ENVIRONMENTAL MANAGEMENT & CONSERVATION | RESEARCH ARTICLE

Adoption potentials and barriers of silvopastoral system in Colombia: Case of Cundinamarca region

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Abstract: Silvopastoral system (SPS) is highlighted as an alternative to conventional cattle farming systems in Colombia, where deforestation, driven by extensive cattle farming, is a severe environmental issue. However, despite its considerable benefits, adoption of SPS remains very limited in Colombia. Thus, the objective of this work is to investigate the potential for scaling up the adoption of SPS by identifying the barriers perceived by farmers, using a case study of tropical land at a high altitude over 2400 m in Cundinamarca department, Colombia. Qualitative research methodology is used in accordance with the conceptual framework constructed on the basis of adoption theories and literature reviews. The data were collected using semi-structured interviews with 27 farmers managing cattle farming. The results show that while farmers perceive numerous benefits of SPS, it is perceived as highly risky due to climate conditions. Additionally, concerns about long-term investments necessary to obtain benefits from SPS as well as its high complexity are discouraging. Furthermore, low

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Seonhwa Lee is a researcher with economic background holding a MSc degree focused in Rural Development in Ghent university in Belgium and Humboldt university in Germany. Her areas of interest are rural resilience, rural inclusion, rural transport, and infrastructure. She has regional specialty primarily in Latin America based on her professional experiences in social development project in Colombia and international organization in the region such as ECLAC, and currently working at the transport division of Inter-American Development Bank (IDB). This research work contributes to the project “Implementing sustainable agricultural and livestock systems for simultaneous targeting of forest conservation for climate change mitigation (REDD+) and peace-building in Colombia,” with the working group Sustainable Land Use in Developing Countries (SusLAND) in Leibniz Centre for Agricultural Landscape Research (ZALF). This project is a part of the International Climate Initiative (IKI) supported by Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) of Germany.

PUBLIC INTEREST STATEMENT

Deforestation driven by extensive cattle farming is a global issue due to the severe environmental impact. In this sense, the agroforestry practices such as Silvopastoral system (SPS) have been encouraged as an alternative of the conventional cattle farming; however, its adoption rate remains at a very low level. Thus, this study has an objective to identify the inhibiting factors of SPS implementation through the bottom-up approach analyzing farmers’ perspective and to establish the enabling conditions for scaling-up its adoption. The research was conducted in Cundinamarca region, Colombia. The results show that while farmers perceive numerous benefits of SPS, some of the characteristics of implementing SPS such as high complexity, high risk, and low compatibility were perceived negatively due to their internal conditions and external barriers. Based on these identified barriers, the enabling conditions such as long-term extension services provision for strengthening farmers’ motivations were recommended for the policy implications.
compatibility due to the socio-economic barriers and traditional belief regarding trees in pasture are also verified as an external barrier for adopting SPS practices. In this context, the enabling conditions for scaling-up SPS adoption in the study area are discussed: strengthening farmers’ motivation with provision of long-term extension services and transforming the conventional concept of tree removal as well as the appropriate project designs given farmers’ socio-economic conditions and the adequate selection of tree species.

**Subjects:** Agriculture & Environmental Sciences; Forestry; Environmental Studies; Environment & Agriculture

**Keywords:** agroforestry; adoption; perception; qualitative research

1. Introduction
Deforestation, defined as a direct and/or human-induced conversion from forestland to a different type of nonforest land in certain period of time (Achard et al., 2012), is a severe environmental issue in Colombia. According to the Institute of Hydrology, Meteorology, and Environmental Studies in Colombia (IDEAM, 2018), 44% more land was deforested in 2016 than in 2015. Among the principal drivers of deforestation, the expansion of the agricultural frontier by extensive cattle farming is highlighted as a main driver, representing 60% of deforested area in Colombia (Morales, 2017). According to Rural Agricultural Planning Unit (UPRA, 2015), of the 38 million ha used for livestock farming, over 70% is extensively managed with low cattle density. This extensive tropical cattle farming has serious consequences, not just with respect to environmental degradation but also the low efficiency and profitability of individual farms (López-Vigoya et al., 2017).

