Assessing the adoption and economic and environmental impacts of Brachiaria grass forage cultivars in Latin America focusing on the experience in Colombia

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Desde 1967 *Ciencia para cultivar el cambio*

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1. Introduction

Brachiaria grasses are native to Africa but were introduced to the Americas in the early 50's due to its easy adaptation to the region and high potential productivity in livestock production systems (Miles, Maass, & do Valle, Brachiaria: biology, agronomy and improvement, 1996). A considerable expansion of Brachiaria grasses has been reported in various countries of Latin-America, especially in Brazil (Instituto Brasileiro de Geografia e Estatística, 2007; Jank, Barrios, do Valle, Simeão, & Alves, 2014; Landers, 2007). Brachiaria Decumbens cv. Basilisk was the first adopted cultivar in Latin-American and remains in current times as one of the important grass forage cultivars in the region.

Since the early 1970's the International Center for Tropical Agriculture (CIAT) has played an important role in expanding the use of Brachiaria grasses to other areas of South and Central America. Together with various national partners, CIAT started a research program that identified some limitations of Brachiaria Decumbens in various countries (i.e., susceptibility to spittlebugs). To address this limitation, CIAT's strategy has been to improve livestock productivity by evaluating and selecting well adapted and highly productive pastures that would not only improve farm productivity but also tropical soil characteristics and the environment (Rao, et al., 2015).

As a result of this strategy, research on tropical pastures has resulted in the release of other Brachiaria cultivars such as B. Brizantha cv. Toledo (CIAT 26110), B. humidicola cv. Humidicola (CIAT 679), cv. Llanero (CIAT 6133) and B. ruziziensis cv. Kennedy, and hybrids of Brachiaria (cvv. Mulato, Mulato II, Cayman, Cobra) that have proved to be superior to the original Brachiaria cultivars in current production conditions. Seeds of these improved Brachiaria cultivars and hybrids have been available to farmers since early 2000 (Miles, do Valle, Rao, & Euclides, 2004) and is expected to have been replacing the native and degraded pastures in Latin America (Hollmann, Argel, & Perez, 2008).

In Colombia, CIAT and other national partners have been working in the Eastern plains and Amazon regions where a large amount of research on Brachiaria grasses has taken place. This collaboration has used the ICA (now CORPOICA) - Carimagua Experimental research station in the Eastern Plains (Llanos Orientales) as the center for knowledge generation and dissemination about the best forage options for livestock producers. This partnership has been key in the expansion of areas under Brachiaria species in Colombia and later in other countries in Latin-America.

Although there are project reports and statistics on seed sales that suggest a large adoption of Brachiaria grasses in Latin-America, there are no rigorous studies that have documented this adoption process. There is also no evidence of the impacts that the adoption of Brachiaria may have generated. This study was designed to contribute to filling this gap and had the following objectives:

- Estimate the current adoption of *Brachiaria* cultivars as measured by percentage of farmers adopting and by the percentage of total grassland area planted with the new/improved *Brachiaria* cultivars
- Estimate the adoption rate across different *Brachiaria* cultivars
- Identify factors that have facilitated or restricted the adoption of *Brachiaria* cultivars
- Estimate the livestock productivity and environmental benefits (i.e., animal productivity, improved soil conditions, etc.) that can be plausibly attributed to the adoption of *Brachiaria* cultivars
- Determine whether those impacts vary by farm size?
- Estimate the projected adoption and impacts of *Brachiaria* cultivars in other countries in Latin America

After the start of the project and given the experience of one of the partners of the study the project added another objective

- To estimate livestock producers' willingness to pay for adopting improved forages and for adopting silvo-pastoral systems.

This document is a final technical report to SPIA of the study, however, not all research activities have not been finalized. The study experienced some delays in the start of the project (Completion of the grant and sub-grant agreements) and some adverse weather conditions that delayed the field data collection and therefore the analysis that could be completed. CIAT and partners have the commitment to complete the overall research process as planned and it is expected to finalize it by December 2017. This report will present the preliminary analysis completed so far that includes the estimation of the level of adoption of Brachiaria and other forage grasses in Colombia an other countries in Latin America, the study of the determinants of adoption of Brachiarias in Colombia and the productivity and income impacts of the adoption of Brachiarias in Colombia.

After the introduction, this report summarizes the analytical approach followed in the study. It starts with the sampling frame and the data collection process implemented to study the adoption and impacts of forge cultivars in Colombia and Nicaragua. This section also describes the protocols used to estimate the adoption of forages cultivars in Peru, Costa Rica and Honduras using panels of expert opinion. The section then continues describing the econometric models used to study the adoption of Brachiarias and to estimate the impacts of this adoption, while a separate sub-section describes the choice experiment and the willingness to pay analysis implemented. Another sub-section describes the methods selected to estimate environmental impacts associated with the use of different forages. Finally we describe the economic surplus model envisioned to aggregate impacts of Brachiarias in Latin-America.

The next section presents different research findings from different analysis performed so far and continues identifying further analysis that will be performed after the close of this SPIA project. This report finalizes by summarizing some concluding remarks.

2. Methodological approach

2.1. Sampling frame

Our sampling strategy used a two stage clustered sampling procedure where we first selected a group of clusters or primary sampling units (PSU) and then selected a sample of households in each PSU. Given the potential loss of variability in some outcome variables for using a two-step procedure we adjusted the standard calculation of minimum sample size coming from a simple random sampling procedure.

The minimum sample size was initially calculated for the studies in Colombia and Nicaragua in order to be able to estimate the adoption of Brachiaria cultivars. In both cases a 95% level of confidence, and a level of precision in the estimated coefficient of 3% were used. It was also expected to find a level of adoption of 30% for Brachiaria cultivars in Colombia and 15% in Nicaragua following reports on the adoption of this forages in Colombia and other Latin-American countries (Hollmman et al., 2008; Rivas et al 2006).

Our unadjusted minimum sample size were calculated in 675 households in Colombia and 392 in Nicaragua. However, with the two stage clustered procedure and estimating an intra-class correlation of 0.027 from prior adoption studies, the final minimum sample size calculated was 820 households in 102 different farm communities in Colombia and 480 households in 80 different farm communities in Nicaragua.

In Colombia, our study also aimed to estimate various impacts related to the adoption of Brachiaria grasses. Unlike the calculation of the minimum sample size for estimating adoption, for estimating impacts we needed to define a minimum detectable effect between adopters and non-adopters in terms of key outcome variables. In addition to the 95% confidence level and the intra-class correlation of 0.027 calculated, we assigned a 80% level of power (associated with type II error).

Existing research on the effect of the use of *Brachiaria* grasses on livestock productivity indicates that this productivity could be increased between 40% and 75% compared to the use of natural pastures (Rivas and Hollmann 2004). There is also evidence that in countries like Costa Rica, Honduras and Mexico the use of *Brachiaria* increased milk productivity in between 11% and 17% and meat productivity in 8% to 25% (Hollmann et al 2004). To be conservative we assumed that the adoption of *Brachiaria* grasses would at least allow us to observe an increase in milk and meat productivity of around 10% between adopters and non-adopters. Following the power calculation suggested by Duflo et al 2008 we estimated that we would need at least 276 household in each of both the treatment and control groups. The total minimum sample would then be 556 households in 56 farm communities. Includes at least 276 adopters or non-adopter, out of the 820 interviewed livestock producers, our sample will still be valid for measuring the impacts of the adoption.

2.2. Questionnaires for data collection

This research used two different surveys for collecting field data needed. The first survey was a comprehensive questionnaire that collected detailed data on socioeconomic characteristics, productive and household assets, livestock-farming variables of interest and a specific section of forage cultivars use and management. The design of the survey questionnaire was performed with the assistance of experts from the forages program at CIAT, and the animal science and veterinary departments at Universidad de los Llanos and Universidad Cooperativa de Colombia. All research protocols were also submitted to CIAT's Institutional Board Review

Previous experiences in CIAT with the usual process of two stages in data collection (survey collection on paper followed by digitalization) proved to be somehow negative in both information quality and costs for full consolidation of a robust database. Hence, for the first questionnaire we opted for the implementation of CAPI based on CS-Pro® software. A digital computer-based questionnaire with strong logic parameters for data consistency was built in CIAT and had it installed on each of the enumerators' assigned computers within a cloud-drive folder. This allowed us to double check the consistency of the collected information each time that the enumerators had connection to the internet, and to request for corrections or additional collection of missed information of interest if possible.

A second questionnaire was designed for a choice experiment questionnaire (see annex 2) and implemented in a sub-sample of the adoption/impact study sample, selected randomly among only livestock-farm-owners. The questionnaire did not ask for any sensitive information from farmers, and instead gathered information to derive a willingness to pay for specific environment conservation-driven land uses within the farms. The data collection of this second survey followed a different procedure than the adoption/impact survey. The choice experiment data was collected in focus group meetings with farmers' associations in the departments of Caquetá, Putumayo, Meta and Arauca. A total of 245 livestock far owners were selected and divided between two land use changes (improved pastures and silvo-pastoral systems) which in turn represented a total of 573 choice sets.

2.3. The data collection process

Given the spread of targeted area of the field surveys that is nationally representative of the topical Colombia, the study team implemented collaborative agreements with different organization to help us in the data collection process. CIAT signed formal agreements with Universidad de los Llanos (public university in the department of Meta; *Unillanos*) and Universidad Cooperativa de Colombia-Arauca (private university in the department of Arauca; *UCC*). For implementing the field work in the Caribbean region of Colombia, the study team also involved the participation of the Colombian Corporation for Agricultural Research (*CORPOICA*, for its acronym in Spanish). All three collaborative partners were instrumental in the implementation of the field work.

From a large set of candidates, 28 enumerators were selected on a face-to-face interview process, following a set of criteria that included relevant experience either in research or data collection activities. Fourteen of the selected enumerators are veterinary students/graduates, six are agronomy students/graduates, while the last seven come from other agricultural backgrounds. Three enumerators from UCC selection process were assigned the collection of 120 surveys across the departments of Arauca and the northern Casanare, while 11 enumerators from Unillanos where in charge of collecting 264 surveys across the departments of Guaviare, Meta, and southern Casanare. Five enumerators with previous data-collection experience with Universidad de los Andes were assigned for 256 surveys in the departments of Caquetá and Putumayo. In the same fashion nine enumerators were selected with the help of CORPOICA for the collection of 178 surveys in the Caribbean departments of Cordoba, Sucre, Bolivar, and Magdalena. Twelve (12) additional surveys were collected directly by CIAT staff in the department of Vichada.

Each enumerator was trained in computer assisted personal interviewing (CAPI), GPS device and data management, and in implementing the experimental questions regarding willingness to pay for environment conservation. In addition, pilot surveys were carried in order to further enhance the on-field performance of the enumerators, and to improve both the CAPI and experimental survey instruments. Enumerators were directly supervised by CIAT researchers during the first days of field-work to provide additional support and suggestions for data collection. Supervision for the rest of the data collection process was led by professors Leonardo Garcia (Uniandes), Luis Carlos Ramirez (Unillanos), and Jose Norberto Arias (UCC). Due to the use of CAPI, the CIAT team was able to monitor on real time the data entry process and advise if any correction or revision was needed.

The data collection process in the Eastern plains were implemented between October and December 2017, in the Amazon region between February and April 2017 and in the Caribbean coast between May and June 2017. Another project being implemented by CIAT and CORPOICA in the Caribbean region is using the same survey instruments to interview another 202 livestock producers. Once this data collection is completed by September 2017, this data could be incorporated in to the analysis, bringing the final total sample to 1024 livestock producers.

2.4. Methods to study the adoption and determinants of adoption: Colombia

Our first task would be to estimate rigorously the overall level of adoption of Brachiaria cultivars in Colombia and then understand the determinants of this adoption. The study used the full sample of 828 livestock producers to estimate the adoption level and for now a total of 650 livestock producers (Eastern Plains and Amazon regions) to study the determinants of adoption. The same survey field data of 650 livestock producers is later used to measure the impacts of the adoption of Brachiaria grasses on cattle productivity and farm income. We have explored alternative model specifications to study the determinants of adoption and we present in this report the two models studied so far.

2.4.1. Adoption determinants: Binary regression analysis

We use a standard binary categorical variable regression model (Long & Freese, 2014), where we consider a farmer household choosing whether or not to adopt a specific technology (Brachiaria forages in our case), based on its expected utility. The utility derived from farmer *i* when chooses to use the Brachiaria grasses is a function of the form:

$$u_i = x_i'\beta + \varepsilon_i. \tag{1}$$

The term $x_i'\beta$ comprises the farmer's non-random expected utility with x_i a set of observable characteristics, and ε_i is the unexpected shock to the utility derived from the use of Brachiaria grasses. In the other hand, we assume farmers to have much more certainty about their expected utility if they keep their native pastures; with no loss of generality we let the utility of using native pastures u_0 to be constant and equal to zero. Hence, with little algebra, our index function on the rational decision of farmer *i* on whether or not to adopt (1 = adoption) would be:

$$y_i = \mathbf{1}(\varepsilon_i < -x_i'\beta). \tag{2}$$

We approximate the determinants of adoption through the probability of adoption, given by the cumulative density function:

$$\Pr(y_i = 1|X) = \mathbf{\Phi}(x_i'\beta) \tag{3}$$

where $\mathbf{\Phi}$ is the standard normal cumulative density function.

