popayán (99%). Another reason is that one actor might ask his contact for different types of information (e.g., credit and animal health). The social Network has a centralization index of 0.02%, which indicates that it is not star shaped, where one actor plays an important role in the network. Actors do not need to pass through the central player in order to get to other actors. The average out-degree of the interviewed smallholder producers was 6.49, which means that each interviewed producer has on average 6.49 relations to formal/informal contacts. 83.5% of the producers have at least one direct connection to a formal institution (e.g., bank, NGO, GO, feed supplier) and 99% of the producers are indirectly connected (via e.g., veterinarians). All producers have various connections to non-institutional informal contacts (e.g., family members, neighbors, or friends). Though the different sub-regions of the research region are not highly connected amongst each other, all of them besides one (Morales) are connected to Popayán. The connections of the sub-regions to the center Popayán can be explained by the relations people have with formal institutions in Popayán. Informal contacts are mostly within a sub-region and only in few cases with another sub-region (Figure 46).



Captions: big circle = interviewed smallholder producer; small circle = non-informal contact (e.g., family member, neighbor, friend); square = formal institution (e.g., bank, NGO, GO, veterinarian, feed supplier)

Figure 45. The social network for credit and training/extension of smallholder swine and chicken producers in the Popayán Region, Colombia

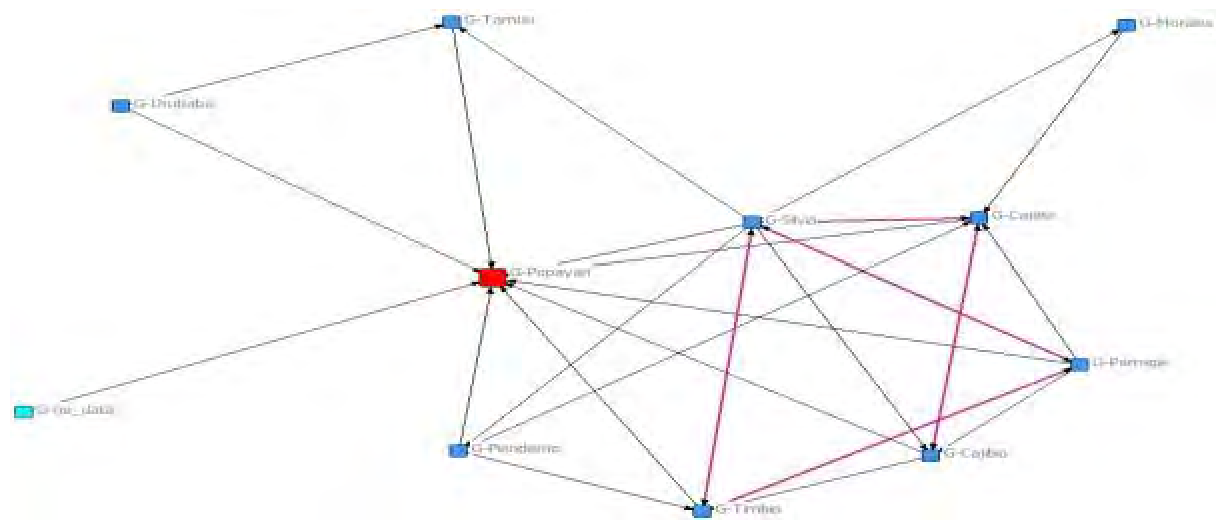


Figure 46. The connection amongst sub-regions and of sub-regions with the network center Popayán

By having a closer look on the particular social networks for each sub-region, important network actors could be detected. For smallholder producers the most important actor groups in the sub-regions (who are at the same time the most important actors for the whole network) are institutions (e.g., banks, GOs), suppliers, women, and neighbors/friends/family members. Institutions give formal credits and trainings to the smallholder producers and are linking the actors together. In some regions the exclusion of institutions would mean the absence of the network. Nevertheless, institutions do not automatically connect the actors directly to each other. But indirectly they help to transmit/share information between the actors. They can be described as network bridges which enhance the network connectivity and enrich the information flow. On the other hand, smallholder producers who made experiences with institutions have more information to share with family members, friends, or neighbors (e.g., on credit experiences, technical assistance experiences). Suppliers (e.g., feed suppliers, veterinarians) are an important group of network actors as all producers have to get their inputs from somebody. Like the institutions, they enrich the information flow and serve as network bridges. Moreover, they offer technical support. Women play an important network role as they are important connection actors in the network. They generally show a higher out-degree than men what means that they are more social than men and therefore have advantages in coping with certain problems (e.g., lack of money, inputs) as they have more options for problem-solving assistance. Friends, neighbors, and family members are of importance for the social network as they are the first contact persons in case of urgent affairs (e.g., lack of money, technical assistance). The reasons for this are e.g.: money can be made available much faster; normally lending money from these persons does not involve interest rates; technical support is available much faster; technical support normally does not involve costs.

To evaluate the influence social networking has on the access to credit and training/extension, important network measures were tested through correlation with the information interviewees gave on credit and training/extension. Important network measures are out-degree (an actors' sum of outgoing ties to other actors in the network), in-degree (an actors' sum of incoming ties from other actors in the network), and betweenness (centrality index). There were no correlations found for betweenness and in-degree. Out-degree correlates with "formal credit received" (0.01 (2-sided) significant) which means that smallholder producers with a higher network activity are more likely to receive credit by a formal institution (e.g., bank, micro-credit institution) than smallholder producers with a lower network activity. There was also a correlation between out-degree and "applied for formal credit" (0.01 (2-sided) significant) which connotes that smallholder producers with a higher network activity are more likely to apply for credit in a formal institution than smallholder producers with a lower network activity. Furthermore, out-degree correlates with “informal credit received” (0.05 (2-sided) significant) which implies that smallholder producers with a higher network activity are more likely to receive informal credit (e.g. from family members, neighbors, friends) than smallholder producers with a lower network activity. Concerning training there exists a correlation between out-degree and “training/extension received” (0.01 (2-sided) significant) which denotes that smallholder producers with a higher network activity are more likely to receive training/extension held by formal institutions (e.g., NGO, GO, feed supplier) than smallholder producers with a lower network activity.

Conclusions

Credit and extension are two main constraints for smallholder producers in the research region and for smallholder producers in general. In order to improve livestock production (the quantity as well as the quality) and to reach more developed markets, credit and extension are necessary inputs for smallholder producers. The results show that the more “social” smallholder producers act, the easier it is for them to get in contact with formal institutions. With more formal/informal contacts, they receive more information on where to apply for a formal credit or where to get training/extension and have more contacts to receive informal credit. Network connectivity also helps smallholders to fulfill the requirements of institutions. As confirmed in the literature, social networks are an important strategy to challenge difficult conditions and serve as providers for informal financial services or problem solving assistance. But social networks not only provide informal services; social networking also simplifies smallholder access to formal credit or extension – two of the most important inputs for development. Higher network connectivity within the sub-regions, amongst sub-regions and between sub-regions and the center of a network could further facilitate this access and help developing the smallholder agriculture. Institutions (e.g., banks, microfinance, GOs, NGOs), suppliers (for feed, veterinary inputs), family/neighbors/friends, and women play important roles in the smallholder producers’ networks.

2.6.3 The value chains for pork and chicken in Colombia and Nicaragua: a graphical illustration

Highlight

- The study shows that the city market in both countries is mostly limited for smallholder pig products due to high quality standards, high quantities needed, and low infrastructure. Thus, smallholder producers mainly sell their pork products on local markets where quality standards are lower, less quantities are needed, and where accessibility is possible. Smallholder chicken production does not play an important role overall as it is mostly used for home consumption or for sales to neighbors/familiy members.

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Rationale and background
A value chain is an economic system, which can be described in two ways. First, it is a progression of coactive business activities (functions) from the supply of particular inputs for a specific product to primary production, transformation, marketing, and up to the final sale of the particular product to consumers (the functional view on a value chain), and second the set of enterprises (operators) performing these functions i.e., producers, processors, traders and distributors of a particular product.

Enterprises are linked by a series of business transactions in which the product is passed on from primary producers to end consumers. According to the sequence of functions and operators, value chains consist of a series of chain links (or stages).

To analyze this economic system and to get a deeper insight, a value chain mapping has to be done. This value chain mapping consists of three steps. Step one is a general value chain mapping (visual representation of the value chain). Step two is the quantification and the description of the value chain in a detailed way (e.g., production facts, costs, political/institutional framework). Step three is analyzing the value chain in an economic way for benchmarking with other countries or similar industries.

Objectives

- To get a graphical description of the pork and chicken value chains in Colombia and Nicaragua (step one of the value chain analysis for both countries)
- To see the relevance of smallholder producers in these value chains

Material and Methods

The data for this study was gathered by using semi-quantitive questionnaires for the stakeholders of the value chains for pork and chicken in Colombia and Nicaragua. These stakeholders were: feed industries, feed/veterinary suppliers, producers, slaughterhouses, meat suppliers (restaurants, Galerías/Mercados, Tiendas/Pulperías, supermarkets, informal butcheries), consumers, banks, microfinance institutions, Governmental Organizations (GOs), and Non-Governmental Organizations (NGOs). Objective of the study was to get an insight in these value chains regarding especially the smallholder producers. This means, that the study shows the linkages between the different stakeholders in the value chains in a graphical way. The research was conducted in Colombia (April 2010) and Nicaragua (July 2010). In Colombia, the research area was Popayán and its surrounding villages; in Nicaragua research took place in Chinandega and its surrounding villages. Students from the Universidad del Cauca in Popayán (Colombia) and from the Universidad Nacional Agraria in Managua (Nicaragua) were trained and asssisted in the surveys. Moreover, two M.Sc. students from the University of Hohenheim contibuted to the research. Furthermore, secondary information from the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) was used.