Furthermore, cattle farming is increasing as farmers give up illicit crops, such as coca, following Colombia’s long-term national conflict, and substitute with cattle farming rather than alternative agricultural cultivation like cocoa or fruit (Castro-Nuñez et al., 2017; Masera et al., 2009; Morales, 2017). Cattle farming is considered to be a preferred livelihood activity, because it is seen as a less risky activity than cash-crop agriculture, which has higher dependency on climate conditions and the market situation of chemical inputs. Thus, this behavior is not just motivated by the profitability of the activity, but also by its benefits as a risk mitigation strategy (Coomes et al., 2008).

Within the aforementioned context, integrating the silvopastoral system (SPS) has significant potential for increasing sustainable land use in Colombia, where the elevated rate of deforestation driven by extensive cattle farming has acute impacts on the regional scale beyond the local level (Montagnini, 2018). Silvopastoral system (SPS) is an agroforestry land use management system in which trees are managed and combined with livestock farming for multiple purposes (Aryal et al., 2019; Calle et al., 2009; Mercer, 2004). Abundant scientific evidence demonstrates that agroforestry, including SPS, can provide both environmental accountability and enhanced production, when it is properly designed and managed (Jose & Dollinger, 2019; Murgueitio et al., 2010; Rami et al., 2004; Rioux, 2012).

Nevertheless, SPS adoption remains at very low levels in Colombia. UPRA (2015) verifies that 26.5 millions of hectares (ha) are used for agriculture, with 15%—4 million ha—has potential for agroforestry, but only 216,000 ha are currently used for agroforestry, which accounts for only 5% of the potential 4 million ha. This marginal adoption of SPS is not only a problem for Colombia, but also other Latin American countries (Braun et al., 2016).

1.1. Conceptual framework
The decision-making processes underlying the adoption a new technology or innovation is widely discussed and an established research area for multiple disciplines. Within agriculture, a new technology or innovation can refer to new alternative farming systems or activities that aim to
improve the sustainability and livelihood of farmers (Zabala, 2015). In order to scale up the adoption of new farming systems or innovations, it is critical to analyze existing theories and models that explain the process of technology acceptance as well as the independent factors that may influence individual decision making.

One of the most renowned and applied theory for adopting process of new technology is the Diffusion of Innovation (DOI) model of Rogers (2003). The DOI model is chosen as the conceptual framework of this study for several reasons: first, since agriculture is considered to be a distinctive economic activity, it is associated with the specific knowledge of innovation to be transferred, thus, an appropriate theoretical approach is necessary. The DOI model is tested using numerous agricultural research projects and is found to be an applicable theory (Frey et al., 2012; Ndah, 2014; Tomaš et al., 2014; Zabala, 2015). Further, comparing adopters and nonadopters in the same community is key for determining the potential of diffusion and the subsequent scaling up SPS adoption. The decision-making process of the DOI model can encompass both nonadopters and adopters, thus helping to clarify the inhibiting factors that farmers face depending upon where they are in the decision making process.

In the DOI model, Rogers (2003) explains three major components of the process of how one innovation can be adopted by the individuals: (1) innovation decision process, (2) adopter characteristics, and (3) characteristics of innovation.

In the (1) innovation decision process, five stages of adopting a new innovation are introduced, going from knowledge, persuasion, decision, implementation, to confirmation. As technology adoption is a multi-dimensional process, a number of independent factors should be considered in each step. Rogers (2003) argues that the adoption decision is not a one-time process, but rather the individuals pass through the process of perceiving the new technology and implementing it as a trial. There is a possibility that the individual may reject the innovation because he or she is not satisfied because of its performance, because the innovation does not meet their needs, or because it does not provide a perceived relative advantage (Sahin, 2006). Taking into account the decision-making process in the DOI model, the conceptual framework is illustrated in the Figure 1 below:
This conceptual framework also illustrates the socio-economic profile of farmers and their characteristics of production in order to obtain information about (2) adopters’ characteristics and provide deeper analysis of their perceptions about SPS and their results of the adoption.