As will be shown in section 3.4, the adoption of any Brachiaria grasses without restriction of variety or time of seeding is high (over 95%). This make it difficult to apply the described model above to study the adoption of any Brachiaria. Nonetheless, we explore to study the determinants of the adoption of Brachiaria in three alternative scenarios. In the first one we defined the use of "modern" Brachiaria grasses ("Case A"), which are the Brachiarias released with CIAT participation and basically excludes the adoption of Brachiaria Decumbens introduced way before the foundation of CIAT. The second scenario uses information of plots seeded since the year 2000 (without restricting Brachiaria variety, namely "Case B"), given that after 15-17 yeas Brachiaria cultivars are usually considered degraded pastures. In the third scenario, we consider the interaction of these two previous scenarios ("Case C").

2.4.2. Adoption determinants: Ordinal categories regression analysis

Further analysis can be put towards the understanding on determinants of adoption of Brachiaria forages. Important insights could be derived if, instead of analyzing not only a binary approach to certain specifications regarding the technology. We will also consider the case to study the adoption of Brachiaria grass forage at different categorical levels of it. We use three definitions as robustness check:

Definition A: - Non-or-low adopters: 0-5% of pastures under Brachiaria grasses.

- Partial adopters: 5-95% of pastures under Brachiaria grasses.

- High-to-full adopters: 95-100% of pastures under Brachiaria grasses.

Definition B: - Non-or-low adopters: 0-25% of pastures under Brachiaria grasses.

- Partial adopters: 25-75% of pastures under Brachiaria grasses.

- High-to-full adopters: 75-100% of pastures under Brachiaria grasses.

Definition C: - Non-or-low adopters: 0-25% of pastures under Brachiaria grasses.

- Low-to-partial adopters: 25-50% of pastures under Brachiaria grasses.

- Partial-to-high adopters: 50-75% of pastures under Brachiaria grasses.

- High-to-full adopters: 75-100% of pastures under Brachiaria grasses.

Now, following the same logic from the binary case we set up a group continuous model, also known as ordinal categories regression model (Long & Freese, 2014). As an extension, we now consider a farmer household that moves through different *levels* of adoption based on its expected utility $u_i(X)$, which is again dependent on the households' attributes. Formally, from *J* ordinal categories (rates of adoption) the farmer household chooses an *m*-th rate of adoption if:

$$\tau_{m-1} \leq u_i(X) < \tau_m \, . \tag{4}$$

The thresholds τ can be considered as opportunity costs related to establish a larger rate *m* of adoption; such costs are assumed to increase with larger rates of adoption. In this case, let y_i be an integer index variable of the *m*-th level of adoption observed from the farmer. Hence, for each category *m*, we want to approximate:

$$\Pr(y_i = m|X) = \Pr(\tau_{m-1} \leq u_i(X) < \tau_m|X) \, . \tag{5}$$

With $u_i(X) = x_i'\beta + \varepsilon_i$, it is straightforward to show that:

$$\Pr(y_i = m|X) = F(\tau_m - x_i'\beta) - F(\tau_{m-1} - x_i'\beta)\,. \qquad (6)$$

Different from the binary case, here the sign of the beta coefficients do not necessarily match with the sign of the marginal effect since

$$\frac{\partial \Pr(y_i = m|X)}{\partial x_{ij}} = \beta_j[f(\tau_m - x_i'\beta) - f(\tau_{m-1} - x_i'\beta)] \qquad (7)$$

which depends in both the characteristics of the farmer household and the adoption level of interest. In this document, we are assuming that the distribution is an ordered logit case.

2.5. Estimating productivity and income impacts of the adoption

A main task in the ex-post impact evaluation of the adoption of Brachiaria grasses is the identification of the treatment effect, which is affected by selection and placement biases. The use of randomization and panel data or repeated cross-sections (aiming to use difference in difference estimates) was ruled out from the beginning given the limited timeframe of the study.

Although there are some reservations on the use of instrumental variable (IV) methods as a valid strategy to induce quasi-randomization (Deaton, 2010; Angrist & Krueger, 2001), under certain conditions this method can identify the impacts of the adoption of Brachiaria grasses (Wooldridge 2002). We will therefore implement the IV method as our preferred identification strategy. To build confidence, careful thought is given to the suitability of potential instruments, and their relationship to a structural model.

Here we set up a model where a farmer maximizes profits π that depend on the share ϕ that it dedicates to modern grass cultivars (N), instead of traditional varieties of pasture (T), as well as the level of inputs (x) that dedicates to each of them. Each type of pasture implicate a specific technology (h^T and h^N, respectively). Hence, farmers' objective is to maximize:

$$\max_{\phi, x^N, x^T}\{\pi = \phi(Ph^N(x^N; z) - P^N x^N) + (1-\phi)(Ph^T(x^T; z) - P^T x^T)\}$$

$$s.t. \quad \phi \in [0,1].$$

Here P^N and P^T are the price vectors for inputs sets x^N and x^T respectively, while P indicates the price for the final output and z are fixed and household-specific covariates. We can then define a reduce form model where:

$$h = f(\phi, P, P^N, P^T; z^p)$$

$$\phi = g(h, P, P^N, P^T; z^s)$$

With f and g unknown functions, and the p, s superscripts on z reflect that a different set of exogenous regressors (with overlap) affect each outcome. We use this intuition to develop an identification strategy—the impact (on farm-level productivity and farm income) of the new technology will be identified by random variations in factors affecting technology supply, and spatial variability of these factors.

We will then assume a productivity (profit) outcome y_i that is a linear function of observable variables v_i , the intensity of technology adoption a_i and an error term ε_i:

$$y_i = v_i'\beta + \delta a_i + \varepsilon_i. \tag{8}$$

Since a_i is an endogenous variable on the decision of how large is the share of modern/improved pastures, we will also assume that it is a linear function of observable variables r_i, and an error term μ_i

$$a_i = \theta r_i + \mu_i \tag{7}$$

Assumptions about the error structure in these equations allow us to identify the effect of the intensity of adoption on the productivity outcome. Identification of such effect requires that at least one variable in r_i is not present in v_i. Estimation of this system of equations is straightforward by two stage least squares.

An important critique of instrumental variable estimates and other forms of quasi-randomization revolves around choice of instruments. The ex-post nature of the study has important implications. While selection bias remains important, the nature of the placement problem is altered. The standard placement bias problem relates to inferences about potential impacts of expansion of a program. Ex-post, spread has occurred, and the placement problem relates to the counterfactual—to whom are we making comparisons? In this context, placement bias becomes akin to the missing variables problem: when we infer impact we want to include all placement-related factors (agro-ecological conditions, etc.). We begin with a search for clear and exogenous sources of variation in causes of technology adoption: factors affecting the availability (supply) of new technologies.

Colombia has suffered for many years of violence and displacement of population due to the political conflicts. Although there is a peace agreement about to be signed, the post-conflict transition may continue some of the current disruptions. These are not likely to be directly associated with productivity, especially if we successfully condition on farm- and area-level fixed inputs. Violence might disrupt supplies of Brachiaria grasses and measures of intensity and spread of violence during periods between the dissemination of Brachiaria and substantial national-level uptake would help identify treatment effects. Hence, we directly asked farmers regarding the presence of political turbulence or violence events that affected the access to input markets and use it as an instrument.

2.6. Expert opinion workshops: adoption of Brachiaria grasses in LAC

We concentrated our efforts to do field data collection in Colombia and to certain extend in Nicaragua. However, in order to include estimates of the adoption of Brachiaria and other forage grasses in Peru, Costa Rica and Honduras we used information elicit from forage experts. In Honduras and Costa Rica we used existing information coming from elicitation workshops implemented by CIAT with forages and livestock experts in these two countries in 2012. This expert elicitation workshops followed the protocols and methodology described during the DIIVA project (Walker and Alwang 2015). Likewise, In Peru the study organized a new expert elicitation process in March 2017 and applied the same methodology developed for the DIIVA project and further refined for the SIAC project in Asia (Maredia et al 2017) spread of violence during periods between the dissemination of Brachiaria and substantial national-level.

In Costa Rica the expert workshop brought together 10 exerts from different disciplines and representing the following organizations: University of Costa Rica, Tropical Agricultural Research and Higher education Center (CATIE), Earth University and The Agricultural Research Direction of the Ministry of Agriculture. In Honduras there were 12 participant experts that represented the Agricultural and Livestock Secretariat (SAG), The Agricultural Science and Technology Direction (DICTA), the Zamorano School, The Natural Resources Secretariat (SRN) and the NGOs Swiss contact and Lutheran world Relieve. Finally in Peru there were 17 livestock experts coming from the following organizations: The National University of Ucayali (UNU) The National Agricultural Research Institute (INIA) The Peruvian Amazon Research Institute (IIAP) the Institute for Veterinary and Tropical Upland research (IVITA), The Ministry of Agriculture (MINAG) and the Regional government of Ucayali (GORU).

In general the methodological approach in each expert workshop. We contacted all selected and invited expert before the day of the workshop and requested them to bring to the discussion existing secondary data that would facilitate the discussion and specially the estimation of adoption of different forages in each country. For example to estimate the total acreage of forage, data was obtained from different sources in each country. We also collected data at aggregate level from FAO to compare aggregate area at country level.

The next step was to define the main livestock producing areas in each country, which was cross-validated by knowledgeable experts participating in the workshop. Once the participant experts where comfortable with the identified major production areas, we then conducted expert elicitation to estimate adoption rates of different forage cultivars at each defined geographical unit. This was done in three steps. First, each individual expert was asked to provide their own perceived aggregate adoption rates of improved and local varieties for the respective geographical unit.

In the second step, experts were grouped into different groups based on their knowledge of the geographical area under consideration and were given the task of estimating aggregate adoption rates of different forage cultivrs in their respective group. The objective of this exercise was to achieve a consensus at each geographical unit. In the final step, we held another round of elicitation-this time all experts together- to achieve consensus on the aggregate adoption rates of forage grasses varieties at all geographical units. We then aggregated adoption rates at each geographical unit considering their relative area share to estimate a representative adoption rate at a country level. We opt to use region specific elicitation procedures instead of country level elicitation, since most of participating experts indicated to be more knowledgeable in their own specific region.

2.7. Estimation of environmental impacts from the use of Brachiaria grasses

For measuring the environmental impacts associated with the adoption of Brachiaria grasses we focused on impacts on forage quality and Green House Gas (GHG) emissions. This activity will combine data and measurements already collected by CIAT though other research projects with measurements performed in selected farms of our study sample.

For the new biophysical measurements preformed with support of SPIA funding we have followed the same protocols used in the previous studies and it is describes below.

Objective: Evaluate soil C stocks, enteric methane emissions and forage quality under different pasture typologies (4) in farms of Meta - Colombia.
Hypothesis: Pasture management increases soil carbon stocks, forage quality and reduce enteric methane emissions when compare to the native savannah

Material and methods:

- This field measurements were conducted on two farms in two locations of Meta department of Colombia (Catama - Foothills and San Martín – high plains, savannah).
- Two farms (one in each region) and four pasture types (native savanna, improved pastures: *B. humidicola* cv. *Llanero, B.decumbens and B.humidicola cv. Tuly*) were selected considering that they are the most common pastures in the region.
- The farms with improved pastures had been converted from native savanna and rice about 2 to 4 years approximately.

- On May 2017, soils and forages were collected from the two farms listed above.
- For soils collection, three representative 80 x 80 cm pits were dug to one meter depth in each farm. In each pit, soils were collected from seven different soil depths (0-10, 10-20, 20-30, 30-40, 40-60, 60-80, 80-100 cm).
- Collected soils were characterized for several soil physical and chemical properties (i.e., bulk density – 56 soil samples, water retention at field capacity – 35 soil samples in five depths, saturated hydraulic conductivity, pH, total C content in 336 soil samples). Soil bulk density (BD) was determined for two duplicate samples collected using aluminum cylinders of 5 cm diameter and 5 cm height.
- The soil volume and mass of dry soil (105ºC for 24 h) was used to calculate the soil bulk density as described by Balcázar (2010). Soil pH was determined in 1:1 soil to water mixture (McLean, 1982) using a potentiometer (Mettler Toledo. Soil saturated hydraulic conductivity, texture, and water retention were characterized for two duplicate samples per pit using methods described in IGAC (2006).
- Estimate total soil carbon (TOC):The TOC was estimated using the methodology proposed by Amezquita (2004). Sampling points consisted of three main pits (1x1x1 m approximately). In each repetition 336 soil samples for the determination of total carbon in seven depths (0-10, 10-20, 20-30, 30-40, 40-60, 60-80, 80-100 cm) they were taken. TOC was determined by liquid combustion process which is quantified by means of an infrared detector. The bulk density was determined by soil cylinder method (Balcázar, 2010). Carbon storage in each depth range was obtained by following formula:
  COT (kg m^{-2}) = ρ. fC. Pm (1)

  Where ρ: soil bulk density (kg m^{-3}), fC: carbon fraction (kg C .soil kg $^{-1}$) and Pm: sampling depth (m)

- For Forage samples were collected to evaluate the forgaqualityof the selected pastures. The following parameters are being evaluated with the cited methodologies:
  1. Dry matter (ISO 6496:1999)
  2. Ash 550°C (AOAC 942.05:2005)
  3. Organic Matter (Incineration in muffle 550°C, Calculation)
  4. Neutral detergent fiber (NDF, ISO 16472:06, AOAC 2002:04, AN 3805 ANKOM)
  5. Acid detergent fiber (ADF, ISO 13906:08, AOAC 973.18, AN 3804 ANKOM)
  6. Crude protein (AOAC 984.13:1990, Kjeldahl AN 3001 FOSS)
  7. The *in vitro* gas production technique (Theodorou et al, 1994)
  8. Methane determination from point 7 (Gas chromatography)
  9. The *in vitro* dry matter digestibility DIVMS (Tilley & Terry 1963, Van soest & Robertson 1985)
  10. Gross energy (ISO 9831:1998 Method for bomb calorimetry)

2.8. Willingness to pay for sustainable livestock land-use practices

This study seeks to understand the preferences of farmers regarding conservation programs related to two different farm management schemes: silvo-pastoral systems and improved pastures implementation. We designed two choice experiments, one for each program, based on interviews with experts carried out in focus groups and relevant literature. We identified the main relevant factors regarding program´s participation taking into account the following dimensions: 1) amount of land retired for conservation practices or improved pastures, 2) technical support and 3) a scheme of payments to support the adoption of silvo-pastoral system or improved pastures.