Results

The results of this study are graphical illustrations of the different value chains for pork and chicken in Colombia and Nicaragua. These value chains are:

- The value chain of pork for city consumption
- The value chain of pork for rural consumption
- The value chain of chicken

Figure 47 describes the pork value chain for the city market in Colombia. A smallholder pig producer works with five main inputs: Feed, veterinary inputs, extension, financial inputs, and piglets. The feed a smallholder pig producer currently uses in most cases is concenrate from feed suppliers. The feed suppliers get the concentrates directly from the feed producers (large industries). Other important feed sources for the smallholder producers are private feed sellers (e.g., neighbors who sell peanuts, other legumes, or maize), the own production of feed (e.g., maize, legumes), or the use of farm/household waste to feed the animals. Piglets are either bought from neighbors/friends, from professional piglet producers, or come from on-farm reproduction. Veterinary inputs consist mainly of vaccinations and medicine. These inputs are purchased either in the stores of the feed suppliers or directly from the veterinarian. The veterinarian moreover assists the smallholder producers with medical services and also offers extension. Additional extension is provided by feed suppliers, GOs, NGOs, and private sources (e.g., neighbors, family members). Financial inputs are given in form of formal and informal credits. Formal credits are given by banks and microfinance institutions. Nevertheless, microfinance institutions were hardly available in the Colombian research area. Informal credits are given by e.g., family members or neighbors. Large parts of the pigs produced by smallholder producers are being held in/around the houses and not in studs. If studs are being used, the construction inputs mainly come from the own farm. Employees are almost never used in smallholder pig production as they are considered cost intensive. Instead, family members are being appointed to do the daily work. The smallholder pig producer has five different distribution channels concerning the city market: direct distribution to city consumers, direct distribution to restaurants, direct distribution to galerías (central market places), direct distribution to informal butcheries, and indirect distribution to galerías and restaurants via municipal slaughterhouses. Nevertheless, smallholder production only contributes to a small part of the city market for pork. Supermarkets, galerías, and restaurants usually purchase the meat from large pork distributors (industrial production). The city market for pork therefore seems to be very limited for smallholder producers which is a result of a lack of quality, small quantities, and very often long distances to the city (cost-intensive, bad infrastructure).

Figure 48 describes the pork value chain for the rural market in Colombia. The description of the input sources is equivalent to the description of the input sources for the city market. Concerning the distribution channels, the rural market offers four different possibilities: direct distribution to rural consumers, direct distribution to rural restaurants, direct distribution to rural galerías, and direct distribution to clandestine butcheries. Parts of the meat sold by rural galerías are purchased from large pork distributors (industrial production). The rural market is currently the major market for smallholder pig products as quality standards are lower, distances are nearer, and smaller quantities are required. Figure 49 describes the chicken market for the research region in Colombia. A smallholder chicken producer works with five main inputs: Feed, veterinary inputs, extension, financial inputs, and chicks. The feed a smallholder chicken producer uses comes in large parts from feed suppliers and is concentrate. The feed suppliers get the concentrates directly from the feed producers (large industries). Other important feed sources for the smallholder producers are private feed sellers (e.g., neighbors who sell maize), the own production of feed (e.g., maize), or the use of farm/household waste to feed the animals. Chicks are usually bought in the stores of the feed suppliers. Veterinary inputs consist mainly of vaccinations and medicine.

These inputs are purchased either in the stores of the feed suppliers or directly from the veterinarian. The veterinarian moreover assists the smallholder producers with medical services and also offers extension. Additional extension is provided by feed suppliers, GOs, NGOs, and private sources (e.g., neighbors, family members). Financial inputs are given in form of formal and informal credits. Formal credits are given by banks and microfinance institutions. Nevertheless, microfinance institutions were hardly available in the Colombian research area. Informal credits are given by e.g., family memebers or neighbors. Large parts of the chicken produced by smallholder producers are being held in/around the houses and not in studs. If studs are being used, the construction inputs mainly come from the own farm. Employees are almost never used in the smallholder chicken production as they are cost intensive. Instead, family members are being appointed to do the daily work. The smallholder chicken production happens on a very low level which means that low quantities are produced in private households and eaten by the family or sold to neighbors. Chicken produced by smallholder producers are usually not sold in professional markets. The chicken sold in galerías, restaurants, supermarkets, and tiendas (small shops) come from vertically oriented industrial chicken producers. Supermarkets usually are located in the cities and not in rural areas.

Figure 50 describes the pork value chain for the city market in Nicaragua. A smallholder pig producer works with five main inputs: Feed, veterinary inputs, extension, financial inputs, and piglets. The input sources are of equivalent origin as in Colombia. The smallholder pig producer has five different distribution channels concerning the city market: direct distribution to city consumers, direct distribution to restaurants, direct distribution to Mercados (central market places), direct distribution to informal butcheries, and indirect distribution to Galerías and restaurants via municipal slaughterhouses. As difference to Colombia, smallholder producers contribute a larger part to the city market in Nicaragua whereas pork distributors contribute a smaller part. Especially the pork sold in Mercados is more often of smallholder origin than in Colombia and moreover, clandestine slaughtering plays a larger role as in Colombia. Supermarkets usually purchase the meat from large pork distributors (industrial production). The city market for pork seems to be partly limited (supermarkets) for smallholder producers which is a result of a lack of quality, small quantities, and very often long distances to the city (cost-intensive, bad infrastructure).

Figure 51 describes the pork value chain for the rural market in Nicaragua. The description of the input sources is equivalent to the description of the input sources for the city market. Concerning the distribution channels, the rural market offers four different possibilities: direct distribution to rural consumers, direct distribution to rural restaurants, direct distribution to rural mercados, and direct distribution to informal butcheries. Informal slaughtering plays a major role. Different from Colombian rural areas is the existence of supermarkets in rural areas in Nicaragua. As in the city market too, the supermarkets in rural areas usually buy their meat from large pork distributors (industrial production). The rural market is currently the major market for smallholder pig products as quality standards are lower, distances are nearer, and smaller quantities are needed.

Figure 52 describes the chicken market for the research region in Nicaragua. A smallholder chicken producer works with five main inputs: Feed, veterinary inputs, extension, financial inputs, and chicks. The feed a smallholder chicken producer uses comes in large parts from feed suppliers and is concentrate. The feed suppliers get the concentrates directly from the feed producers (large industries). Other important feed sources for the smallholder producers are private feed sellers (e.g., neighbors who sell maize), the own production of feed (e.g., maize), or the use of farm/household waste to feed the animals. Chicks are usually bought in the stores of the feed suppliers. Veterinary inputs consist mainly of vaccinations and medicine. These inputs are purchased either in the stores of the feed suppliers or directly from the veterinarian. The veterinarian moreover assists the smallholder producers with medical services and also offers extension. Additional extension is provided by feed suppliers, GOs, NGOs, and private sources (e.g., neighbors, family members). Financial inputs are given in form of formal and informal credits. Formal credits are given by banks and microfinance institutions. Microfinance was more available in the Nicaraguan research area. Informal credits are given by e.g., family memebers or neighbors. Large parts of the chicken produced by smallholder producers are being held in/around the houses and not in studs. If studs are being used, the construction inputs mainly come from the own farm. Employees are almost never used in the smallholder chicken production as they are cost intensive. Instead, family members are being appointed to do the daily work. The smallholder chicken production happens on a very low level which means that low quantities are produced in private households and eaten by the family or sold to neighbors. Chicken produced by smallholder producers are usually not sold in professional markets. The chicken sold in galerías, restaurants, supermarkets, and pulperías (small shops) come from vertically oriented industrial chicken producers. Different from Colombia is the availability of chicken in supermarkets in rural areas. All scenarios are described from a general view on the smallholder producers business. This means, that the situation for a single smallholder producer might differ from this general view.

Figure 47. Pork value chain in Colombia, focus on smallholder producers in general, city market overview.

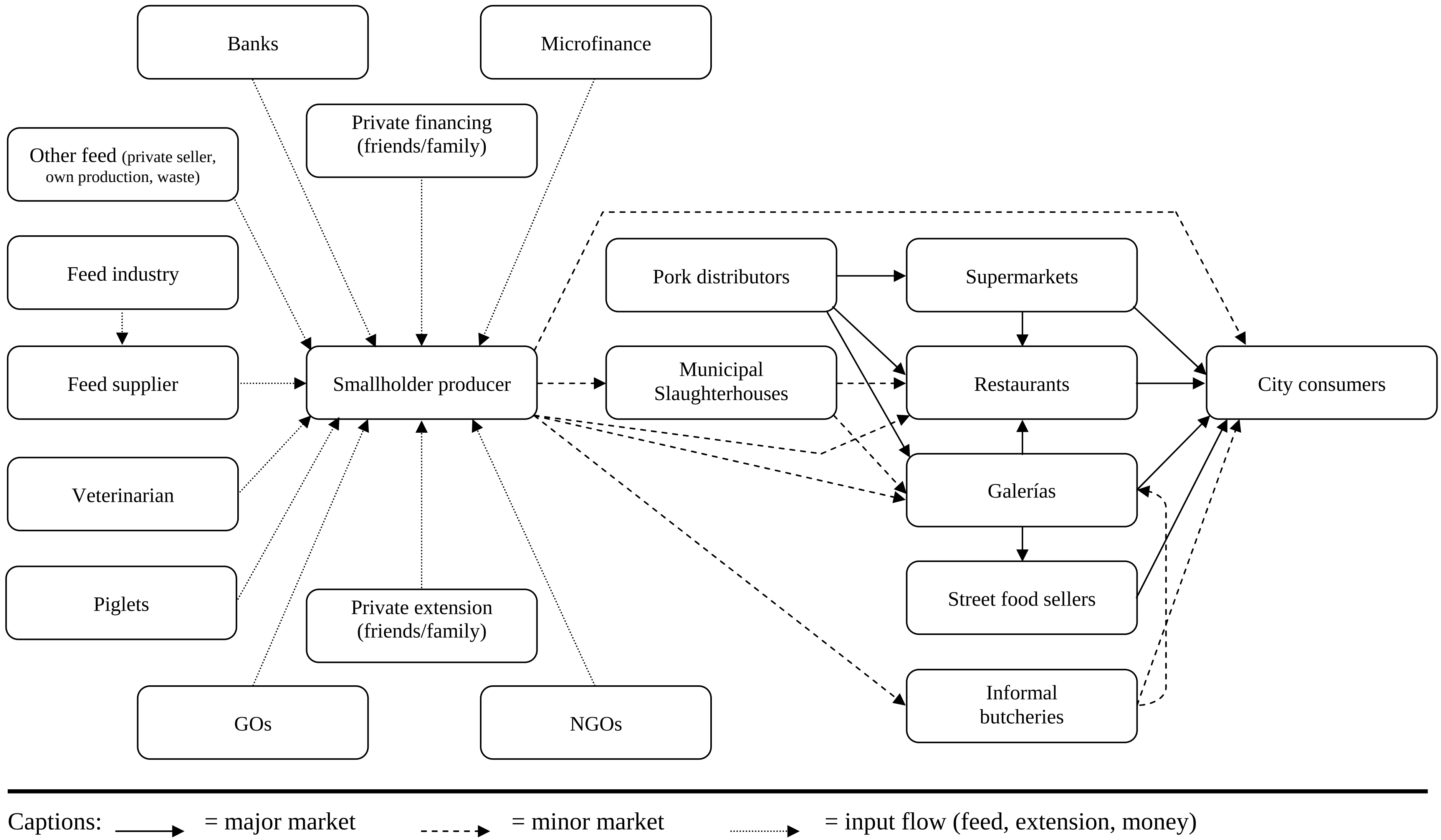


Figure 48. Pork value chain in Colombia, focus on smallholder producers in general, rural market overview.