Moreover, (3) five characteristics of an innovation are identified by Rogers (2003), as perceived by the adopters and influencing to their decision-making: relative advantage, compatibility, complexity, trialability, and observability. Rogers (2003) argues that innovations offering more relative advantage, compatibility, simplicity, trialability, and observability will be adopted relatively faster than other innovations.

In this study, according to the inherent characteristics of SPS, Rogers (2003) five characteristics of an innovation are partly modified and amplified to seven characteristics in order to analyze farmer perceptions as following:

(i) **Cost of implementing SPS:** Relative advantage in the DOI model by Rogers (2003) consists of costs and benefits of adopting the new system. Thus, the cost level to build and maintain SPS as perceived by farmers is investigated.

(ii) **Benefit of implementing SPS:** How much the economic benefits or the profitability of SPS as perceived by farmers is investigated.

(i) **Time to obtain the benefit of SPS:** Since the literature frequently mentions the long-term process to earn the benefits as one of the main barriers for SPS (Braun et al., 2016; Dagang & Nair, 2003; Masehcha, 2003), farmer perceptions toward this extended timeframe to obtain benefits are investigated.

(ii) **Complexity of SPS:** The level of complexity, meaning how complex or difficult it is to realize the practices of SPS from the perspective of farmers is clarified.

(iii) **Compatibility of implementing SPS:** How farmers perceive the time and labor required for implementing SPS is asked. Additionally, whether the current conditions of farmers and their farms are able to manage SPS is also ascertained.

(iv) **Risk of adopting SPS:** Here how farmers perceive the risk—whether there is a high probability that the system will not work as expected in the future—related to implemented SPS.

(v) **Observability of the change in the farm after implementing SPS:** Observability indicates whether the farmers can observe any physical difference in their farm’s environment after adopting SPS, since it is important if the farmers can actually recognize the difference before and after implementing SPS practices by themselves.

For the data analysis, it was assumed that all the behavioral results of the interviewed farmers could be classified into three categories: (i) farmers who are not aware of SPS or have very little knowledge (Before knowledge stage), (ii) farmers with certain level of knowledge and perceptions, but who have decided not to adopt SPS (in decision stage), and (iii) farmers who adopted SPS, at different stages of implementation (in implementation stage).

Therefore, the main research question is: **How can the adoption of the Silvopastoral system (SPS) be scaled-up in the study area?** This study aims to understand the underlying factors that discourage farmers from adopting SPS by analyzing farmer perceptions regarding SPS.
implementation. A bottoms-up approach to understand the farmers’ perspective is indispensable for identifying the conditions that enable scaling-up the adoption of sustainable land use systems. In this sense, capturing the main motivations and barriers that determine farmers’ decisions for adopting and implementing SPS through farmers’ perceptions was the core of this research project. Farmers might show more negative perception toward specific categories and, additionally, perceptions might vary across categories depending on many factors like farmers’ characteristics, adoption level, or adopted practices, etc. Based on the results, the barriers in each stage of the farmers’ decision-making process were verifiable and the enabling conditions to scale-up the farmers’ adoption and implementation of SPS were discussed.

2. Data collection and methods

2.1. Study area

With the support of University of Applied and Environmental Sciences (Universidad de Ciencias Aplicadas y Ambientales—U.D.C.A.), the research area comprised four subareas close to Bogotá D.C., where livestock farming was a dominant agricultural activity. The first is the Chiquaque and Ubaque (Belén, Quente, Barro Blanco, and Alto del Ramo villages) municipalities. The second is the Suesca municipality (Güita and San Vicente Villages), where the respondents were split up across some villages in the region. The third comprises the Mochuelo Alto Village, which is located within the Ciudad Bolívar locality of Bogotá city, keeping in mind that this is a rural context despite being part of Bogotá. Finally, the fourth area is the peri-urban area at the very north side of Bogotá city called Guaymaral (shown in Figure 2).