The choice experiments are based on the assumption that the participants choose the alternative that gives them more utility in comparison with the other alternatives presented in the choice set (Hensher et al., 2005). In the context of this study, this means that a landowner will choose conservation option 1 over option 2 if $U(X_1, Z) > U(X_2, Z)$, where U represents the landowner's utility function, X_1 represents the attributes of option 1, X_2 represents the attributes of option 2, and Z represents a vector of sociodemographic characteristics of the landowner and physical characteristics of his farm.

Experimental Design for the Silvo-pastoral System

After several meetings with groups of cattle owners in the departments of Cauca (outside the Orinoco Region) and Casanare, we identified four attributes as the most relevant for describing a conservation program based on the adoption of a silvo-pastoral system. These, with their respective levels, are shown in table 1 below.

Table 1. Attributes and Levels for Silvo-pastoral System Choice Experiment

Area for Silvopastoral System	Forage assistance	Production assistance	Subsidy for the implementation of silvopastoral system
0%	No	No	COP 0
15%	Basic	Basic	COP 625,000
30%	Complete	Complete	COP 1,000,000
			COP 1,625,000

Area for silvo-pastoral system indicates the percentage of the total area of the farm where the silvo-pastoral system would be implemented. The forage assistance consist of three levels: No, Basic and Complete. The level "No" indicates that the program does not provide technical assistance in the form of advice to cattle owners for the production of grass. The "Basic" level indicates that agricultural technicians will assist in planning the production of grass that the farmer currently has. This means that they will help to calculate total forage production, to recommend how many animals they should have per pasture area, and to advice on the usage time of each pasture area, and rotation patterns. The level of “Complete” forage assistance indicates that in addition to the benefits included in the basic assistance, technicians will conduct experiments on the farm to determine the type of grass that will give cattle owners more profit and productivity.

The production assistance is also made up of three levels. The level “No” indicates that the program does not provide any technical assistance in animal health, wellbeing, and genetic improvement of their cattle. The “Basic” level indicates that cattle owners will be given assistance in control and treatment of illnesses such as Bovine Brucellosis, Bovine Rage, Bovine Tuberculosis and others that affect the production and reproduction of cattle. The level “Complete” indicates that additional to the benefits given in the “Basic” level, the cattle owner will receive technical support regarding the genetic improvement of animals in order to obtain a higher production of milk and meat.

Finally, the compensation for the implementation of silvo-pastoral system has 4 levels: COP 0, COP 625,000, COP 1,000,000 and COP 1,625,000. Each level is a percentage of the total implementation cost per hectare (equivalent to COP 2,300,000) and the average annual maintenance cost per hectare for three years (COP 2,300,000 + COP 425,000). This data was obtained from the Colombian Federation of Cattle Breeders (Fedegan) and through direct questions to breeders in the area of Casanare and Cauca when collecting evidence from focus groups´ participants.

Cattle owners were informed about the economic and environmental advantages of silvo-pastoral system adoption. As trees generate shade for cattle during summer seasons, this reduces the amount of energy they spend trying to cool off. This reduces their fatigue and therefore helps maintain cattle healthy and with adequate weight. The environmental advantages include the decrease of soil erosion, which improves the ecosystem’s balance. Also, roots and tree fruits help feed the cattle, as well as increase nutrient (nitrogen) concentration in the soil, which in turn increases its fertility. These benefits help increase income and decrease risk. Additionally, trees increase CO2 capture, which helps combat climate change and supports global environmental goals like the Paris Agreement.

After randomizing these attributes with their levels, 290 choice sets were created in the JMP software, each with three alternatives (option 1, option 2, and program absence option). In the process, we eliminated programs that did not make sense (i.e. receive a subsidy for the implementation of the silvo-pastoral system when the area designated for it is zero) and trivial combinations (when all attributes are equal to zero). Below is an example of a choice set for this case.

Table 2. Example of Choice set for silvo-pastoral system

Cuestionnaire 97 - Choice Set 1

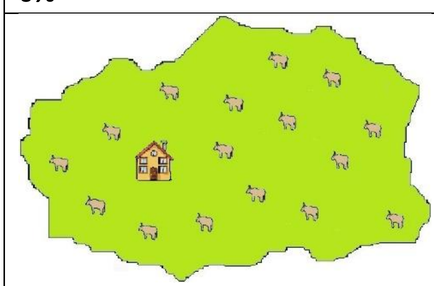
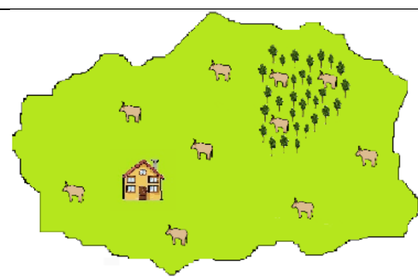
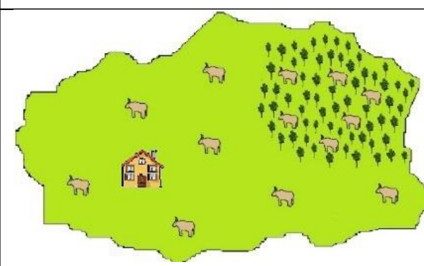
	Option 1	**Option 2**
Silvo-pastoral area	30%	15%
Forrage Assistance	No	Complete
Production Assistance	Complete	Basic
Subsidy for silvopastoral adoption	COP 625.000	COP 1.000.000

¿Which option do you prefer?

Option 1 __ Option 2 __ Neither __

To facilitate the understanding of each option, three drawings were designed showing each percentage of silvo-pastoral area. These are shown below.

Table 3 Visualizations of percentages of silvo-pastoral area

0%	**15%**	**30%**
		

Experimental Design for Introduced Pastures

Similar to the experiment for the silvo-pastoral system, after various interviews with groups of cattle owners, three relevant attributes were chosen, each with different levels. These attributes and levels are shown below.

Table 4 Attributes and Levels for Improved Pastures Choice Experiment

Area for improved pastures	Production Assistance	Compensation for the implementación of improved pastures
0%	No	COP 0
10%	Basic	COP 440,000
15%	Complete	COP 640,000
		COP 940,000

In this case, only production assistance was included, since forage assistance is included in the subsidy for the implementation of improved pastures. Production assistance is as described before in the silvo-pastoral system. Additionally, each subsidy level is a percentage of total implementation costs and half of the annual maintenance cost per hectare ($ 1,200,000 + $ 340,000).

Cattle owners were also informed about the economic and environmental advantages of improved pasture (*Brachiarias*) adoption. Since these pastures are grown with genetically improved seeds, they have more nutrients for the cattle, which make it gain weight faster. This of course, results in higher production and income for the farmer. These grasses are also more resistant to droughts and floods, which reduces risk and in turn increases income. Additionally, they have environmental benefits because by being more efficient in the feeding process, more cows can be placed per hectare. This leaves free land which can be used for tree planting, or for other crops.

As in the first experiment, these attributes and levels were randomized, after eliminating meaningless and trivial combinations, a total of 283 choice sets were created. The following is an example of a choice set for this case.

Table 5. Example of Choice set for Improved Pastures

Cuestionnaire 1 - Choice Set 1

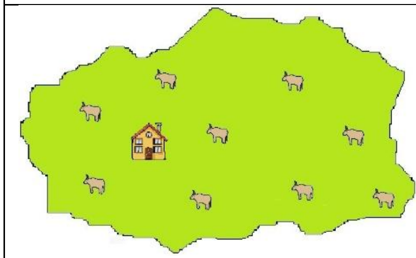
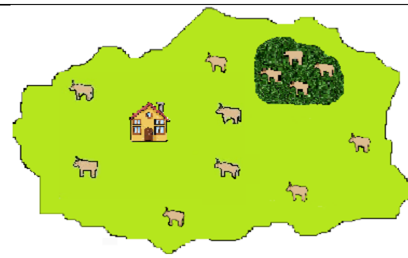
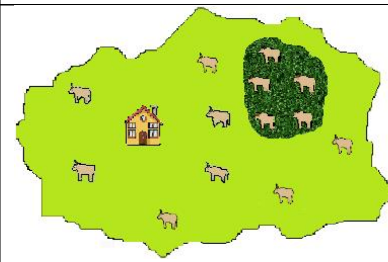
	Option 1	**Option 2**
Area with improved pastures	10%	15%
Producción assistance	Basic	None
Subsidy for adoption of improved pastures	$940.000	$640.000

¿Which option do you prefer?

Option 1 __ Option 2 __ Neither __

Finally, as in the previous experiment, three drawings were designed showing each percentage of area with improved pastures, to facilitate the understanding of the farmers. These are shown below.

Table 6. Visualization of percentages of area with improved pastures

0%	**10%**	**15%**
		

Econometric Model:

We estimated silvo-pastoral and improved pastures choice experiments using the Random Utility Models paradigm and the conditional multinomial logit model. We assume that the i-th cattle owner face 3 choices (j=1,2,3), namely select program option 1, program option 2 or neither.

The utility that person i obtains from alternative j is:

$$U_{ij} = \beta x_{ij} + \varepsilon_{ij} \quad (1)$$

If the cattle farmer makes choice j, then we assume that U_{ij} is the maximum among the J utilities. In other words the statistical model assumes that choice j is made when

Prob $(U_{ij} > U_{ik})$ for all other $k \neq j$

If we let Y_i be a random variable indicating the program´s choice made, and we assume $\varepsilon_{ij} \sim$ iid extreme value type 1 with (Gumbel) distribution $F(\varepsilon_{ij}) = \exp(-e^{-\varepsilon_{ij}})$. Thus,

$$Prob\ (Y_i = j) = \frac{e^{\beta X_{ij}}}{\sum_j e^{\beta X_{ij}}} \quad (2)$$

For the silvopastoral experiment, we have that the utility that each individual (*n*) obtains from his choice (*i*) depends on the levels of the attributes of this choice. In other words,,

$$U_{ij} = \beta_0 + \beta \quad SilvopastoralArea_n + \alpha \quad ForageAssistance_n + \gamma \quad ProductionAssistance_n + \vartheta \quad Subsidy_n + \varepsilon_{ni} \quad (3)$$

On the other hand, for the improved pastures experiment, we have that the utility that each individual (*n*) obtains from his choice (*i*) is:

$$U_{ij} = \beta_0 + \beta \quad PastureArea_n + \alpha \quad ProductionAssistance_n + \gamma \quad Subsidy_n + \varepsilon_{ni} \quad (4)$$