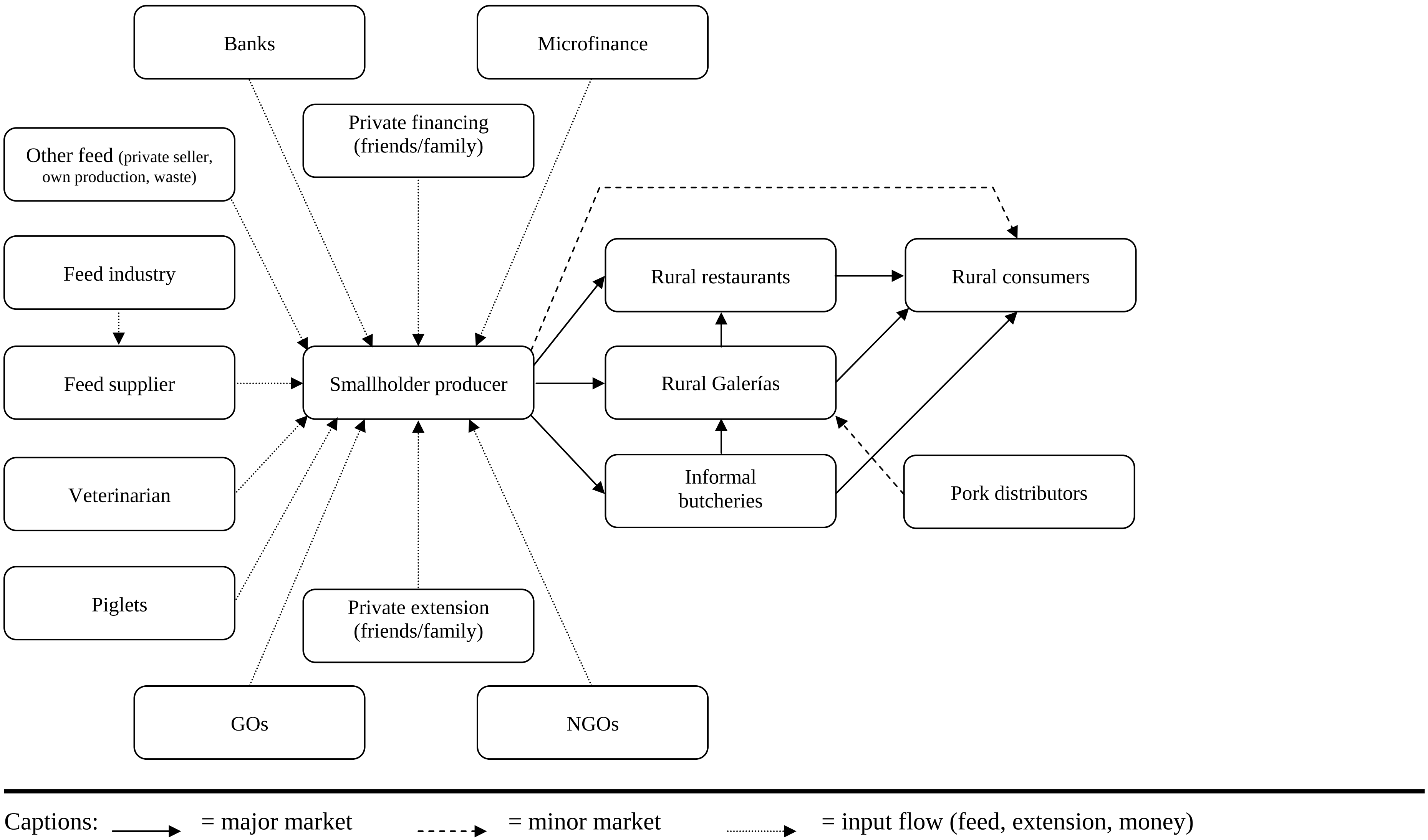


Figure 49. Chicken value chain in Colombia, focus on smallholder producers in general.

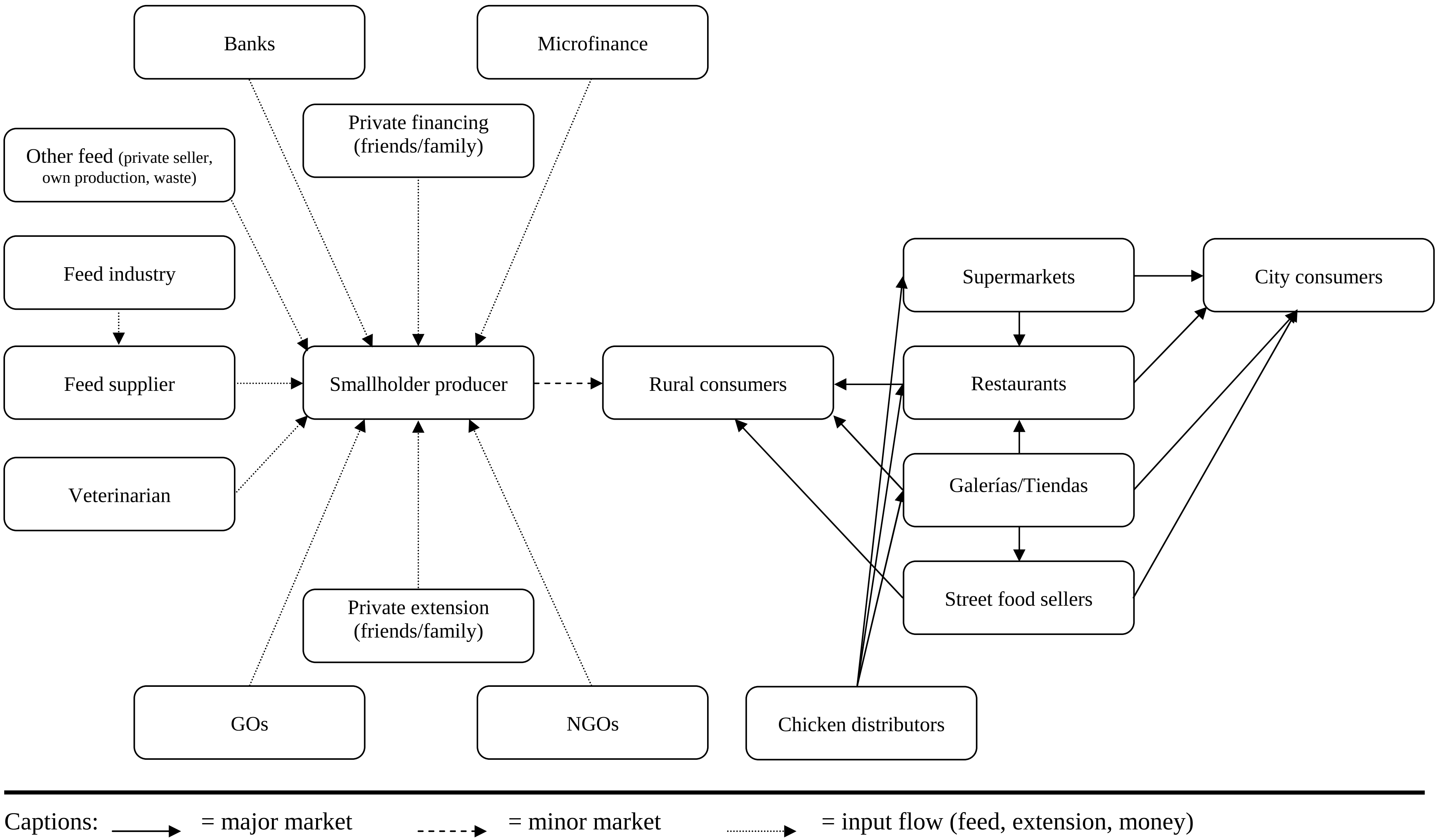
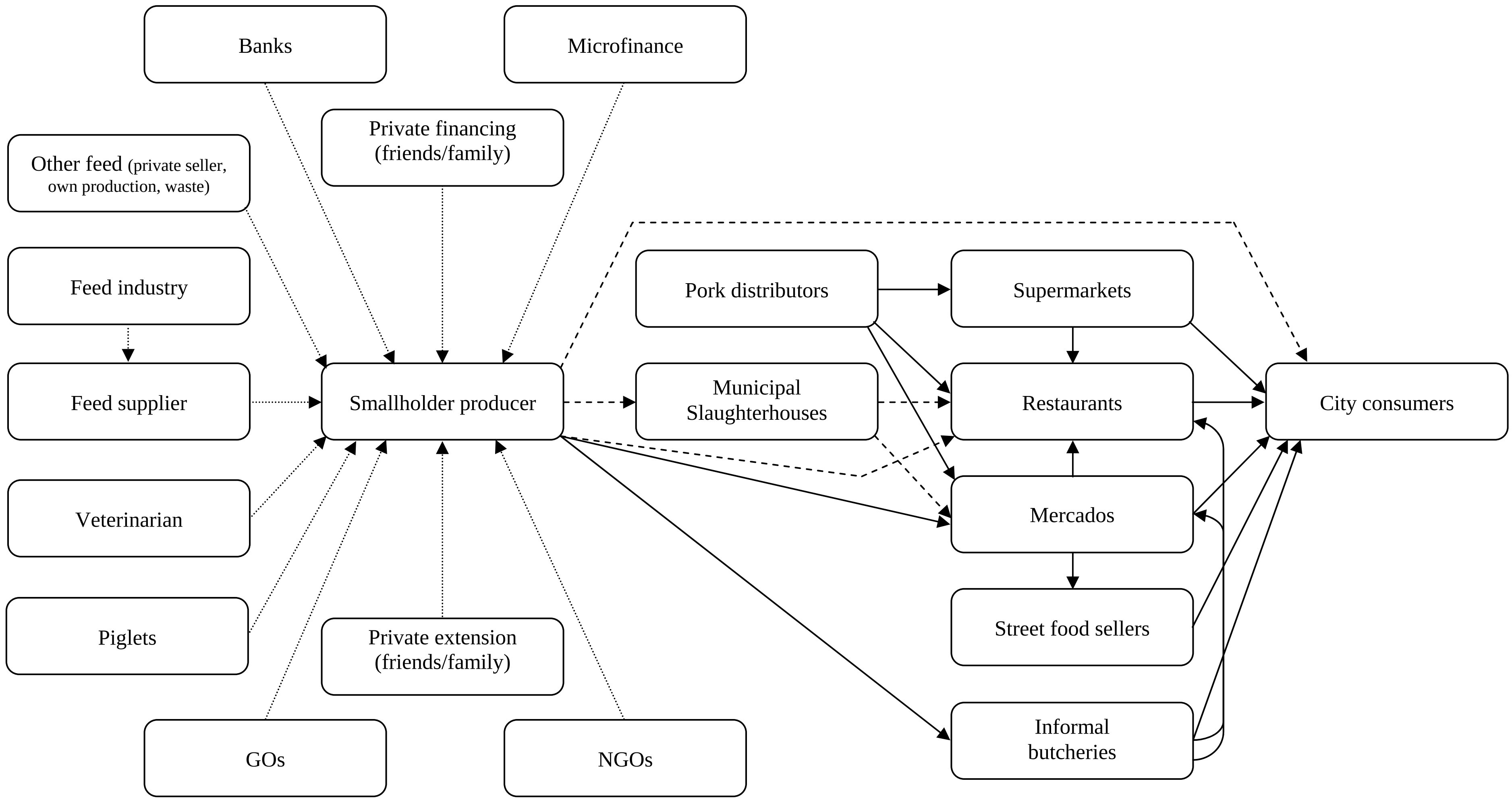