The research areas not only share the common characteristics of being geographically located within close access to Bogotá D.C., but also as being classified as high altitude tropical land, at over 2400 m. The Cundinamarca region comprises tropical land with high altitude (Trópico alto), where the altitude is more than 2000 m, with this region having different climate conditions in terms of temperature, dry season, humidity, precipitations, etc. versus low altitude tropical lands (Castriñón, 2013). The study area belongs to the cold thermal floor (el Piso térmico frío), which represents land between 2000 m and 3000 m, with temperatures between 12 and 18°C throughout the year. El Piso térmico frío makes up almost 33% of the Cundinamarca region (IDEAM, 2018) and, in this region, milk production dominates over beef production.

Figure 2. Study area
2.2. Data analysis methods

Qualitative research methods are a suitable approach in this case, since these “can reveal insights about behaviors or processes that are not obtainable from quantitative data” (Imas & Rist, 2009). To address sustainability challenges, it is necessary to previously map what are central elements of the problematics. In this sense, as pointed out by Nature Sustainability (2020), a lot of knowledge is only uncovered through qualitative means. Such methods can be more practicable to address urgent issues or where large samples are difficult to access: “often few people are pivotal to gain certain insight, so a large-N survey or experiment cannot replace a rich and nuanced interview or focus group discussion” (Nature Sustainability, 2020). Considering the lack of farmer-oriented studies from the study area, this research also aims to provide informative data for later studies.

A qualitative research methodology was chosen because it is an especially useful tool in exploratory studies, as it can contextualize the issue, providing the foundation for subsequent quantitative research (Prokopy, 2011). The research questions were better suited for qualitative research approaches since the objective was to explore the farmers’ subjective perceptions and behaviors with respect to implementing a new system. In this case, qualitative data provided by semistructured interviews are more useful to understand the process and to identify the mechanisms of farmers’ decision-making process than one-time surveys (Prokopy, 2011).

To investigate farmers’ perceptions of SPS and their motivation for (non) adoption, semistructured interviews were conducted. Data collection was done by using applying a questionnaire constructed according to the conceptual framework of this work, consisting of three main parts: (i) exploring farmers’ socio-economic characteristics and current farm and production; (ii) categorizing farmers depending on their knowledge level of SPS and its adoption level through face-to-face interviews and farm observations; (iii) investigating their perceptions regarding the seven characteristics of implementing SPS. For those farmers who were unaware of SPS, the interview focused more on their current livestock farming system and their general perceptions of agroforestry.

In total, 27 interviews with farmers were conducted; 10 farmers in peri-urban areas of Bogotá, 8 in Suesca, and 9 in Chipaque. The approach adopted to define the number of people interviewed within the communities was based on three criteria: (a) diversity, (b) number, and (c) minimum equilibrium. For (a) diversity, it was determined that the sample should include all different communities in the territory/case of study but also share similar characteristics. Also, (b) the number of farms to be sampled was arbitrarily set to be of around 1% of the total number of farms that had any kind of SPS in the given municipality. The total number of farms and farms with any kind of SPS in study area are shown in Table 1 and among 27 interviewed farmers, 11 farmers using SPS practices were identified initially by previous participation in activities with the university; in the sequence, the snowball sampling method was used to identify other farmers. Also, for the comparison between adopters and nonadopters, the farms with cattle ranching were randomly selected by the farm visit. (c) minimum equilibrium, the collected material should present repeated

<table>
<thead>
<tr>
<th>Region</th>
<th>Total number of farms</th>
<th>With any kind of SPS</th>
<th>Visited farms</th>
<th>% of visited farms with any SPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bogotá</td>
<td>4,912</td>
<td>577</td>
<td>10</td>
<td>6 (1.03%)</td>
</tr>
<tr>
<td>Suesca</td>
<td>3,519</td>
<td>280</td>
<td>8</td>
<td>2 (0.71%)</td>
</tr>
<tr>
<td>Chipaque</td>
<td>3,767</td>
<td>303</td>
<td>9</td>
<td>3 (0.99%)</td>
</tr>
<tr>
<td>Total</td>
<td>12,198</td>
<td>1160</td>
<td>27</td>
<td>11 (0.95%)</td>
</tr>
</tbody>
</table>