Equations (3) and (4) were estimated by maximum likelihood using NLOGIT™

3. Results

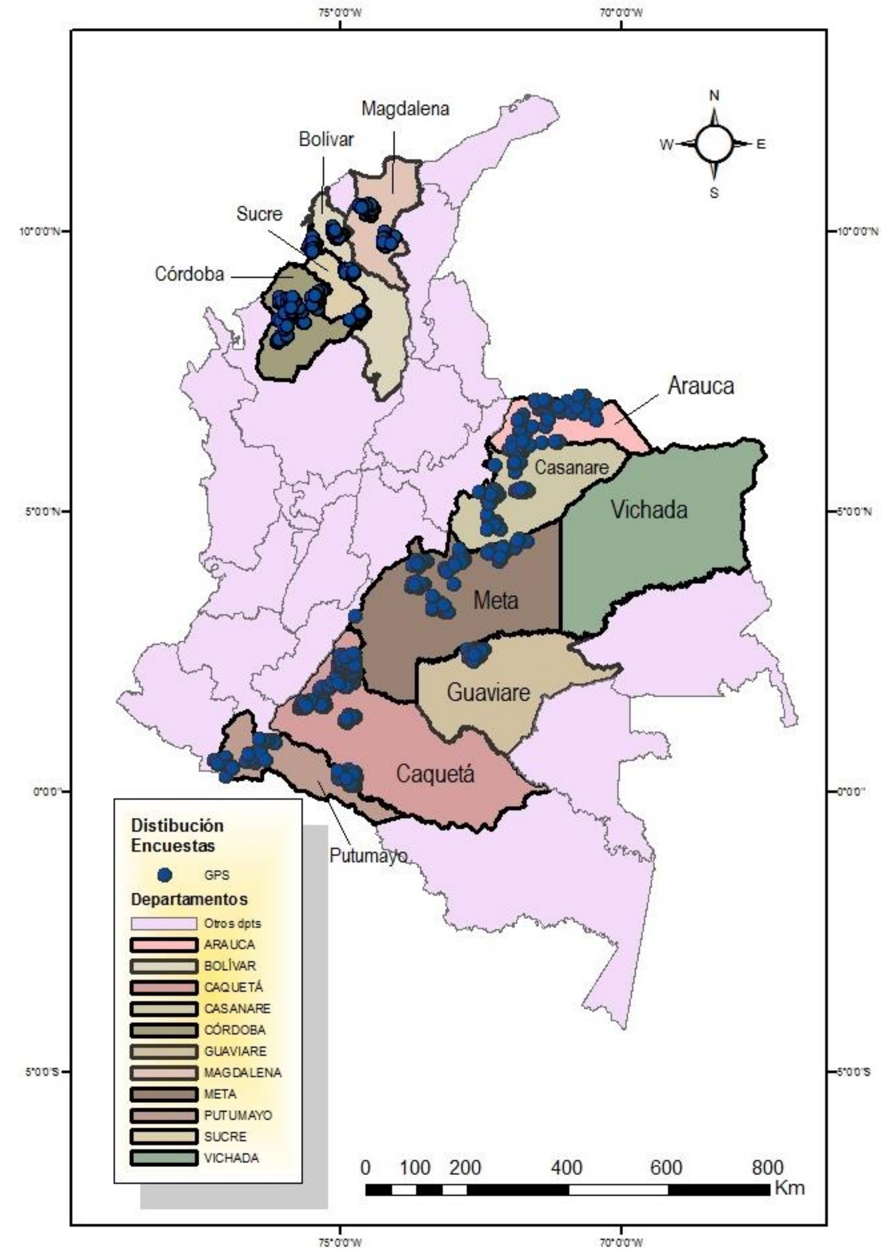
3.1. Distribution of interviewed livestock producers

In the study sample, interviewed farmers where distributed across the *Llanos Piedmont* and eastern plain areas of the departments of Guaviare, Meta, Casanare, Arauca, and Vichada, as well as in the Amazon region, within the departments of Caquetá (across Caquetá's piedmont) and Putumayo. In addition, information was also collected from livestock farmers in the Caribbean region, namely the Departments of Cordoba, Sucre, Bolivar and Magdalena (see figure 1 for detailed distribution of interviewed livestock producers).

According to the *Instituto Geográfico Agustin Codazzi*[1] (IGAC, 2016), the Eastern Plains and the Llanos Piedmont provide the greatest potential for cattle ranching despite a considerable soil acidity. Furthermore, they acknowledge the use of improved pastures as one of the main instruments to overcome the natural limitations of this sector within this region. In addition, areas as the Amazonian piedmont (which contains large areas in Caquetá and Putumayo) and Caribbean region are also of great potential for livestock farming. Our sample covers a vast are from this regions, making the representativeness of our Sample one of the main outputs of this study.

[1] IGAC, for its acronym in Spanish; Colombia's official and state-run institute of geography.

Figure 1: Spatial distribution[2] of collected data



Additional information regarding the number of bovines within each department (see Figure A1 in the appendix) shows that the study sample have not only been covering areas of intensive livestock farming, but of extensive livestock-farming as well. Likewise, based on satellite data from IGAC, we found that our sample matches with areas of high suitability for forestry within the tropical areas (see Figure A2 in the appendix). This is of great importance since the remote sensing within this regions assigns this characteristic (of high suitability for forestry) to zones

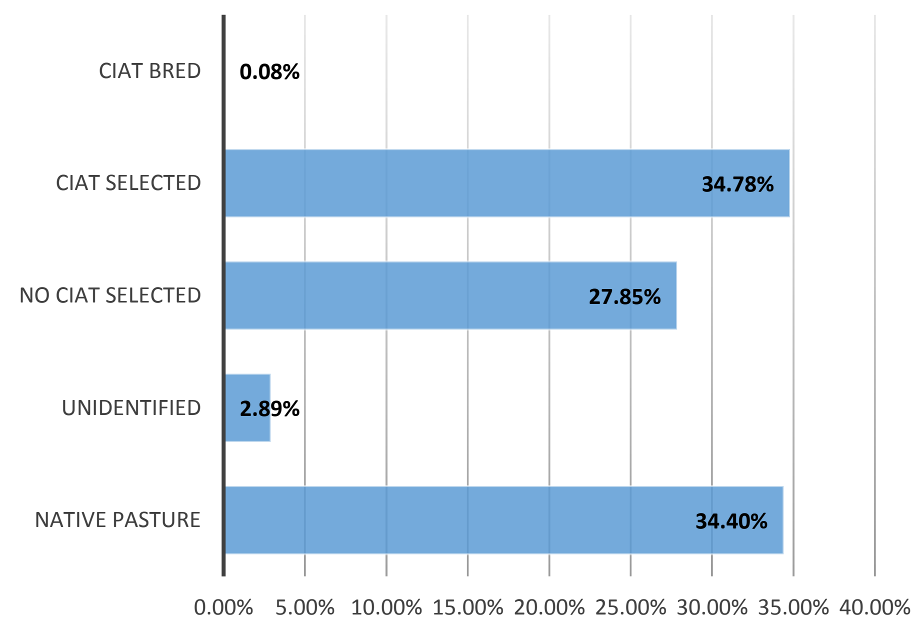
[2] Only observations from Vichada are excluded from this map due to missing GPS coordinates. Since this data is from a remote location, it was considered as a separate cluster of livestock farmers.

that are essentially dedicated to permanent crops for livestock farming (pastures). Hence, our findings and results could be extrapolated in a reliable way to the whole extent of tropical regions of Colombia.

3.2. Descriptive stats: overall adoption rate

To assess the level of adoption of different pastures we need to define what kind of forage grasses are considered as improved pastures in this study. Here we distinguished between genetic improved pastures and introduced/selected pastures, but consider both as improved pasture as they offer superior characteristics than the local or native pastures and that would not have been available for cattle ranchers in Colombia without the research implemented by CIAT and partners. From the data collected we estimated that the rate of adoption of improved pastures is relatively large, exceeding 62% of the total pasture acreage in the Tropical Colombia (estimated in 8.78 million hectares). As show in Figure 2, the large majority of improved pastures used in Colombia are introduced/selected with a slight predominance of varieties introduced by CIAT research (34.8%). Genetic improved variety remains with a very low adoption rates and the level of native pastures remains also important.

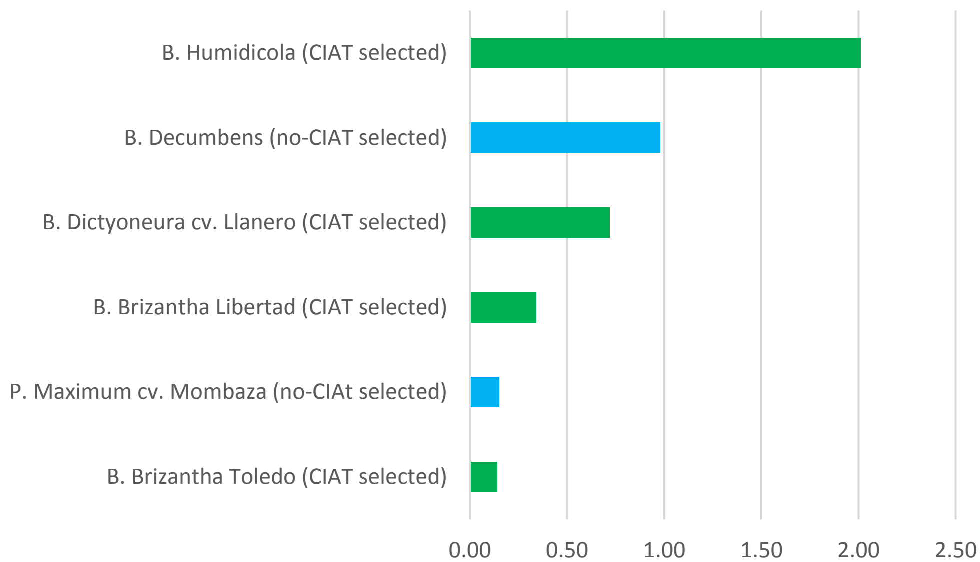
Figure 2: Adoption rate of improved/selected pastures in Tropical Colombia



At the forage variety level, figure 3 describes the level of adoption estimated for various forage cultivars. The largest adoption rate corresponds to Brachiaria Humidicola cv. Humidicola, Brachiaria Humidicola (ex-Dictyoneura) cv. Llanero and Brachiaria Decumbens. The dominant presence of the first two cultivars reflect the suitability of these varieties to tolerate the soil acidity of the Eastern Plains and Amazon regions. On the other hand, Brachiaria grasses like Decumbens and Brizantha (which are more tolerant to alkalinity) are most preferred in the Caribbean regions and few areas on the Amazon region where alkalinity of soils can reduce the potential of livestock farming.

Figure 3: Projected adoption of improved/selected pastures in tropical Colombia

(Most representative varieties, millions of ha)

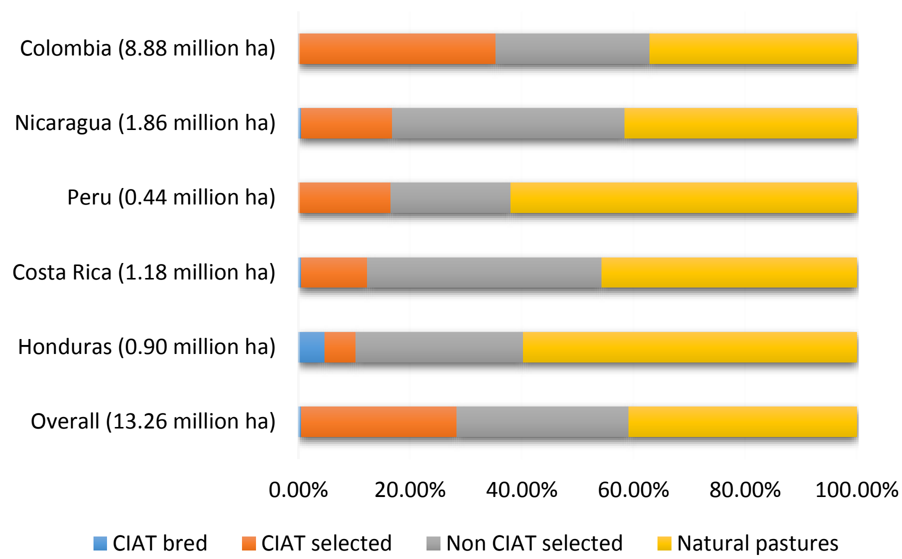


Many of the Brachiaria pastures included in this study have been established for over than 17 years, which implies a considerable process of degradation of genetic advantages that are expected from a selected material. We will further discuss this issue in following sections. The study also collected data collected on the use of fertilizers which is part of the recommendations made by CIAT and partners to favor the adoption of Brachiaria grasses and to enhance the potential impacts on productivity of these Brachiarias. The analysis of the data reveals that in the Eastern Plains and Llanos Piedmont (the largest region within the sample) less than 14% of those pastures are subject to some kind of fertilization process. The situation in the Amazon region (Caquetá and Putumayo) is even more dramatic as less than 3% of the pastures are under fertilization.

In addition to Colombia, we have also calculate the level of adoption of different forage cultivars from field data in Nicaragua (n=480 livestock producers) and using expert opinion estimates in Peru, Costa Rica and Honduras which are key countries where CIAT research has promoted the use of Brachiaria grasses. Figure 4 summarizes and compare the level of adoption of improved pastures in all countries considered in this study.

The situation of the adoption of improved pastures in most countries considered are different than the patterns observed in Colombia. In general there is a trend to observe a larger proportion of native pastures that ranks between 40 to 62% and having Peru as the country with less proportion of improved pastures (Figure 4).

Figure 4: Overall adoption rate of improved/selected pastures in selected countries



The low uptake of genetic improve varieties present a similar situation in all countries of the study. Perhaps Honduras showed a moderate diffusion of the improved hybrids (especially Mulato II), but the total adoption only reaches around 5% of the total acreage of the country. The level of adoption of introduced/selected improved varieties led by CIAT research reduces its importance outside of Colombia. In these countries the level of adoption of CIAT related varieties range between 7 and 15%. Other introduced/selected cultivars (mainly Brachiaria decumbens) seems to have been more widely distributed. Perhaps the presence of CIAT headquarters in Colombia may explain the differences among countries, but in general there is room to keep offering improved pastures to livestock producers in Latin-America. In any case, the expert opinion adoption estimation would need to be further verified with more rigorous adoption studies.