Figure 50. Pork value chain in Nicaragua, focus on smallholder producers in general, city market overview.



Captions: = major market = minor market = input flow (feed, extension, money)

Figure 51. Pork value chain in Nicaragua, focus on smallholder producers in general, rural market overview

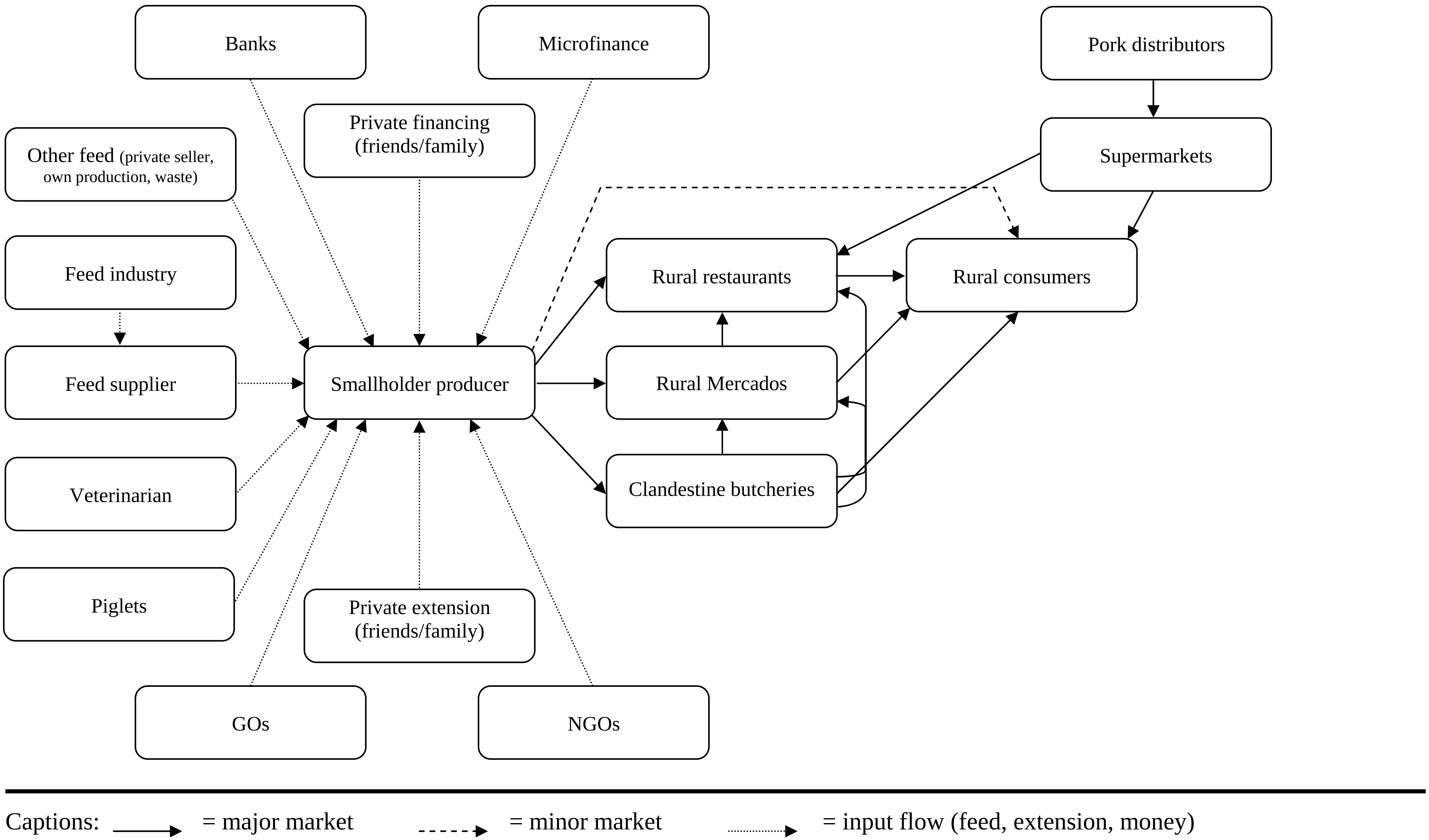
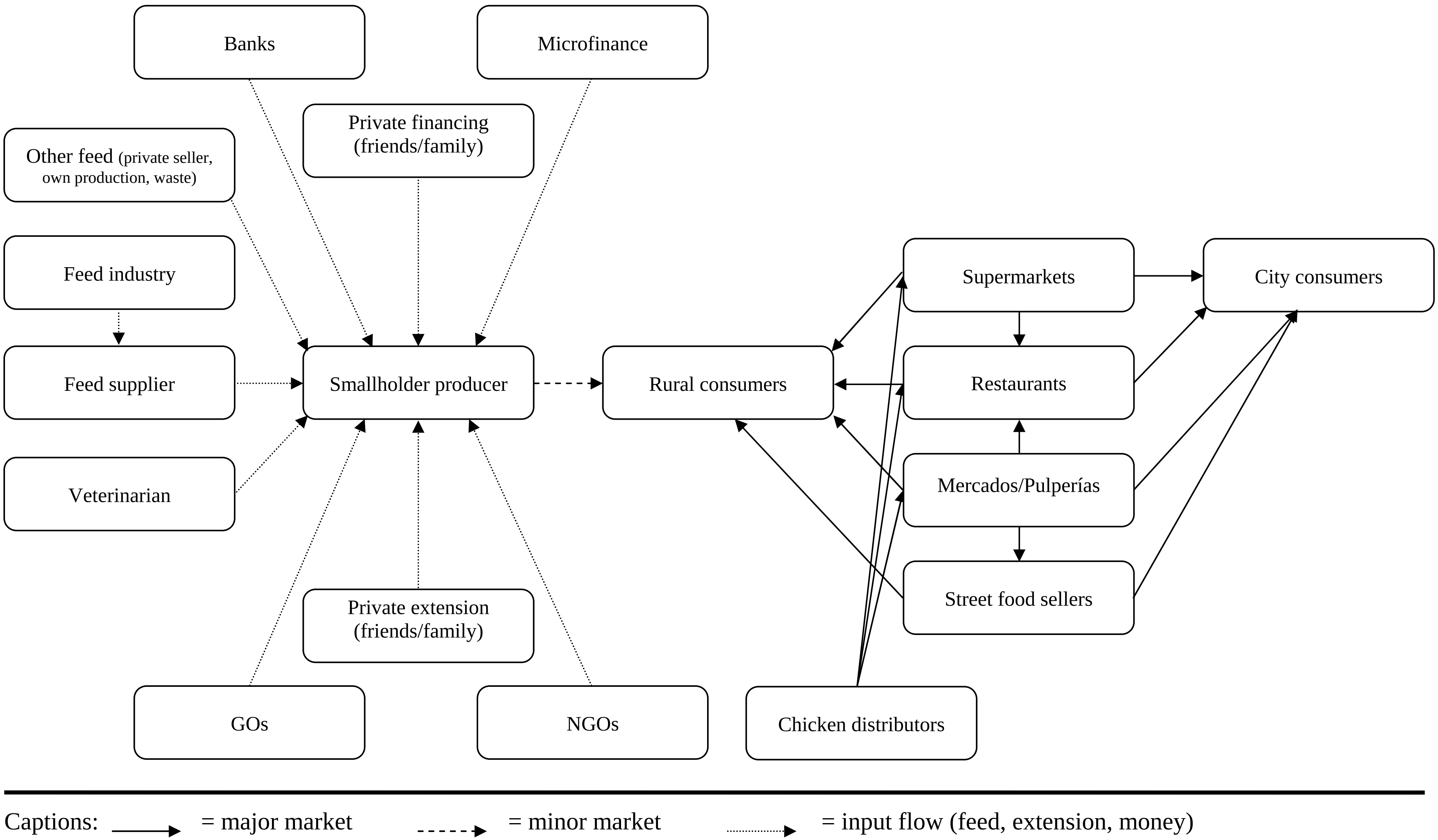


Figure 52. Chicken value chain in Nicaragua, focus on smallholder producers in general



Conclusions

The city market for pork in Colombia seems to be limited for smallholder pig producers. On a very small scale smallholders sell pigs to restaurants, Galerías, informal butcheries, or private consumers. Mostly they know their customers since many years (trust), are friends with them, or are related to them. The distribution channel "supermarket" is closed for smallholder producers. The small share in the city market is mainly caused by the lower quality of their pigs (no quality control, no feeding strategies, no management), the lower quantity (not suficcient for e.g., supermarkets), their remoteness (far away from the cities, bad infrastructure), and the missing trust of the city market in smallholder production. Very large parts of the city market are covered by large scale, industrially organized producers. Most pigs produced by smallholder producers in Colombia are sold on the rural market. Quality standards there are lower, the control system is weaker, quantities sold are lower, the producers live closer to the markets, and they are better known amongst their customers (trust). Nevertheless, even in rural areas, many distributors (e.g., restaurants, Galerías) have changed their suppliers from smallholder producers to large scale industrially organized producers. The chicken market in Colombia is in very large parts covered by large scale, vertically oriented, industrially organized chicken producers which fulfill all quality standards required by the government and the consumers. Chicken produced by smallholder producers do not play an important role. They are used for home consumption or as additional family income if they are sold amongst neighbors or friends.