(Source: DANE—Agricultural Consensus, 2014)
information as a collective representation (symbolic systems, ideas, values, attitudes, and perceptions) in relation to the research issues. Thus, to establish the sample we also observed if it was possible to identify a certain pattern, a common practice from the material obtained, and allowing set conditions for generalization (Bonatti et al., 2016). Thus, the number of respondents was considered sufficient when it was possible to identify a pattern, a common practice from the material obtained, and allowing set conditions for generalization (Bonatti et al., 2016).

Farmers’ responses were collected using open-ended questions and each farmer could mention distinct responses as much as he/she would like to answer, regardless of positive or negative aspects. All interviews were recorded and transcribed verbatim during the data analysis stage, with each statement described in one category, then counted and grouped. This analysis involved the process of coding key words or phrases in the communication and then classifying each into positive or negative perceptions using an ordinal scale that can be added or subtracted in the same manner (Frey et al., 2012).

In order to capture the difference of how one group of farmers perceive each characteristic of SPS, whether relatively more positively or negatively, net perception mean percentages for each category were calculated. Following the method of Frey et al. (2012), each respective distinctive response was considered in ordinal scale and multiplied by the number of farmers who gave that response. As Frey et al. (2012) mention, this method might not be ideal for capturing the exact net perception of farmers, since it assumes that the farmers place equal weight on the importance of each of the different factors that they mention. However, if the farmers identified disadvantages of SPS less frequently relative to number of perceived benefits, it could be deduced that the farmers have a favorable view to the system in terms of the specific category in general.

3. Results

3.1. Social diagnosis of respondents and farming characteristics
The respondents’ characteristics and farm profiles are summarized in Table 2. Of the interviewed farmers, 63% were male and over 80% of farmers were older than 40, averaging more than 10 years of cattle farming experience. In the research area, there was a variety of farm ownership, with more than 60% of interviewed farmers owning their own farm property; there were also farmers who rent the farm with their own cattle and those who were employed by the land owner without their own cattle. Most interviewed farmers (77%) had less than 10 ha, with a maximum size of 70 ha; all are classified as small-holder farmers in Colombia. The most dominant production type in research area was milk production and double-purpose production, with average production of 12–13 liter per day in the dry season and 2.98 units of cows per ha calculated.

3.2. Farmers’ adoption of SPS in research area
Depending on the number of practices adopted on each farm, the implementation level of SPS was determined; for example, one to three practices is considered as a low-level adoption and four to five practices with a fodder bank is a high level of adoption. Although there might be certain limitations to determining farmers’ implementation level by the number of practices they adopted, it can be used as a way of categorizing farmers in the initial adopting stage. Further, in verifying farmers’ adoption, it was important that the farmers should recognize the function of SPS practices on the farm and understand its objectives.

Therefore, as shown in Tables 3 and 4, the adoption level remained low, with 11 farmers (41%) adopting up to three practices, mostly living fences, dispersed trees in paddocks, and wind-breakers, but none of the farmers had implemented a protein bank for animal feed use. Another six farmers had a certain level of knowledge about SPS and had some perceptions about it; however, their decisions resulted in nonadoption of SPS. The last ten farmers were unaware of SPS or had very little knowledge of how the system works.
Table 2. Summary of respondents' characteristics