3.3. Livestock farmers' production and socio-economic conditions

As the submission of this technical report to SPIA we have fully processed the information of 651 surveys located in the Orinoquia (Eastern Planes and Llanos Piedmont) and Amazon regions. We are still working in the data cleaning and processing the information from the 178 surveys collected from the Caribbean region. However, The preliminary analysis that we are presenting in this report seems to fairly represent the overall tropical livestock farming in Colombia, which is essentially composed of meat and double purpose production systems (with the latter being a relatively small fraction). From now on, we present results based on these 651 observations. Table 1 summarizes some descriptive statistics of this subset of the study.

Table 1: Descriptive statistics for Orinoquia and Amazon regions

		Overall				Orinoquia		Amazon	
Variable	Obs.	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Mean	Std. Dev.
Farm size	651	243.6	535.1	1.5	7000.0	331.7	656.9	106.8	17e5.6
Extension Services	651	0.16	0.37	0.00	1.00	0.17	0.38	0.14	0.34
Farmer association	651	0.16	0.36	0.00	1.00	0.18	0.39	0.11	0.31
Access to credit	651	0.14	0.35	0.00	1.00	0.13	0.34	0.15	0.36
Fertilization (1 = Yes)	651	0.14	0.35	0.00	1.00	0.17	0.38	0.09	0.28
Weed control (1 = Yes)	651	0.86	0.35	0.00	1.00	0.85	0.36	0.87	0.34
Number of bovine vaccines	651	4.73	2.31	1.00	11.00	3.78	1.35	6.20	2.70
Farming assets index	651	3.36	1.89	0.00	9	4.10	1.83	2.22	1.34
Hired labor per hectare of pasture	651	0.37	0.70	0.00	10.00	0.45	0.66	0.25	0.73
Average wage per day	651	21415.8	12661.3	0.0	60000.0	25652.5	9468.9	14836.6	14119.7
Owner of the farm is the manager	651	0.58	0.49	0.00	1.00	0.57	0.50	0.60	0.49
Household head education: Primary	649	0.59	0.49	0.00	1.00	0.54	0.50	0.66	0.48
Household head education: Secondary	649	0.24	0.43	0.00	1.00	0.26	0.44	0.22	0.41
Household head education: Tertiary	649	0.10	0.31	0.00	1.00	0.16	0.37	0.01	0.11
Female HH	651	0.09	0.29	0.00	1.00	0.08	0.28	0.11	0.31
Household assets index	651	5.34	2.21	0.00	11	6.10	2.04	4.18	1.94
Arauca	68	10%							
Casanare	148	23%							
Guaviare	33	5%							
Meta	135	21%							
Vichada	12	2%							
Caquetá	160	25%							
Putumayo	95	15%							

Nearly 60.8% of information comes from farms located in the Orinoquia region, while 24.6% is located in department of Caquetá and 14.6% in Putumayo. This distribution of our study sample is consistent with the observed distribution of bovines across the same regions. The descriptive statics reports that the livestock producers are generally large producers in Colombia with an average farm size of about 243 hectares, reaching on average 535 hectares in the Orinoquia region (Table 1). In this area the study also found better average conditions in fertilization, extension services and participation in farmers' associations, household and farming assets, and level of education. Wages are also higher in the Orinoquia region, which makes sense due to the opportunity cost to hire labor in these remote areas. Better conditions of management like vaccination of the herd are found in the Amazon, given that these areas are geographically closer to tropical forests which can bring considerable diseases that affect livestock farming. On the other hand the study found that household heads / farm managers are less educated in this region compared to the Orinoquia.

3.4. Econometric results: determinants of adoption of Brachiaria grasses

In section 2.4 we described three specifications to model the determinants of technology adoption as a binary decision. Table 2 reports the distribution of adopters and non-adopters of Brachiaria according to the three cases previously defined. As noted before considered adoption of any Brachiaria yields an adoption level of almost 95%, but excluding old Brachiarias introduced before the existence of CIAT (basically Brachiaria Decumbens and specific cases of Brachiaria Ruziziensis) , the adoption of Brachiarias reaches 80%.. When considering any kind of Brachiaria that has been established since the year 2000, the rate of adoption is roughly 39%, and restricting both modern varieties and recent establishments gives an adoption rate of less than 37%. All these three definitions of adoption of Brachiarias can be modelled as binary decision and would allow to identify consistent determinants for its adoption.

Table 2: Adoption rates by four definitions

	Basic Definition		Case A		Case B		Case C	
	Obs.	Share	Obs.	Share	Obs.	Share	Obs.	Share
Non-adopter	33	5.1%	130	20.0%	396	60.8%	412	63.3%
Adopter	618	94.9%	521	80.0%	255	39.2%	239	36.7%

The econometric specifications reported in Table 3, show some interesting correlations that hold statistical significance even after controlling for fixed effects by department. A larger share of the farm into pastures for livestock production is associated with higher likelihood to adopt improved pastures. This correlation can be explained by livestock produces' interest in improving their expected income after reaching a large operation in cattle ranching. Being part of a farmer association and having access to credit is also related to being more likely to have plots that are more recently seeded with Brachiarias, as well as to have more of modern pasture varieties within those plots (Table 2). As expected, farms that are more intensive in labor are directly related with adoption of improved pastures. Likewise, the study found that areas with larger observed wages make it less likely to adopt better pastures. Although extension services seem to have an influence in the achievement of having plots that are more recently seeded than in the average, we found no correlation of them with the specific adoption of improved pastures either recently seeded or not.

Table 3: Binary regression model results[3]

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	Adoption Case A		Adoption Case B		Adoption Case C	
Owner of the farm is the manager (1 = yes)	-0.0733**	-0.0677	0.195***	0.132**	0.188***	0.125**
	(0.0331)	(0.0375)	(0.0571)	(0.0613)	(0.0567)	(0.0604)
Household head education: Primary	0.0405	0.0457	0.0409	0.0358	0.0711	0.0671
	(0.0553)	(0.0566)	(0.0894)	(0.0864)	(0.0838)	(0.0804)
Household head education: Secondary	0.0377	0.0378	0.0339	0.0220	0.0587	0.0453
	(0.0462)	(0.0492)	(0.0900)	(0.0870)	(0.0856)	(0.0845)
Household head education: Tertiary	-0.0673	-0.0588	-0.0371	-0.0310	0.0187	0.0199
	(0.0877)	(0.0848)	(0.0972)	(0.0988)	(0.0970)	(0.0985)
Female household head	0.00773	0.00171	-0.132**	-0.115*	-0.111*	-0.0958*
	(0.0421)	(0.0446)	(0.0601)	(0.0589)	(0.0581)	(0.0577)
Household assets index	0.0158**	0.0193***	0.0180*	0.0143	0.0237**	0.0179
	(0.00617)	(0.00669)	(0.0107)	(0.0115)	(0.0108)	(0.0111)
Farm size	5.50e-05	0.000108	-1.97e-05	-5.46e-05	6.73e-06	-2.36e-05
	(8.99e-05)	(0.000111)	(0.000102)	(0.000135)	(9.52e-05)	(0.000121)
Farm size (sq.)	-7.28e-09	-3.57e-08	1.39e-08	1.04e-10	9.33e-09	-8.21e-09
	(1.30e-08)	(2.64e-08)	(1.60e-08)	(3.44e-08)	(1.43e-08)	(3.09e-08)
Share of farm on pastures (%)	0.222***	0.213***	0.362***	0.316***	0.277**	0.224**
	(0.0740)	(0.0736)	(0.113)	(0.104)	(0.115)	(0.104)
Extension Services	-0.000837	0.0108	0.147**	0.134**	0.0677	0.0537
	(0.0443)	(0.0422)	(0.0640)	(0.0671)	(0.0701)	(0.0726)
Farmer association	0.00833	0.0199	0.190***	0.175**	0.140**	0.120*
	(0.0447)	(0.0454)	(0.0710)	(0.0710)	(0.0675)	(0.0676)
Access to credit	-0.0591	-0.0548	0.181***	0.149**	0.153***	0.127**
	(0.0517)	(0.0488)	(0.0554)	(0.0605)	(0.0514)	(0.0563)
Farming assets index	0.0227*	0.0219	0.00365	0.00161	-0.000949	-0.00639
	(0.0135)	(0.0134)	(0.0147)	(0.0161)	(0.0145)	(0.0156)
Distance to closest input market	0.00110	0.00184	0.00209	0.000842	0.00275*	0.00117
	(0.00134)	(0.00134)	(0.00156)	(0.00202)	(0.00150)	(0.00195)
Hired labor per hectare of pasture	0.0583	0.0699**	0.0868**	0.0715**	0.0867**	0.0719**
	(0.0357)	(0.0344)	(0.0386)	(0.0357)	(0.0368)	(0.0339)
(Log) Average wage per day	0.00611*	0.00442	-0.0118*	-0.0124**	-0.00936	-0.0116*
	(0.00341)	(0.00367)	(0.00654)	(0.00608)	(0.00664)	(0.00626)
Main customer: Auction	-0.0851	-0.117	-0.338***	-0.329***	-0.310***	-0.304***
	(0.109)	(0.120)	(0.0635)	(0.0627)	(0.0611)	(0.0585)
Acquired knowledge about Brachiaria within 10 yrs.	-0.0685	-0.0591	-0.103**	-0.0964*	-0.110**	-0.0916*
	(0.0454)	(0.0448)	(0.0512)	(0.0540)	(0.0483)	(0.0527)
Did use Brach previously?	0.159***	0.150***	0.0927	0.0961	0.100*	0.105*
	(0.0542)	(0.0565)	(0.0613)	(0.0602)	(0.0566)	(0.0559)
Observations	629	629	629	629	629	629
Department fixed effects	No	Yes	No	Yes	No	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Additional insights from different levels of adoption can be derived from the descriptive analysis from different quantiles of adoption intensity reported in Table 4. These quantiles of adoption intensity refers to any kind of Brachiaria grass within the farm's pastures. On average it is observed that larger farms are less likely to adopt improved pastures. In another interesting result, Table 4 shows that better pasture management conditions (better fertilization) and wealthier livestock producers (measured using a household assets index) are concentrated

[3] Reporting marginal effects.

between livestock producers in the second and fourth quantiles of adoption. On the other hand, some other management practices like weed controls and larger vaccination seem to be associated with smaller farmers (third and fourth quantiles of adoption). Since the relation between feasible explanatory variables and the different levels of adoption rate does not seem to be strictly linear, analyzing an ordinal model as proposed would be a good robustness check.

Table 4: Descriptive statistics for different quantiles of adoption intensity

	Q1		Q2		Q3		Q4	
N	33		159		150		309	
Variables	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Share of farm on pastures	0.0	0.0	0.3	0.2	0.8	0.1	1.0	0.0
Farm size	352.0	658.2	413.3	860.8	183.0	419.8	174.2	266.6
Extension services	9.1%		16.4%		18.7%		15.2%	
Farmer association	12.1%		20.8%		17.3%		12.3%	
Access to credit	6.1%		15.1%		22.0%		10.4%	
Fertilization (1 = yes)	6.1%		17.0%		11.3%		14.2%	
Weed control (1 = yes)	63.6%		86.2%		88.7%		86.7%	
Number of bovine vaccines	4.4	2.7	4.4	2.0	5.2	2.5	4.7	2.3
Household asset index	2.9	1.9	3.6	1.9	2.9	1.6	3.5	1.9
Hired labor per hectare of pasture	0.3	0.7	0.3	0.5	0.4	0.8	0.4	0.8
(log) Average wage	6.5	5.0	8.0	4.2	7.6	4.5	8.2	4.1
Owner of the farm is the manager	69.7%		71.7%		68.7%		45.0%	
HH Education: None	12.1%		4.4%		7.4%		6.8%	
HH Education: Primary	51.5%		57.2%		62.2%		58.6%	
HH Education: Secondary	15.2%		27.7%		21.6%		24.6%	
HH Education: Tertiary	21.2%		10.7%		8.8%		10.0%	
Female HH	15.2%		10.1%		7.3%		9.4%	

Tables 5, 6, and 7 show results of the ordered probit models considering the 3 scenarios defined in the methodological section. Although with are presenting the models with and without fixed effects for illustration, we concentrate our interpretations of the results on the models with fixed effects which helps to further control for unobservable effects specifically attributed to farmers' location.

Larger farms are less likely to fully establish Brachiaria grasses on the pasture land, presumably due to scale constraints. Managing large extension of land is a challenging task in the tropical areas of Colombia due to several factors that include security issues and lack of infrastructure. We also found that livestock farms where managers are also the land owners are also less likely to be high-or-full adopters. This can be explained by the fact that the larger the farm, owners may need to hire separate managers to efficiently managing the whole farm. Having the owner/manager combined role might make it harder and reduce the chances of innovate with new technologies. Apparently there is no significant correlation between the levels of education of the household head or his/her gender with the level of adoption intensity. Neither we found significant relations with extension services, farmer associations, or the fact of a farm having auctions as the main market channel for commercialization.