In Nicaragua, the city market for pigs is also limited for smallholder pig producers. Nevertheless their share is higher as informal slaughtering plays a more important role and pork sold in Mercados very often comes from smallholder producers. The reasons for the limited access to city markets are equivalent to the ones in Colombia. Most of the pigs produced by smallholder producers are sold on the rural market, where clandestine slaughtering plays even a larger role as in the city market. Nevertheless, the share of smallholder produced pork in rural markets is, compared to Colombian rural markets, smaller. This results from the availability of supermarkets in rural areas which connote a large part of the rural pork sales. The chicken market in Nicaragua is similarily organized to the one in Colombia and therefore very limited for smallholder producers.

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

Contributors: Chavarría, E.; van der Hoek, R. (CIAT); Benavidez, A. (INTA-Nicaragua)

Rationale

In the hillsides of Central-America, intensification of land use results in soil nutrient depletion is leading to a decline in agricultural productivity. Moreover, the main crops maize and beans can only be grown during two short successive rainy seasons, and livestock suffers forage shortage during the long dry season of 5 to 6 months. Milk production during the dry season is lower due to reduced quantity and quality of native pastures and crop residues. Most affected by the declined soil fertility are resource-poor smallholders, due to their marginalized situation to overcome production constraints.

The low agricultural production does not allow for a substantial income from the sale of the products. Sufficient amounts of mineral fertilizers are not affordable. In these conditions the introduction of cover crop legumes can be beneficial due to their ability to add nitrogen via symbiotic nitrogen fixation, to provide surface mulch during the dry season or to provide fodder to livestock. In a joint project by ETH-Zürich, INTA-Nicaragua and CIAT, *Canavalia brasiliensis* CIAT 17009, a highly drought adapted cover crop legume (stays green during 5 months of dry season), native from Latin America, was introduced to overcome soil fertility decline and increase feed availability, adding 20-50 kg of nitrogen per hectare or augmenting milk production by 1 kg per animal in the dry season. This section describes, as a spin-off of this project, the evaluation of other accessions of *Canavalia brasiliensis* and *Canavalia* sp.

Evaluation of accessions of Canavalia

Fertilizer value

As the second part of the trial in 2009 (see corresponding annual report), the fertilizer value was evaluated of 12 accessions of *Canavalia brasiliensis* and *Canavalia* sp. The trial consisted of three replicates of 3x3 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, cut at flowering stage and incorporated in the soil
- 5 fertilizer levels (without canavalia), of 0, 40, 80, 120 and 160 kg/ha (urea)

Figure 53 shows the effect of the different treatments on maize yield. In general, application of fertilizer resulted into significantly higher yields ($p<0.05$, Duncan) than many Canavalia accessions. Within these, no significant differences were found, likely due to high variability and low maize yields due to drought.

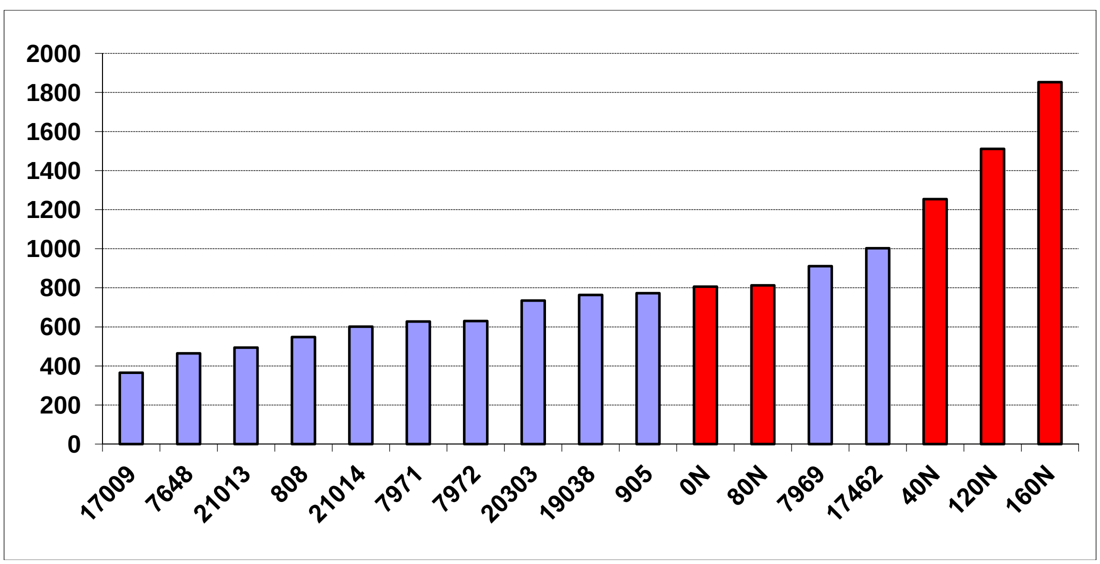


Figure 53. Effect of different Canavalia accessions (blue) and N-levels (red) on maize yield (kg/ha)

Agronomic performance
As a follow-up of a similar trial in 2009/2010 with 12 accessions, a repetition was established at the same plots at the San Dionisio site, Matagalpa, with the best eight accessions of 2009 (including the "control" CIAT 17009 used in this project) to evaluate again agronomic characteristics and fertilizer value (effect on subsequent maize production). The trial consists of three replicates of 3x3 m plots with the following treatments:

- 8 accessions - *Canavalia brasiliensis* CIAT 17009 (control), CIAT 17462, CIAT 19038, CIAT 7648, CIAT 7969, CIAT 7971, CIAT 7972, CIAT 905
- 5 fertilizer levels (without canavalia), of 0, 40, 80, 120 and 160 kg/ha (urea)

Results and discussion

The accessions CIAT 7948, 7969, 7972 and 905 show highest soil cover and biomass production and the control *Canavalia brasiliensis* CIAT 17009 is performing relatively poor (Figures 54 and 55). Due to drought, yields were considerably lower than in 2009.

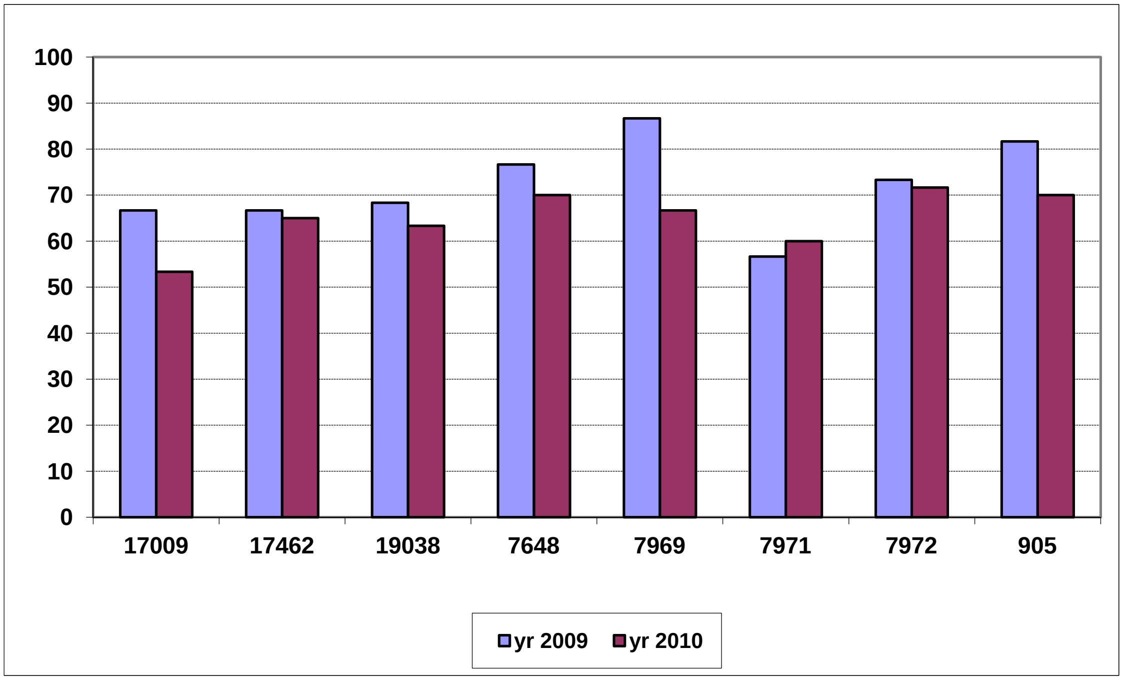


Figure 54. Soil cover (%) of different accessions of *Canavalia brasiliensis* in 2009 and 2010

In each plot, the four corner plants were left for seed production, the accessions 17462, 905 and 7969 producing higher quantities (up to 1 t/ha) than the others.

Outlook in 2011: 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, at three sites the most promising accessions will be planted in larger areas for further green manure and feeding trials.

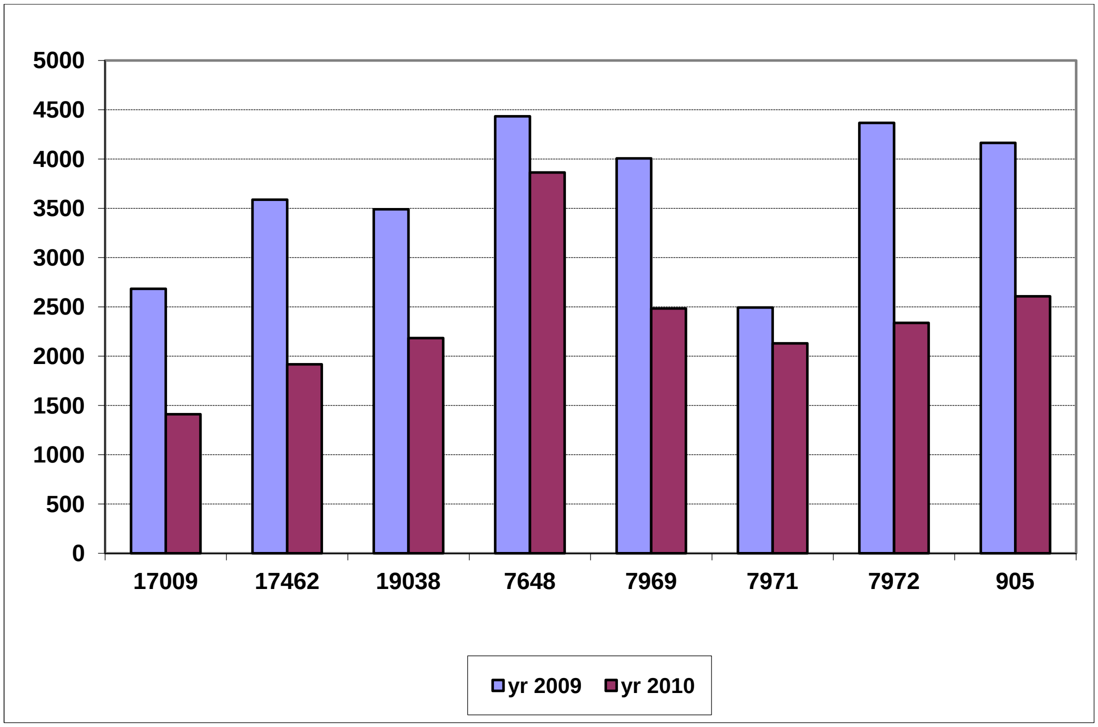


Figure 55. Dry Matter biomass production (kg/ha) of different accessions of *Canavalia brasiliensis* in 2009 and 2010

2.8 Routine multiplication and distribution of forage seeds, by request

Highlight

- A total of nearly four tons of seed was produced in 2010 (Table 82). Of this total, nearly 90% is accounted for by seed of cowpea (89%). Seed of 78 different accessions of eleven distinct tropical forage species was produced.