Table 5: Regression results for Ordered Model by *Definition A*[4]

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	Non-to-low Adopt (0-5%)		Partial Adopt (5-95%)		High-to-full Adopt (95-100%)	
Owner of the farm is the manager (1 = Yes)	0.0657***	0.0428***	0.256***	0.202***	-0.321***	-0.245***
	(0.0133)	(0.00983)	(0.0489)	(0.0455)	(0.0548)	(0.0506)
Household head education: Primary	0.000451	0.000826	0.00176	0.00390	-0.00221	-0.00473
	(0.0185)	(0.0165)	(0.0722)	(0.0777)	(0.0908)	(0.0942)
Household head education: Secondary	-0.00377	-0.00414	-0.0147	-0.0196	0.0185	0.0237
	(0.0188)	(0.0172)	(0.0735)	(0.0820)	(0.0923)	(0.0992)
Household head education: Tertiary	0.00836	0.0104	0.0326	0.0490	-0.0409	-0.0594
	(0.0249)	(0.0212)	(0.0949)	(0.0979)	(0.120)	(0.119)
Female household head	-0.00842	-0.00419	-0.0328	-0.0198	0.0412	0.0240
	(0.0177)	(0.0153)	(0.0681)	(0.0720)	(0.0857)	(0.0873)
Household assets index	-0.00398*	-0.00515**	-0.0155*	-0.0243**	0.0195*	0.0295***
	(0.00207)	(0.00205)	(0.00820)	(0.00961)	(0.0101)	(0.0114)
Farm size	0.000103***	8.39e-05***	0.000399***	0.00039***	-0.00050***	-0.00048***
	(2.53e-05)	(2.18e-05)	(8.47e-05)	(9.47e-05)	(0.000100)	(0.000108)
Farm size (sq.)	-1.3e-08***	-1.1e-08***	-5.1e-08***	-5.1e-08***	6.5e-08***	6.2e-08***
	(5.07e-09)	(4.15e-09)	(1.72e-08)	(1.75e-08)	(2.15e-08)	(2.09e-08)
Share of farm on pastures (%)	0.0413	0.0376	0.161	0.178	-0.202	-0.215
	(0.0292)	(0.0252)	(0.110)	(0.111)	(0.138)	(0.135)
Extension Services	-0.00356	-0.0101	-0.0139	-0.0476	0.0174	0.0576
	(0.0115)	(0.0106)	(0.0445)	(0.0481)	(0.0559)	(0.0585)
Farmer association	0.0128	0.00345	0.0499	0.0163	-0.0627	-0.0197
	(0.0111)	(0.00986)	(0.0453)	(0.0467)	(0.0561)	(0.0566)
Access to credit	-0.00533	-0.0120	-0.0207	-0.0568	0.0261	0.0688
	(0.0116)	(0.0113)	(0.0455)	(0.0553)	(0.0571)	(0.0663)
Farming assets index	-0.00678**	-0.00493	-0.0264**	-0.0233*	0.0332**	0.0282*
	(0.00330)	(0.00304)	(0.0121)	(0.0133)	(0.0151)	(0.0162)
Distance to closest input market	0.000445	0.000218	0.00173	0.00103	-0.00218	-0.00125
	(0.000343)	(0.000316)	(0.00135)	(0.00155)	(0.00168)	(0.00187)
Hired labor per hectare of pasture	0.00855	0.00194	0.0333	0.00916	-0.0418	-0.0111
	(0.00668)	(0.00589)	(0.0252)	(0.0278)	(0.0316)	(0.0337)
(Log) Average wage per day	-0.00200*	-0.000945	-0.00778*	-0.00447	0.00978*	0.00541
	(0.00110)	(0.000997)	(0.00427)	(0.00461)	(0.00530)	(0.00558)
Main customer: Auction	0.0359	0.0284	0.140	0.134	-0.176	-0.162
	(0.0293)	(0.0278)	(0.117)	(0.134)	(0.145)	(0.161)
Acquired knowledge about Brachiaria within 10 yrs.	0.0143	0.00946	0.0557	0.0447	-0.0700	-0.0541
	(0.0138)	(0.0130)	(0.0509)	(0.0574)	(0.0644)	(0.0702)
Did use Brach previously?	-0.0323	-0.0273	-0.126*	-0.129*	0.158*	0.156*
	(0.0204)	(0.0182)	(0.0661)	(0.0697)	(0.0855)	(0.0870)
Observations	629	629	629	629	629	629
Department fixed effects	No	Yes	No	Yes	No	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Another finding of this analysis refers to a no significant correlation between the observed level of adoption and farm-and-production specific characteristics, like the distance with respect to inputs markets, labor intensity or wages, and the having known Brachiaria grasses during the last ten years. On the other hand, models results show that having previous experience with Brachiaria grasses makes the farmer more likely to be a high-or-full adopter of this improved pastures. Although variables like access to credit and farming assets that has been traditionally

[4] Reporting marginal effects for each category.

identified as determinants of technology adoption showed similar trends of influencing a full adoption of Brachiarias, patterns, we found no significant effects through the three specifications.

Table 6: Regression results for Ordered Model by *Definition B*[5]

VARIABLES	(1) Non-to-low Adopt (0-25%)	(2)	(3) Partial Adopt (25-50%)	(4)	(5) High-to-full Adopt (75-100%)	(6)
Owner of the farm is the manager (1 = yes)	0.127***	0.0870***	0.145***	0.118***	-0.272***	-0.205***
	(0.0313)	(0.0255)	(0.0341)	(0.0331)	(0.0601)	(0.0555)
Household head education: Primary	-0.0347	-0.0331	-0.0398	-0.0447	0.0746	0.0777
	(0.0406)	(0.0343)	(0.0467)	(0.0477)	(0.0870)	(0.0817)
Household head education: Secondary	-0.0136	-0.0150	-0.0156	-0.0203	0.0292	0.0354
	(0.0398)	(0.0351)	(0.0459)	(0.0484)	(0.0857)	(0.0835)
Household head education: Tertiary	-0.0157	-0.0126	-0.0180	-0.0171	0.0338	0.0297
	(0.0544)	(0.0470)	(0.0633)	(0.0642)	(0.118)	(0.111)
Female household head	0.0235	0.0316	0.0270	0.0427	-0.0504	-0.0743
	(0.0338)	(0.0309)	(0.0398)	(0.0435)	(0.0735)	(0.0741)
Household assets index	-0.0116***	-0.0153***	-0.0133**	-0.0207***	0.0249***	0.0360***
	(0.00442)	(0.00450)	(0.00552)	(0.00619)	(0.00967)	(0.0102)
Farm size	0.00022***	0.00018***	0.00026***	0.00025***	-0.00049***	-0.00043***
	(5.55e-05)	(5.00e-05)	(6.30e-05)	(6.81e-05)	(0.000109)	(0.000111)
Farm size (sq.)	-2.8e-08***	-2.4e-08***	-3.25e-08***	-3.2e-08***	6.08e-08***	5.6e-08***
	(8.77e-09)	(8.66e-09)	(9.32e-09)	(1.11e-08)	(1.72e-08)	(1.91e-08)
Share of farm on pastures (%)	0.0839	0.0714	0.0963	0.0965	-0.180	-0.168
	(0.0583)	(0.0481)	(0.0636)	(0.0628)	(0.121)	(0.110)
Extension Services	-0.0117	-0.0314	-0.0135	-0.0424	0.0252	0.0738
	(0.0222)	(0.0214)	(0.0252)	(0.0273)	(0.0473)	(0.0482)
Farmer association	0.0318	0.0164	0.0365	0.0222	-0.0684	-0.0386
	(0.0243)	(0.0231)	(0.0279)	(0.0309)	(0.0519)	(0.0539)
Access to credit	-0.0325	-0.0419*	-0.0373	-0.0567*	0.0698	0.0986*
	(0.0256)	(0.0235)	(0.0288)	(0.0319)	(0.0540)	(0.0546)
Farming assets index	-0.00300	-0.00353	-0.00345	-0.00478	0.00645	0.00831
	(0.00586)	(0.00603)	(0.00668)	(0.00799)	(0.0125)	(0.0140)
Distance to closest input market	0.000969	0.000278	0.00111	0.000375	-0.00208	-0.000653
	(0.000758)	(0.000749)	(0.000913)	(0.00103)	(0.00166)	(0.00178)
Hired labor per hectare of pasture	0.00671	-0.00793	0.00770	-0.0107	-0.0144	0.0187
	(0.0121)	(0.0135)	(0.0140)	(0.0179)	(0.0260)	(0.0314)
(Log) Average wage per day	-0.00282	-0.00186	-0.00324	-0.00252	0.00606	0.00438
	(0.00278)	(0.00239)	(0.00333)	(0.00330)	(0.00608)	(0.00568)
Main customer: Auction	0.0488	0.0396	0.0559	0.0535	-0.105	-0.0931
	(0.0516)	(0.0481)	(0.0623)	(0.0677)	(0.114)	(0.115)
Acquired knowledge about Brachiaria within 10 yrs.	0.0295	0.0335	0.0338	0.0452	-0.0633	-0.0787
	(0.0265)	(0.0262)	(0.0290)	(0.0330)	(0.0553)	(0.0588)
Did use Brach previously?	-0.0638*	-0.0562*	-0.0732*	-0.0760*	0.137*	0.132*
	(0.0383)	(0.0334)	(0.0388)	(0.0390)	(0.0762)	(0.0715)
Observations	629	629	629	629	629	629
Department fixed effects	No	Yes	No	Yes	No	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

[5] Reporting marginal effects for each category.

Table 7: Regression results for Ordered Model by *Definition C*[6]

VARIABLES	(1) Non-to-low Adopt	(2) Low-to-partial Adopt	(3) Partial-to-high Adopt	(4) High-to-full Adopt
Owner of the farm is the manager (1 = yes)	0.0856***	0.0470***	0.0606***	-0.193***
	(0.0250)	(0.0137)	(0.0188)	(0.0531)
Household head education: Primary	-0.0337	-0.0185	-0.0239	0.0761
	(0.0348)	(0.0192)	(0.0260)	(0.0795)
Household head education: Secondary	-0.00765	-0.00420	-0.00542	0.0173
	(0.0346)	(0.0191)	(0.0248)	(0.0785)
Household head education: Tertiary	-0.0123	-0.00675	-0.00871	0.0278
	(0.0480)	(0.0265)	(0.0344)	(0.109)
Female household head	0.0368	0.0202	0.0261	-0.0830
	(0.0315)	(0.0184)	(0.0231)	(0.0724)
Household assets index	-0.0151***	-0.00828***	-0.0107***	0.0341***
	(0.00486)	(0.00307)	(0.00341)	(0.0107)
Farm size	0.000174***	9.54e-05***	0.000123***	-0.000392***
	(5.36e-05)	(2.74e-05)	(4.18e-05)	(0.000114)
Farm size (sq.)	-2.34e-08***	-1.29e-08***	-1.66e-08**	5.29e-08***
	(9.04e-09)	(4.24e-09)	(6.51e-09)	(1.89e-08)
Share of farm on pastures (%)	0.109**	0.0598**	0.0773**	-0.246**
	(0.0536)	(0.0284)	(0.0387)	(0.117)
Extension Services	-0.0220	-0.0121	-0.0156	0.0496
	(0.0210)	(0.0113)	(0.0139)	(0.0460)
Farmer association	0.00901	0.00494	0.00638	-0.0203
	(0.0253)	(0.0140)	(0.0178)	(0.0571)
Access to credit	-0.0425*	-0.0233*	-0.0301*	0.0958*
	(0.0251)	(0.0139)	(0.0179)	(0.0558)
Farming assets index	-0.00325	-0.00178	-0.00230	0.00733
	(0.00583)	(0.00312)	(0.00409)	(0.0130)
Distance to closest input market	0.000340	0.000187	0.000241	-0.000768
	(0.000753)	(0.000424)	(0.000546)	(0.00172)
Hired labor per hectare of pasture	-0.0103	-0.00564	-0.00728	0.0232
	(0.0150)	(0.00816)	(0.0104)	(0.0335)
(Log) Average wage per day	-0.00101	-0.000552	-0.000712	0.00227
	(0.00245)	(0.00136)	(0.00176)	(0.00556)
Main customer: Auction	0.0461	0.0253	0.0326	-0.104
	(0.0488)	(0.0280)	(0.0364)	(0.113)
Acquired knowledge about Brachiaria within 10 yrs.	0.0336	0.0184	0.0238	-0.0759
	(0.0278)	(0.0144)	(0.0192)	(0.0607)
Did use Brach previously?	-0.0613*	-0.0336**	-0.0434**	0.138**
	(0.0329)	(0.0169)	(0.0194)	(0.0675)
Observations	629	629	629	629
Department fixed effects	Yes	Yes	Yes	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

[6] Reporting marginal effects for each category. Only cases with department fixed effects are reported due to space limitations.