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

Rationale

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

Materials and Methods

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

Results and Discussion

A total of nearly four tons of seed was produced in 2010 (Table 83). Of this total, nearly 90% is accounted for by seed of cowpea (89%). Seed of 78 accessions of eleven different tropical forage species was produced.

Of the nearly four tons of seed produced, over two tons were distributed during 2010 (Table 84), doubling for the second straight year the volume of the immediately previous year (Ann. Report 2009).

Nearly all (99.7%) of seed distribution during 2010 was within Colombia, with very small amounts being distributed to Lao PDR or to Nicaragua, through CIAT's Asia or Central America Regional Programs, respectively (Table 85).

Table 83. Forage seed produced during 2010, by species

Genus	Species	No. accessions	Seed produced (kg)	% of total
BRACHIARIA	BRIZANTHA	7	62.300	1.58
BRACHIARIA	HUMIDICOLA	11	18.725	0.48
BRACHIARIA	JUBATA	1	1.000	0.03
BRACHIARIA	LACHNANTHA	1	1.000	0.03
BRACHIARIA	RUZIZIENSIS	1	8.500	0.22
CANAVALIA	BRASILIENSIS	8	22.000	0.56
CANAVALIA	SP.	3	9.200	0.23
CENTROSEMA	ACUTIFOLIUM	2	0.500	0.01
CENTROSEMA	BRASILIANUM	5	2.000	0.05
CENTROSEMA	MACROCARPUM	1	3.800	0.10
CENTROSEMA	MOLLE	1	1.400	0.04
CRATYLIA	ARGENTEA	9	122.900	3.13
DENDROLOBIUM	LANCEOLATUM	1	1.000	0.03
DENDROLOBIUM	TRIANGULARE	9	4.000	0.10
DESMODIUM	HETEROCARPON	1	0.250	0.01
DESMODIUM	VELUTINUM	7	5.100	0.13
FLEMINGIA	MACROPHYLLA	2	1.280	0.03
LEUCAENA	DIVERSIFOLIA	2	22.730	0.58
LEUCAENA	LEUCOCEPHALA	2	142.000	3.61
PANICUM	MAXIMUM	1	1.500	0.04
PUERARIA	PHASEOLOIDES	1	0.300	0.01
VIGNA	UNGICULATA	2	3,500.000	89.02
Total: 11	**Total: 22**	**78**	**3,931.485**	**100.00**

Table 84. Distribution of forage seed during 2010, by genus

Genus	No. Samples	Wt. (kg)	% of Total
ARACHIS	1	0.030	0.00
BRACHIARIA	39	153.071	6.98
CALLIANDRA	3	1.060	0.05
CALOPOGONIUM	1	0.100	0.00
CANAVALIA	40	80.280	3.66
CENTROSEMA	17	22.520	1.03
CLITORIA	4	0.150	0.01
CRATYLIA	26	377.160	17.20
DENDROLOBIUM	2	0.050	0.00
DESMODIUM	19	12.287	0.56
FLEMINGIA	5	0.234	0.01
LABLAB	22	207.510	9.46
LEUCAENA	21	44.680	2.04
MUCUNA	5	11.330	0.52
PUERARIA	4	0.240	0.01
STYLOSANTHES	6	0.152	0.01
VIGNA	22	1,282.181	58.47
Total: 17	**237**	**2,193.035**	**100.00**

Table 85. Seed distribution during 2010, by recipient country

Country	No. Samples	Wt. (kg)	% of Total
COLOMBIA	212	2,187.310	99.74
LAO PDR	23	5.685	0.26
NICARAGUA	2	0.040	0.00
Total: 3	**237**	**2193.035**	**100.00**

Forage seed was distributed from the Forage Program's Seed Unit to a diversity of institutions, the bulk (63%) going to users within CIAT (Table 86).

Table 86. Seed distribution during 2010, by type of recipient institution

Type of Institution	No. Samples	Wt. (kg)	% of Total
CGIAR CENTER	82	1,353.537	63.38
COMMERCIAL COMPANY	18	152.450	7.14
FARMER	4	26.500	1.24
GENEBANK	6	5.400	0.25
NATIONAL AGRIC. RESEARCH SER.	1	175.000	8.19
DESTINATION UNKNOWN	3	5.000	0.23
PRIVATE INDIVIDUALS	36	409.000	19.15
REGIONAL ORGANIZATION	4	3.100	0.15
UNIVERSITY	42	5.696	0.27
Total: 9	**196**	**2,135.683**	**100.00**

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

Contributors: Vivas, N.; Morales, S. (U. del Cauca); Peters, M.; Hernández, L.A.; Franco, L.H.; Hincapié, B.; (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* subsp. *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* (cv. Massai).

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 19 and 20).

While establishment of herbaceous species was good, for the shrub *Desmodium velutinum* (six accessions: CIAT 33443, 23982, 23996, 13953, 23981 y 13218, Photo 21) and *Leucaena diversifolia* (nine accessions: CIAT 21242, 17503; ICRAF-45/87/09, ILRI16570, ILRI 15551, ILRI505; K782, K787 and control *L. leucocephala* CIAT 2188, Photo 22 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. Following Tables show the results of the collections of *Canavalia* spp. and *Lablab purpureus.*

Photo 19. Multilocational trial of C*anavalia* 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.

Across sites, highest DM yields were recorded in 'El Limonar', 'Versalles' 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, 17009, 7648, 17462, and 7969, all with more than 2.6 t DM/ha in 8 weeks of regrowth. During the dry period yields were substantially lower; equally soil cover decreased to below 65%, with accession CIAT 21012 most severely affected (Table 87 y 88).

Table 87. Multilocational evaluation of *Canavalia* spp. in Patía, Cauca: Soil cover and DM yield after 8 weeks of regrowth in the wet period. (Mean of three cuts in the wet season)

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	93	2428	67	2148	89	3456
CIAT 17462	92	4134	95	2383	55	1565	88	2773
CIAT 7648	68	3864	97	2718	58	1685	92	3322
CIAT 7971	93	3826	95	2015	59	1842	81	2527
CIAT 17009	90	3737	80	2576	63	2064	89	3294
CIAT 19038	73	3263	70	2146	45	1463	91	3050
CIAT 7969	90	3150	95	2469	54	1948	89	3074
CIAT 21012	60	2136	70	2272	44	1285	63	2521
Mean	83	3669	87	2375	56	1750	85	3002
LSD (P<0.05)	37.73	3603.39	29.74	1029.28	20.00	1073.78	35.96	1656.27

Table 88. Multilocational evaluation of *Canavalia* spp. in Patía, Cauca: Soil cover and DM yield after 8 weeks of regrowth in the dry period (Mean of two cuts in the dry season)

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	68	2630	77	3035	52	1972	48	2280
CIAT 17462	59	2221	72	2765	41	1507	48	2240
CIAT 7969	56	2185	64	2376	46	2098	54	1978
CIAT 905	60	2107	85	3193	54	1676	51	2391
CIAT 17009	61	2013	81	3959	51	1834	58	2516
CIAT 7648	49	1536	70	3231	48	1876	56	1951
CIAT 19038	44	1404	61	2914	44	1383	35	2060
CIAT 21012	36	1326	54	2807	46	1831	32	1511
Mean	54	1928	72	3035	48	1772	48	2116
LSD (P<0.05)	34.77	1258.35	33.78	1464.07	26.97	1187.62	33.93	1306.15

Significant differences between sites were found for DM yields in both the dry ($P < 0.05$) and wet season. Highest yields were recorded at 'Limonar' in the dry and 'La Cocha' and 'Versalles' in the wet season, respectively (Table 89).

Table 89. Multilocational evaluation of *Canavalia* spp. in Patía, Cauca: Plant height, vigor, soil cover and DM yield after 8 weeks of regrowth in the dry and wet period. (Mean of two cuts in the wet and three in the dry season)

Sites	Plant height	Cov	Vigor	Mean DM yield	Plant height	Cov	Vigor	Mean DM yield
	Dry				Wet			
	cm	%	1-5	Kg/ha	cm	%	1-5	Kg/ha
Limonar	45	72	4	3035	38	87	4	2376
Versalles	33	48	3	2116	50	85	5	3002
La Cocha	33	54	3	1928	46	83	4	3669
Porvenir	28	48	4	1772	29	56	4	1750
Mean	35	55	3.5	2213	41	78	4.3	2699
LSD (P<0.05)		30.24		917.23		15.37		958.31

It was observed that *Canavalia* grew best in slightly shaded environments, however with sufficient light not to limit growth.

Lablab

In the multilocational evaluation of *Lablab* (Photo 20), only at 'La Cocha' and 'Limonar' significant (P<0.01) differences between accessions in soil cover were recorded in the wet and dry season, respectively. 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, 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 were high (average 2763 kg DM/ha in 8 weeks). Soil cover at the 'Punto de la I' site was low, however reduction of DM yields was not as drastic as at Porvenir. Accessions CIAT 22604 and 22663 yielded more than 2.9 t/ha in 'La Cocha', 'Limonar' and 'Punto de la I',with substantially lower yield at the other sites (P <0.01). The accessions CIAT 22663, 22598 and 22768 yielded more than 2.1 t/ha of DM in dry season while CIAT 22768, 22663 and 22759 yielded more than 1.6 t/ha of DM in wet season (Tables 90, 91 and 92).