3.5. Econometric results: productivity & income impacts of adoption of Brachiaria grasses

To estimate productivity impacts associated with the adoption of Brachiaria cultivars the study defines a productivity variable that considers not only the weight of the animals within the pastures, but also the specific specialization of different animals on the farm herd (whether it is a cow for milk production, or is it a calf, steer, or a bull for meat commercialization). We separately account for animals devoted to with milk production and animals that are targeted to be commercialized for meat and then aggregate these animal units.

$$Milk\ Animal\ Units = \frac{weight\ of\ cows}{650Kg}$$

$$Meat\ Animal\ Units = \frac{weight\ of\ calfs, steers\ and\ bulls}{450Kg}$$

$$Farm\ Productivity = \frac{[Milk\ Animal\ Units] + [Meat\ Animal\ Units]}{Area\ in\ pastures}$$

To analyze the partial effect of the share (as percentage) of Brachiaria grasses on farm's productivity we converted the productivity measure into its logarithmic scale. Likewise for estimating impacts of Brachiaria pastures on farm income, we estimated livestock income from cattle sales during the last reported year and analyzed its partial effect also with respect to the share of Brachiaria among farm pastures. We noted that not all of livestock producers reported livestock sales during the last year, due to several factors that include not having cattle with adequate age for selling (2-3 years old). This situation generated that model specifications for impacts on livestock income where performed with a smaller sample size.

Tables 8 and 9 summarizes the results of the 2SLS regression models of productivity and income impacts in columns two and four while they also report the first stage regression results in columns one and three. These first regressions include several variables to control for the intensity of adoption of Brachiaria grasses that were not included in the productivity equation, and explicitly test the relationship of our selected instrument *violence that limited access to input markets* and the decision to intensify the use of Brachiaria grasses. We found the expected partial effect of the instrument on the endogenous variable of interest: violence is significantly correlated with a smaller share of pastures dedicated to Brachiaria grasses, which makes the selected instrument to meet the first criteria for a good instrument.

Table 8: First and second stage regressions: impact of Brachiaria intensity in productivity

VARIABLES	(1) Share of pastures on Brachiaria (%)	(2) (log) Animal units per ha / weighted	(3) Share of pastures on Brachiaria (%)	(4) (log) Animal units per ha / weighted
Share of pastures on Brachiaria (%)		1.174***		0.480
		(0.379)		(0.479)
Farm size	-0.000360***	-0.00103***	-0.000309***	-0.00126***
	(5.55e-05)	(0.000185)	(5.47e-05)	(0.000201)
Farm size (sq.)	4.61e-08***	1.27e-07***	4.38e-08***	1.76e-07***
	(1.03e-08)	(2.80e-08)	(1.01e-08)	(3.49e-08)
Extension Services	0.0358	-0.0539	0.0453	-0.0235
	(0.0364)	(0.0815)	(0.0354)	(0.0760)
Farmer association	-0.0480	0.103	-0.0220	0.0626
	(0.0354)	(0.0849)	(0.0346)	(0.0775)
Access to credit	0.0407	0.0247	0.0612*	0.0651
	(0.0365)	(0.0829)	(0.0357)	(0.0789)
Fertilization	0.00841	0.0126	0.0150	-0.00154
	(0.0383)	(0.0952)	(0.0378)	(0.0882)
Weed control	0.0291	-0.0831	0.0334	-0.0616
	(0.0365)	(0.103)	(0.0355)	(0.0995)
Number of vaccines that applies to cattle	0.0185***	-0.0372**	0.0192***	0.0131
	(0.00593)	(0.0173)	(0.00640)	(0.0196)
Farming assets index	0.00687	0.0622***	0.00878	0.0488**
	(0.00827)	(0.0205)	(0.00822)	(0.0199)
Hired labor per hectare of pasture	0.00549	0.201***	0.0171	0.193***
	(0.0187)	(0.0508)	(0.0182)	(0.0358)
(Log) Average wage per day	0.00651*	-0.000633	0.00464	-0.00663
	(0.00343)	(0.00956)	(0.00341)	(0.00907)
Owner of the farm is the manager (1 = yes)	-0.166***		-0.116***	
	(0.0283)		(0.0289)	
Household head education: Primary	0.00456		0.00265	
	(0.0514)		(0.0498)	
Household head education: Secondary	0.000451		0.000721	
	(0.0552)		(0.0536)	
Household head education: Tertiary	-0.0418		-0.0541	
	(0.0661)		(0.0646)	
Female household	-0.0235		-0.0328	
	(0.0435)		(0.0422)	
Household assets index	0.0192***		0.0222***	
	(0.00646)		(0.00648)	
Violence limiting access to inputs	-0.112***		-0.0881***	
	(0.0309)		(0.0316)	
Distance to closest input market	-0.00104		0.000109	
	(0.000834)		(0.000848)	
Main customer: Auction	-0.0673		-0.0631	
	(0.0805)		(0.0785)	
Acquired knowledge about Brachiaria within 10 yrs.	-0.0529*		-0.0505	
	(0.0318)		(0.0321)	
Did use Brach previously?	0.106***		0.0898***	
	(0.0305)		(0.0305)	
Constant	0.595***	-1.032***	0.371***	-0.603**
	(0.0770)	(0.280)	(0.0953)	(0.259)
Observations	632	624	632	624
R-squared	0.230	0.225	0.288	0.347
Method	2SLS (1st Stage)	2SLS	2SLS (1st Stage)	2SLS
Department fixed effects	No	No	Yes	Yes
Hansen test p-value		0.42		0.07
Excluded instruments test p-value		0.00		0.00

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Colum 2 shows that without including department fixed effect there is a positive and significant effect of the intensity use of Brachiaria on Farm productivity after controlling for endogeneity associated with the adoption of Brachiarias. This suggest that an additional 1% adoption of Brachiaria grasses is associated with an extra 1.17% of animal unit per hectare of land (Table 8). However, once department fixed effect are accounted for, the treatment effect is no longer significant, in spite of exploiting the exogenous variation of the instrument. These preliminary results may indicate no increases in productivity that can be attributed to a larger share of Brachiaria grasses. Hansen's test and the test for excluded instruments performed to the 2SLS specifications make resulted in statistical validity and relevance of the instruments and therefore of the model results.

We used the same instrument for estimating the impact of the share of Brachiaria grasses on livestock income and the 2SLS regression results along with the first regression results are reported in Table 9. Without controlling for department fixed effects the regression results show that an increase of 1% of the share of pastures in Brachiaria grasses is related to a significant increase of 2.76% on sales income. Furthermore, after controlling for this department fixed effects, we still found statistically significant increase of sales income in about 1.57% due to an increase in 1% on the adoption level of Brachiaria grasses. Although this finding may offer evidence of a positive impact of Brachiaria grasses, the Hansen test p-value showed no statistical significance, not providing the support that the instrument is working well in this estimation. An explanation for this result may be related to the loss of observations in the income model. We will further test this hypothesis once we will be able to add the observations coming from the Caribbean region. Unfortunately, so far we cannot provide evidence on the impacts of the use of Brachiaria grasses on livestock income.

Table 9: First and second stage regressions: impact of Brachiaria intensity in cattle sales

VARIABLES	(1) Share of pastures on Brachiaria (%)	(2) (Log) Income from livestock sales	(3) Share of pastures on Brachiaria (%)	(4) (Log) Income from livestock sales
Share of pastures on Brachiaria (%)		2.764***		1.578*
		(0.717)		(0.853)
Farm size	-0.000332***	-0.000688**	-0.000277***	-0.00109***
	(6.54e-05)	(0.000347)	(6.48e-05)	(0.000320)
Farm size (sq.)	4.27e-08***	7.79e-08	4.00e-08***	1.44e-07***
	(1.18e-08)	(4.75e-08)	(1.16e-08)	(4.76e-08)
Extension Services	0.0541	-0.156	0.0825*	-0.0798
	(0.0445)	(0.173)	(0.0438)	(0.169)
Farmer association	-0.0458	0.0406	-0.0254	-0.0312
	(0.0433)	(0.196)	(0.0423)	(0.167)
Access to credit	0.0617	-0.0877	0.0739*	0.0253
	(0.0447)	(0.190)	(0.0438)	(0.176)
Fertilization	0.0195	-0.0437	0.0164	-0.161
	(0.0464)	(0.201)	(0.0460)	(0.191)
Weed control	0.0702	-0.636***	0.0663	-0.410**
	(0.0516)	(0.213)	(0.0507)	(0.201)
Number of vaccines that applies to cattle	0.0187**	-0.174***	0.0183*	-0.0743*
	(0.00919)	(0.0438)	(0.00980)	(0.0424)
Farming assets index	0.00368	0.125***	0.00534	0.0956**
	(0.0109)	(0.0453)	(0.0109)	(0.0405)
Hired labor per hectare of pasture	0.0200	0.357**	0.0397	0.297**
	(0.0273)	(0.140)	(0.0269)	(0.122)
(Log) Average wage per day	0.0103**	-0.0579**	0.00959*	-0.0612***
	(0.00495)	(0.0234)	(0.00493)	(0.0212)
Owner of the farm is the manager (1 = yes)	-0.151***		-0.0920**	
	(0.0379)		(0.0394)	
Household head education: Primary	0.0186		0.0199	
	(0.0795)		(0.0775)	
Household head education: Secondary	0.0175		0.0255	
	(0.0830)		(0.0807)	
Household head education: Tertiary	-0.0493		-0.0641	
	(0.0917)		(0.0898)	
Female household	-0.0971		-0.106*	
	(0.0644)		(0.0626)	
Household assets index	0.0198**		0.0251***	
	(0.00843)		(0.00846)	
Violence limiting access to inputs	-0.132***		-0.106**	
	(0.0404)		(0.0413)	
Distance to closest input market	-0.00146		-0.000194	
	(0.00104)		(0.00106)	
Main customer: Auction	-0.0395		-0.0281	
	(0.0864)		(0.0851)	
Acquired knowledge about Brachiaria within 10 yrs.	-0.110**		-0.116**	
	(0.0473)		(0.0473)	
Did use Brach previously?	0.0881**		0.0918**	
	(0.0391)		(0.0392)	
Constant	0.510***	11.95***	0.207	12.37***
	(0.118)	(0.451)	(0.139)	(0.389)
Observations	414	414	414	414
R-squared	0.229	0.112	0.288	0.309
Method	2SLS (1st Stage)	2SLS	2SLS (1st Stage)	2SLS
Department fixed effects	No	No	Yes	Yes
Hansen test p-value		0.66		0.13
Excluded instruments test p-value		0.00		0.01

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

3.6. Expected environmental impacts from adoption of Brachiaria grasses

As mentioned before, this is an ongoing activity that will offer preliminary results beyond this SPIA project. So far the forages samples collecting in farms in the Orinoquia have been processed by 60%. The data from in vitro gas production and the corresponding analyzes will be available by the end of September 2017

3.7. Econometric results: Willingness to pay for sustainable livestock land-use practices

Descriptive Statistics

The main descriptive statistics of silvo-pastoral (SP) and improved pasture (IP) questionnaires are reported in Appendix 1. Most livestock producers in our sample were male (83.6% in the SP survey and 89.3% in the IP. See tables 8 and 12). The average age for respondents was 49 years. The educational level of respondents is relatively low. Most of them have completed elementary school but only 17% of SP respondents and 17% of IP respondents have completed higher education (See tables 9 and 13). There were some differences on farm size by region. For the sample of livestock producers who responded the SP survey, the regions with highest average farm size were Casanare and Vichada with mean size of 1017 ha and 1.556 ha, respectively. The same pattern was observed for farm land of improved pastures´ respondents. The smaller farms were found in the department of Caquetá from the Amazon region, with average farm size of 92 hectares for the IP respondents and 84 hectares for the SP respondents. Average farm size in Arauca and Meta ranged from 248 to 752 hectares. The average forest area of the farms of SP respondents was 56.6 ha while the average grass area (savanna) was 312 ha. For the IP respondents, the average forest area was 54.7 ha, the average cover in savanna was 358 ha while the average cover in improved pastures was 92.7 ha. Only 15% of the respondents of SP survey considered to be very knowledgeable on silvo-pastoril systems while most of them (73%) considered that SP systems were very important for their farms. Statistics from the frequencies of responses from the choice sets are reported from table 17 to table 23.

Estimation Results

Table 8 presents the results of the conditional logit model of equations (3) and (4). Table 9 presents the direct elasticity effect of each of the attributes on the likelihood of adopting a conservation program, namely silvo-pastoral adoption (SP) and introduced pastures (IP). Table 10 presents the compensation payments (Willingness to Accept WTA) in Col $ per hectare/year for each of the conservation programs, for each the attributes of the programs.