Photo 20. Multilocational trial of de *Lablab purpureus* in the Valle del Patía, Cauca

Table 90. Multilocational evaluation of *Lablab purpureus* in Patía, Cauca: Soil cover and DM yield after 6 weeks of regrowth in the wet season

Accessions	Sites							
	La Cocha*		El Limonar*		Porvenir*		Punto de la i**	
	Cov %	DM Kg/ha	Cov %	DM Kg/ha	Cov %	DM Kg/ha	Cov %	DM Kg/ha
CIAT22768	77	3355	62	1387	12	1292	38	1493
CIAT22663	75	3252	62	973	20	800	28	1631
CIAT22759	87	2984	71	1600	15	680	41	1159
CIAT21603	68	2778	38	680	4	180	18	1305
CIAT22598	38	2353	55	1213	20	653	32	1260
CIAT22604	30	1853	70	1760	18	720	27	954
Mean	63	2763	60	1269	15	757	31	1281
LSD (P<0.05)	11.86	1613.04	30.63	1002.41	22.51	1073.45	71.11	1329.75

***** Mean one cut.
** Mean two cuts.

Table 91. Multilocational evaluation of *Lablab purpureus* in Patía, Cauca: Soil cover and DM yield after 6 weeks of regrowth in the dry season

Accessions	Sites							
	La Cocha*		El Limonar**		Porvenir**		Puntode la i***	
	Cov %	DM Kg/ha	Cov %	DM Kg/ha	Cov %	DM Kg/ha	Cov %	DM Kg/ha
CIAT22604	47	3195	58	2909	15	280	44	2200
CIAT22598	49	2491	38	2849	18	907	55	2473
CIAT22663	47	2365	72	3335	15	340	20	3207
CIAT21603	48	1959	33	1424	8	147	55	2421
CIAT22759	48	1836	85	1992	10	460	60	1802
CIAT22768	33	1604	57	2157	6	253	48	2636
Mean	45	2242	57	2444	12	398	49	2412
LSD (P<0.05)	34.61	2123.55	30.42	4224.55	17.60	901.61	83.65	3338.06

***** Mean three cuts.
** Mean one cut.
*** Mean two cuts.

Table 92. Multilocational evaluation of *Lablab purpureus* in Patía, Cauca: Soil cover and DM yield after 6 weeks of regrowth in the dry and wet period

Sites	Plant height	Cov	Vigor	Mean DM yield	Plant height	Cov	Vigor	Mean DM yield
	Dry				Wet			
	cm	%	1-5	Kg/ha	cm	%	1-5	Kg/ha
Limonar**	76	57	3	2444	53	60	3	1269
Punto de la i***	56	49	3	2412	65	31	3	1281
La Cocha*	61	45	3	2242	80	63	3	2763
Porvenir**	60	12	1	398	41	15	2	757
Mean	63	41	2.5	1909	60	44	2.7	1566
LSD (P<0.05)		10.56		1134.53		8.74		598.47

***** Mean three cuts in the dry season one cut in the wet season.
** Mean one cut in the dry and wet season
*** Mean two cuts in the dry and wet season

Desmodium

Based on a single site evaluation in Santander de Quilichao and field observations six accessions of *Desmodium velutinum* (Photo 21) were selected for a multilocational trial. Plants wer raised in the greenhouse and transplanted to the field 8 weeks after sowing. Establishment in general was slow and required some replanting. No significant (P<0.05) differences between accessions in ease of establishment and 1st year DM yields were detected. Significant (P<0.01) differences, however were found between sites in DM yield, both in the dry and wet season. At 'Versalles' the highest DM yields were measured, with 195 and 115 g/plant DM in the wet and dry season, respectively; accessions CIAT 23982 and 13218 had yields above 230 g/plant DM in the wet season and accessions CIAT 23982, 13218 and 13953 more than 125 g/plant DM in the dry season, respectively (Tables 93, 94 and 95).

Photo 21. Multilocational trial of de *Desmodium velutinum* in Limonar, Valle del Patía, Cauca

Table 93. Multilocational evaluation of *Desmodium velutinum* in Patía, Cauca: Regrowing points and DM yield after 8 weeks of regrowth in the wet period. (Mean of four cut)

Accessions	Versalles		Punto de la i		Limonar	
	Regrowing points	Mean DM yield	Regrowing points	Mean DM yield	Regrowing points	Mean DM yield
	No.	g/pl	No.	g/pl	No.	g/pl
CIAT23982	54	241	39	142	34	20
CIAT13218	48	232	57	120	28	15
CIAT23981	58	197	64	85	48	34
CIAT33443	52	193	55	120	32	25
CIAT13953	54	173	45	85	41	29
CIAT23996	54	163	43	149	35	48
Mean	53	199	52	117	36	28
LSD (P<0.05)		124.20		144.53		30.28

Table 94. Multilocational evaluation of *Desmodium velutinum* in Patía, Cauca: Regrowing points and DM yield after 8 weeks of regrowth in the dry period. (Mean of three cut)

Accessions	Versalles		Punto de la i		Limonar	
	Regrowing points No.	Mean DM yield g/pl	Regrowing points No.	Mean DM yield g/pl	Regrowing points No.	Mean DM yield g/pl
CIAT23982	67	147	39	112	40	20
CIAT13218	50	129	47	132	32	10
CIAT13953	53	127	45	90	39	15
CIAT33443	57	120	45	83	44	10
CIAT23996	63	98	38	58	40	22
CIAT23981	60	78	52	105	51	35
Mean	58	116	44	96	41	19
LSD (P<0.05)		66.41		101.96		40.43

Table 95. Multilocational evaluation of *Desmodium velutinum* in Patía, Cauca: Regrowing points and DM yield after 8 weeks of regrowth in the dry and wet period. (Mean of three cut in dry season and four cut in the wet season)

Sites	Plant height	Regrowing points	Vigor	Mean DM yield	Plant height	Regrowing points	Vigor	Mean DM yield
	Dry				Wet			
	cm	No.	1-5	g/pl	cm	No.	1-5	g/pl
Versalles	64	58	4	116	85	53	3	200
Punto de la i	118	44	4	96	111	52	4	117
Limonar*	50	41	3	19	62	36	3	28
Mean	77	48	3.6	76	86	47	3.3	115
LSD (P<0.05)				29.21				34.93

Leucaena

Of the six sites utilized for a multilocational trial of *Leucaena* spp. (Photo 22), results of only two sites are shown, due to variation in germination across sites and between accessions. Based on data from the two sites, DM yields differed significantly (P<0.05) between accessions, in the dry as in the wet season. At the same time there were significant (P<0.01) differences encountered between sites (Tables 96, 97 and 98).

Table 96. Multilocational evaluation of *Leucaena* spp. in Patía, Cauca: Regrowing points and DM yield after 8 weeks of regrowth in the wet period (Mean two cut in the Argentina and one cut in Sena)

Accessions	Sena		La Argentina	
	Regrowing points	Mean DM yield	Regrowing points	Mean DM yield
	No.	g/pl	No.	g/pl
K782	31	217	18	84
K787	24	199	11	50
ILRI15551	29	152	14	30
CIAT21242	22	136	11	39
ICRAF-45/87/09	20	111	.	.
ILRI505	19	91	13	47
ILRI16507	10	40	12	37
CIAT17503	12	33	14	26
CIAT21888	7	22	6	2
Mean	19	111	12	40
LSD (p<0.05)		122.39		43.21

Accessions K782, K787, ILRI15551 and CIAT 21242 had DM yields above 115 g/plant at the 'El Sena' site in both the wet and dry season, while yields at the 'Argentina' location was lower.

Photo 22. Multilocational trial of de *Leucaena* spp. in The Meseta of Popayán, Cauca

Table 97. Multilocational evaluation of *Leucaena* spp. in Patía, Cauca: Regrowing points and DM yield after 8 weeks of regrowth in the dry period (One cut)

Accessions	Sena		La Argentina	
	Regrowing points	Mean DM yield	Regrowing points	Mean DM yield
	No.	g/pl	No.	g/pl
K782	14	194	26	87
K787	12	155	17	61
ILRI15551	17	195	15	41
CIAT21242	10	116	20	32
ICRAF-45/87/09	7	78	.	.
ILRI505	9	140	15	65
ILRI16507	6	64	18	55
CIAT17503	5	44	13	29
CIAT21888	5	22	8	5
Mean	9	112	17	48
LSD (p<0.05)		94.40		59.43

Table 98. Multilocational evaluation of *Leucaena* spp. in Patía, Cauca: Soil cover and DM yield after 8 weeks of regrowth in the dry and wet period (One cut in the dry and two cut in the wet season in La Argentina and one cut in the dry and wet season in Sena).

Sites	Plant height	Regrowing points	Vigor	Mean DM yield	Plant height	Regrowing points	Vigor	Mean DM yield
	cm	No.	1-5	g/ha	cm	No.	1-5	g/ha
	Dry				Wet			
Sena	150	9	4	112	164	19	4	111
La Argentina	142	17	4	48	132	12	3	40
Mean	146	13	4	82	148	16	3.5	78
LSD (P<0.05)				25.29				55.74

Grass options co-developed with farmers

Smallholder farmers were exposed to a range of grass options in four locations, for selection and adaptation to specific production systems. Establishment of the forage plots was quick in 'El Limonar', 'Versalles' and 'La Cocha'(Photo 23); one location 'Mercaderes' suffered from lack of adaptation of the forage likely mainly due to the high pH of soils and very low rainfall. Results of the multilocational comparison is shown in tables 99 to 102, constraints were the erratic rainfall and entrance of animals in the 'Versalles' site.

Photo 23. Multilocational trial of grasses in El Limonar, Versalles and La Cocha, Valle Del Patía, Cauca.

Significant (P<0.05) yield differences between accessions were found in the dry season at 'Versalles' and in the wet season at 'La Cocha', 'El Limonar' and 'Versalles'; differences in soil cover were significant (P<0.05) only at 'El Limonar' in the wet season. There were significant (P<0.01) differences between sites for DM yield and cover in both the rainy and the wet season, moreover accession*site interactions were found. Accessions *Panicum máximum* CIAT16031, *Pm* cv. Massai, *Pm* CIAT 6962, Brachiaria hybrid Mulato II, and *Brachiaria brizanta* cv. Toledo CIAT 26110 all had yields above 4 t/ha DM in the wet and above 2 t/ha in the dry season, respectively. Good competiveness with weeds and low incidence of pests and diseases were observed.

Table 99. Multilocational evaluation of grasses in Patía, Cauca: Soil cover and DM yield after 8 weeks of regrowth in the wet period (Mean of two cuts)

Accessions	La Cocha		Limonar		Versalles*	
	Cov	Mean DM yield	Cov	Mean DM yield	Cov	Mean DM yield
	%	kg/ha	%	kg/ha	%	kg/ha
*Pm*CIAT16031	75	9684	88	5409	90	6729
Pm cv. Massai	79	6660	97	4719	94	6449
*Bb*CIAT26110	82	4426	93	4087	88	4179
*Pm*CIAT6962	47	4130	85	4529	83	7448
cv. Mulato II	70	3649	92	4499	88	4656
*Bh*CIAT16866	57	2323	56	2444	97	3614
*Bh*CIAT26159	77	2088	90	3183	95	3126
*Bh*CIAT16888	50	1901	53	1978	98	4204
Mean	67	4358	82	3856	92	5051
LSD (P<0.05)	40.70	3743.81	40.66	1798.95	14.50	3049.28

***accidentally grazed by animals

Table 100. Multilocational evaluation of grasses in Patía, Cauca: Soil cover and DM yield after 8 weeks of regrowth in the dry period (Mean of two cuts)

Accessions	La Cocha		Limonar		Versalles	
	Cov	Mean DM yield	Cov	Mean DM yield	Cov	Mean DM yield
	%	kg/ha	%	kg/ha	%	kg/ha
*Pm*CIAT16031	58	867	79	2534	96	8167
*Pm*CIAT6962	64	613	77	2206	93	7333
Pm cv. Massai	63	767	77	2731	97	4472
*Bb*CIAT26110	61	680	73	2347	93	3680
cv. Mulato II	60	520	62	2718	94	3508
*Bh*CIAT16888	74	340	66	1571	94	3219
*Bh*CIAT16866	78	47	57	1287	89	2457
*Bh*CIAT26159	75	368	55	2404	91	2331
Mean	67	525	68	2225	93	4396
LSD (P<0.05)	23.24	741.28	27.88	2459.19	11.31	4829.04

Table 101. Multilocational evaluation of grasses in Patía, Cauca: Soil cover and DM yield after 6 weeks of regrowth in the dry and wet period

Sites	Plant height	Cov	Vigor	Mean DM yield	Plant height	Cov	Vigor	Mean DM yield
	cm	%	1-5	Kg/ha	cm	%	1-5	Kg/ha
	Dry				Wet			
Versalles	90	93	5	4396	74	92	5	5051
Limonar	70	68	4	2225	77	82	4	3856
La Cocha	50	67	4	525	56	67	4	4358
Mean	70	76	4.3	2382	69	80	4.3	4421
LSD (P<0.05)		11.36		1263.44		7.91		1333.34

***accidentally grazed by animals

Table 102. Multilocational evaluation of grasses in Patía, Cauca: Soil cover and DM yield after 8 weeks of regrowth in the dry and wet period

Accessions	**Cov**	**Dry Mean DM yield**	**Cov**	**Wet Mean DM yield**
	%	**Kg/ha**	**%**	**Kg/ha***
*Pm*CIAT16031	77	3856	84	7274
*Pm*CIAT6962	78	3384	72	5369
Pm cv. Massai	79	2656	90	5943
cv. Mulato II	72	2248	83	4268
*Bb*CIAT26110	76	2236	88	4231
*Bh*CIAT16888	78	1710	67	2694
*Bh*CIAT26159	73	1701	87	2799
*Bh*CIAT16866	75	1264	70	2794
Mean	76	2382	80	4421
LSD (P<0.05)	11.55	1662.18	48.03	1565.88

*****accidentally grazed by animals

Legumes options co-developed with farmers

Table 103 shows the results of the legumes which could be established well in Versalles (Photo 24). Concerning the yields in DM/ha, highly significant differences (P<0.01) were observed in the dry season, respectively significant ones (P<0.05) in the rainy season. Ground cover instead only showed significant differences (P<0.01) in the rainy season. The yields in DM/ha of Canavalia Brasiliensis CIAT 17009 were much higher than the ones achieved by other accessions. However, the DM yields of *Stylosanthes guianensis* CIAT 11995, CIAT 15160 and *Centrosema molle*, *Desmodium heterocarpon* subsp. *ovalifolium* CIAT 13651 were higher than 2.1t/ha in the rainy season, respectively higher than 1 t / ha in the dry season. Excepted from this is *Centrosema brasilianum* CIAT 5234.

Table 103. Evaluation of Legumes in Versalles, Patía: Soil cover and DM yield after 8 weeks of regrowth in the dry and wet period (Mean of two cut in the dry and three cut in the wet season)

Accessions	Cov.	Dry Mean DM yield	Cov.	Wet Mean DM yield
	%	Kg/ha	%	Kg/ha
C. brasiliensis CIAT 17009	85	4389	94	3396
D. heterocarpon CIAT 13651	88	1722	81	2170
S. guianensis CIAT 11995	48	1348	64	2660
A. Pintoi 22160	67	1140	65	1104
C. molle CIAT 15160	80	1067	86	2444
C. brasilianum CIAT 5234	67	963	77	1735
Mean	73	1772	75	2254
LSD (P<0.05)	37.12	1589.61	19.53	1538.58

Photo 24. Multilocational trial of de Legumes in Versalles,Valle Del Patía, Cauca

Based on the feedback of farmers, in the 2nd half of 2010 semi-commercial pastures were established in more than 30 farms. The forage option selcted by farmers included: the grasses Mulato II, *Brachiaria brizantha* cv.Toledo, *Brachiaria humidicola*, *Panicum maximum* cv. Tanzania and Mombaza. At the same time the following forage legumes were selected and established: *Cratylia argéntea*, *Leucaena leucocephala*, *Canavalia brasiliensis*, *Centrosema molle, Desmodium velutinum, D. heterocarpon* and *Vigna unguiculata*.

2.10 Agreement with CENIPALMA

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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 weather 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 2010 field visits were carried out to 4 resgions where trials with cover crops had been established, including the Llanos (Villanueva, Casanare) (Photo 25). While there were differences in adaptation and development of the cover crops, *Canavalia brasiliensis, Mucuna pruriens, Desmodium heterocarpon* and *Pueraria phaseoloide* performed best across sites. We observe a very high interest of palm producers to establish nurseries of these.

Photo 25. Establishment of cover crops in palm plantations in Villanueva, Casanare and Valledupar, Cesar

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 Nacional Sede Palmira, U. San Martín Sede Cali, and for technicians and farmers in collaboration with Cogancevalle, (a Producers Association).

Annex

List of publications 2010

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Capacity Building (Training)

Bs Theses

Student name	Status	University	Title
Aguirre B., Lina María	Completed	Universidad del Valle, Cali, Colombia	Mechanisms of resistance to adult feeding damage in *Brachiaria* spp.
De la Cruz Jiménez, Juan	On-going	Universidad Nacional de Colombia, Sede Palmira, Colombia	Waterlogging tolerance in *Brachiaria*
Giller, Onno	On-going	University of Sussex, England	Crop and forage adaptation to abiotic stress factors
Latorre, Michael	Completed	Universidad del Valle, Cali, Colombia	Morphological, pathogenic and molecular characterization of isolates of *Rhizoctonia* spp. obtained from *Brachiaria* spp. with foliar blight
Muñoz, Giovanna	On-going	Universidad Nacional de Colombia, Sede Palmira, Colombia	Responses of different tropical legumes to waterlogging
Rivera, Katherine Lorena	On-going	Universidad del Valle, Colombia	Biologia floral de " Yapacani" (*Cratylia argentea*)
Uehlinger, Noémi	On-going	ETH, Zurich	Realizing the benefits of cover crop legumes in smallholder croplivestock 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

Student 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
Contreras, Carolina	Completed	University of Hohenheim, Stuttgart, Germany	Social Network Analysis of the Monogastric animal production in the Popayan Region of Colombia
Hegglin, Django	Completed	ETH-Zurich	Phosphorus cyclig in silvo-pastoral systems established on highly weathered tropical soils
Holle, David	Completed	University of Hohenheim, Stuttgart, Germany	Social Network Analysis of the Monogastric animal production in the Popayan Region of Colombia
Heinritz, Sonia	On-going	University of Hohenheim, Stuttgart, Germany	Ensiling suitability of high protein tropical forage and their digestibility in pigs
Kahle, Robert Christopher	On-going	University of Hohenheim	Responses of different tropical legumes to individual and combined stress factors of acid soils and drought
Matthiesen, Theda	On-going	Georg-August-University Göttingen, Germany	Contribution of cavies (*Cavia porcellus* L.) to livelihoods of rural people: a case study in Tanzania.
Molano, Martha Lucia	On-going	Universidad Nacional de Colombia, Sede Palmira	Evaluación nutricional de especies forrajeras mediante la técnica de NIRS.
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
Mutimura, Mupenzi	On going	University of KwaZulu-Natal/ Pietermaritzburg Campus/ South Africa	On-farm evaluation of *Brachiaria* grass options in Rwanda

PhD Theses

Student name	Status	University	Title
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
Cardoso, Juan Andres	On-going	University of Granada	Abiotic stress adaptation in forage grasses and legumes
Castro, Aracely	Completed	National University, Palmira	Nutrient dynamics in the Quesungual slash and much agroforestry system
Douxchamps, Sabine	Completed	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
Keding, Gudrun B.	Completed	Justus-Liebig-University Giessen, Germany	Linking nutrition security and agrobiodiversity: the importance of traditional vegetables for nutritional health of women in rural Tanzania.
Mutegi-Murori, Rosemary	Completed	Georg-August-University Göttingen, Germany	Towards identifying the physiological and molecular basis of drought tolerance in cassava (*Manihot esculenta*).
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
Polreich, Severin	Completed	Georg-August-University Göttingen, Germany	Assessing successive leaf yield performance of dual-purpose (*Vigna unguiculata*) to decrease seasonal shortage of nutrients in resource-poor small-scale households of Tanzania and Uganda.
Reiber, Christoph	On going	University of Hohenheim, Germany	Encouraging adoption of researchbased offerings with contrasting extension approaches
Torres, Julieta	On-going	Universidad Nacional de Colombia, Sede Palmira	Evaluación nutricional de Leguminosas Tropicales para pequeños productores de monogastricos (aves y cerdos)', utilizando la rata como modelo

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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

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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 - Arbustivas - 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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