Table 8. Estimation results of the conditional logit model

Variable	Silvopastoral	Introduced pastures
	coefficient (SD)	Coefficient (SD)
Area in silvo-pastoral use	0.03181*** (0.0096)	
Area with improved pastures		0.07299*** (0.02387)
Basic technical assistance in forrages	0.47362** (0.2140)	
Complete technical assistance in forrages	0.9125*** (0.2358)	
Basic technical assistance in production	0.3826** (0.2068)	0.9444*** (0.2332)
Complete technical assistance in production	1.1342*** (0.2583)	1.9269*** (0.3342)
Payment for adoption	0.1234E-05*** (0.1963E-06)	0.2493E-05*** (0.3871E-06)
Constant program 1	-0. 2014 (0.4062)	0.5724 (0.5758)
Constant program 2	-0.1051 (0.3994)	0.7185 (0.5676)
Total Obs	290	256
Log-likelihood	-186.8121	-142.7

**** Significant at 99%, ** Significant at 95%, *Significant at 90%*

Most respondents in both programs (SP and IP) respondents would prefer to join a conservation program than never choosing a scheme option. Among the program´s attributes, the compensation payment has the greatest direct influence on adoption (See direct elasticity effect on table 9) while the basic production assistance has the lowest influence. Payment compensation increases the likelihood of adopting Silvo-pastoral scheme by 34%. The same attribute increases the likelihood of adopting the improved pastures scheme by 32% (lower bound). Technical assistance in forages and in production seem valued similarly by farmers responding the Silvo-pastoral survey; basic technical assistance in forages and in production increases the likelihood of SP program participation by 8.2% and 7.3% respectively. The likelihood of participation increases as the assistance level increase. The probability of SP program participation increases by 11.49% with the presence of complete technical assistance in forages and by 11.9 with complete technical assistance in production. Interestingly the likelihood of participation in larger for the IP program in the presence of technical assistance. Basic technical assistance in production increases program participation by 18.2 % while complete technical assistance increases the likelihood of participation by 16%. Increasing the area in silvo-pastoral use or improve pastures has a positive effect on program participation. The likelihood of participation increases with this attribute by 24% in the SP program and by 29% in the IP program.

Table 9. Direct elasticities

Variable	**Silvopastoril**		**Introduced pastures**	
	Lower bound Elasticity (SD)	Upper bound Elasticity (SD)	Lower bound Elasticity (SD)	Upper bound Elasticity (SD)
Area in silvopastoral use	0.2410 (0.2305)	0.2627 (0.2411)		
Area with improved pastures			0.2924 (0.2734)	0.3834 (0.3120)
Basic technical assistance in forrages	0.0821 (0.1395)	0.0927 (0.1480)		

Complete technical assistance in forrages	0.1149 (0.2256)	0.1243 (0.2383)		
Basic technical assistance in production	0.0734 (0.1128)	0.0876 (0.1267)	0.1872 (0.2997)	0.1965 (0.2901)
Complete technical assistance in production	0.1192 (0.2560)	0.1233 (0.2644)	0.1603 (0.390)	0.1935 (0.4534)
Compensation payment	0.3405 (0.3624)	0.3596 (0.3800)	0.3212 (0.3734)	0.4157 (0.4680)

Table 10 reports farmers' valuations for the attributes based on the compensation payments (WTA measure). Our monetary valuation results suggests that the main incentive to participate in the conservation program is given by the technical assistance attributes. The most valued attribute of the program is the complete technical assistance in production; in the silvo-pastoral scheme the average valuation of this attribute is $856,000 ha/year. The monetary valuation of the technical assistance in forages is $688,755 per ha/year. Basic technical assistance in production for the respondents of the improved pasture (IP) program was valued at $378,808 while the valuation for the complete assistance in production was $772843. The calculated average compensation payment for retiring land for silvo-pastoral uses is $24,012 per ha/year while the compensation for retiring land for improved pastures was $29,276 per ha/year.

Table 10. Compensation payments

Compensation payment	Silvopastoral Compensation (SD)	Introduced pastures Compensation (SD)
Area in silvopastoral use	24012** (12060)	
Area with improved pastures		29276*** (12030)
Basic technical assistance in forrages	357469** (189342)	
Complete technical assistance in forrages	688755*** (268437)	
Basic technical assistance in production	*288776* *(177474)*	378808*** (97146)
Complete technical assistance in production	856044*** (320745)	772843*** (149137)
Wald statistic:	8.7470	30.0370

****** Significant at 99%, ** Significant at 95%, *Significant at 90%*

Discussion

This document investigates cattle farmers´ willingness to accept for two conservation programs. The first encompassed a silvo-pastoral scheme while the second focused on the implementation of improved pastures using different types of Brachiarias. Understanding farmers 'preferences for the adoption of conservation programs is important for designing economic incentive schemes aimed to mitigate environmental impacts of extensive livestock systems. The application of choice experiments is a very flexible analytical tool to understand the monetary valuation for non-marketable attributes of conservation programs, which may be useful for guiding environmental policies.

Our results are suggestive but non-conclusive. First most interviewed farmers are willing to participate in the choice experiments´ proposed programs. Second, estimation results suggest that the likelihood of participation increases with payment compensation, as it would be expected from a theoretical point of view. Furthermore, attributes such as complete technical assistance are highly valued by farmers. The monetary valuation of both complete assistance in forages and production were much higher in magnitude that their basic technical assistance versions, in both the silvo-pastoral scheme and the improved pastures one.

This research could inform policies oriented to the conservation of the Colombian Orinoco Region, especially in a moment where the Payment for Environmental Services are part of the Colombian environmental regulation process (decree 870 of 2017). Implementing environmentally friendly grazing management options to increase productivity and protect the environment requires of the understanding of farmer´s preferences for incentive based conservation programs. This research aimed to contribute in this regard.

4. Concluding remarks and the way forward

Documenting the adoption and impacts of Brachiaria and other grasses is a relevant and under evaluated. This document reports on activities implemented through the project funded and supported by SPIA but highlighting that this is still an ongoing effort that will be completed beyond the timeframe of the SPIA initiative.

The project faced delays at the beginning of its implementation due to delays in completing the main agreement contract and the related sub-contracts with participating partners. The field work faced further challenges as it was hit with an unusual and strong rainy period that made it difficult to complete data collection as planned. The original timeframe of 18 months to complete the study was already challenging. Having at the end only 13 months to complete the task put even more challenges on to the team. Although a no-cost extension was not feasible due to commitments of SPIA with the donor to finalize the SIAC project, the partner organizations in this study have decided to continue working beyond the end of the SPIA project and complete all deliverables that were envisioned at the beginning of the study.

Some activities were however completed during the implementation of this study. For the first time there are rigorous estimates of the level of adoption of Brachiaria grasses and we could identify a variety of determinants of this adoption. We have provided preliminary results of the productivity and income impacts of the adoption of improved pastures. Although there are some trends that suggest some impacts of the use of Brachiaria grasses, we still do not have sound evidence of these impacts. We are working on robustness checks of our models, trying alternative specifications and adding extra observations to the analysis that were not available to complete this preliminary analysis.

We are currently implementing the analysis of biophysical measurements performed in Colombia to estimate environmental effects of the adoption of Brachiaria grasses, but definite results could only be completed by the end of 2017. Likewise, we need to complete all pieces of adoption and impact estimates in order to estimate the aggregate impacts of the adoption of Brachiaria forage grass in Latin-America. This activity will be performed using an economic surplus model and it is expected to be completed by December 2017 as well.

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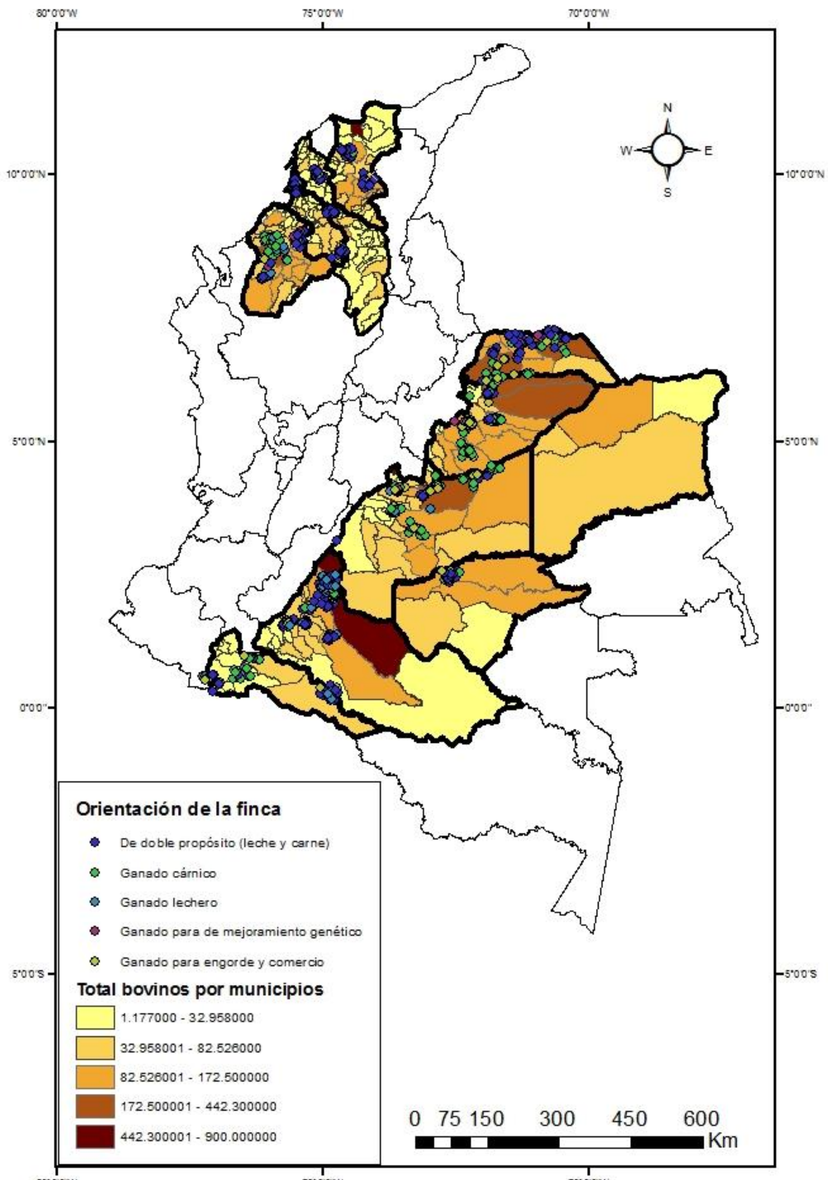
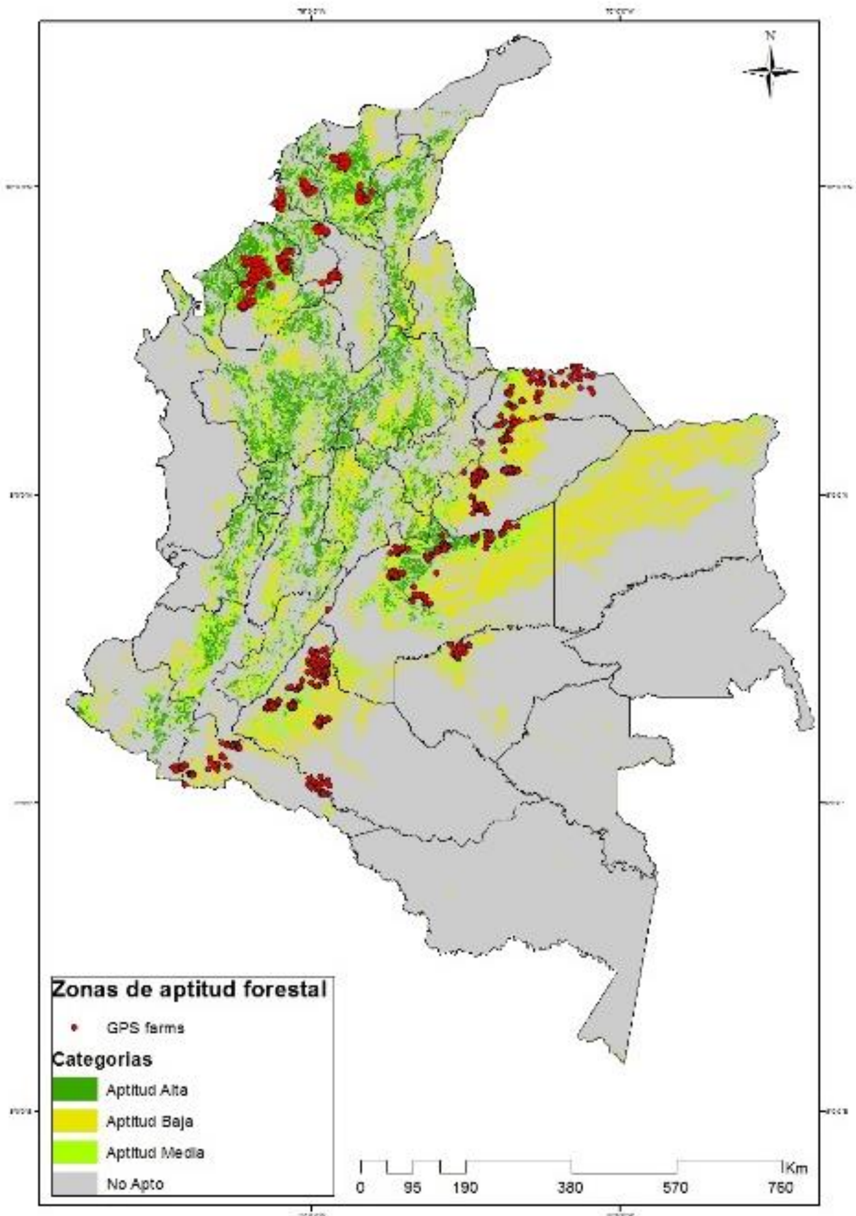
Appendix

Figure A1: Sample data location with respect to number of bovines at the municipality level



Source: Own elaboration with data from ICA (2016).

Figure A2: Sample data location with respect to forestry suitability



Source: Own elaboration with data from IGAC (2017)