<table>
<thead>
<tr>
<th>Category</th>
<th>Variables</th>
<th>No. of farmers</th>
<th>% in total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Male</td>
<td>17</td>
<td>63%</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>10</td>
<td>37%</td>
</tr>
<tr>
<td>Age</td>
<td>Less than 40 years old</td>
<td>5</td>
<td>18%</td>
</tr>
<tr>
<td></td>
<td>Older than 40 years old</td>
<td>22</td>
<td>82%</td>
</tr>
<tr>
<td>Working period of cattle farming</td>
<td>Less than 10 years</td>
<td>5</td>
<td>19%</td>
</tr>
<tr>
<td></td>
<td>More than 10 years</td>
<td>22</td>
<td>81%</td>
</tr>
<tr>
<td>Farm ownership</td>
<td>Own property</td>
<td>17</td>
<td>63%</td>
</tr>
<tr>
<td></td>
<td>Family member's property</td>
<td>4</td>
<td>15%</td>
</tr>
<tr>
<td></td>
<td>Rented land with farmer's own cattle</td>
<td>2</td>
<td>7%</td>
</tr>
<tr>
<td></td>
<td>Employed</td>
<td>4</td>
<td>15%</td>
</tr>
<tr>
<td>Farm size</td>
<td>1–10 ha</td>
<td>21</td>
<td>77%</td>
</tr>
<tr>
<td></td>
<td>10–50 ha</td>
<td>2</td>
<td>7%</td>
</tr>
<tr>
<td></td>
<td>50–100 ha</td>
<td>4</td>
<td>15%</td>
</tr>
<tr>
<td>Production type</td>
<td>Milk production</td>
<td>14</td>
<td>52%</td>
</tr>
<tr>
<td></td>
<td>Meat production</td>
<td>1</td>
<td>4%</td>
</tr>
<tr>
<td></td>
<td>Double-purpose production</td>
<td>9</td>
<td>33%</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>3</td>
<td>11%</td>
</tr>
<tr>
<td>Production unit</td>
<td>Average number of cattle per ha</td>
<td>2.98</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average milk production quantity per cattle (litter/day)</td>
<td>12–13</td>
<td></td>
</tr>
</tbody>
</table>

Source: Author's own calculation

Table 3. Number of adopters and nonadopters of SPS practices

<table>
<thead>
<tr>
<th>Decision-making categories</th>
<th>Nonadopters</th>
<th>Adopters</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before knowledge</td>
<td>Decided not to adopt</td>
<td>Decided to adopt in low level</td>
</tr>
<tr>
<td>Number of farmers</td>
<td>10 (37%)</td>
<td>6 (22%)</td>
<td>11 (41%)</td>
</tr>
</tbody>
</table>

Source: Author's own calculation

Table 4. Number of adopted SPS practices

<table>
<thead>
<tr>
<th>Practices of SPS</th>
<th>Living fences</th>
<th>Windbreaker</th>
<th>Dispersed trees in paddocks</th>
<th>Fodder bank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of farmers</td>
<td>11</td>
<td>3</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>

Source: Author's own calculation

3.3. Perception analysis

For the group of 11 adopters and 6 nonadopters with a certain knowledge level of SPS, their perceptions of SPS were investigated. Table 5 summarizes their perceptions: For the adopters' group, 30 distinctive responses were collected in total, comprising 20 positive responses and 10
<table>
<thead>
<tr>
<th>Category</th>
<th>Perception (+: positive, -: negative)</th>
<th>Rate of response (%)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Adaptors</td>
<td>Nonadopters</td>
</tr>
<tr>
<td>Cost</td>
<td>+</td>
<td>45%</td>
<td>.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>36%</td>
<td>.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>18%</td>
<td>16%</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>36%</td>
<td>33%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>18%</td>
<td>.</td>
</tr>
<tr>
<td>Benefit</td>
<td>+</td>
<td>55%</td>
<td>.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>55%</td>
<td>33%</td>
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<tr>
<td></td>
<td></td>
<td>27%</td>
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<tr>
<td></td>
<td></td>
<td>27%</td>
<td>.</td>
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<tr>
<td></td>
<td></td>
<td>18%</td>
<td>16%</td>
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<td></td>
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<td>18%</td>
<td>16%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>18%</td>
<td>.</td>
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<tr>
<td></td>
<td></td>
<td>9%</td>
<td>.</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>.</td>
<td>16%</td>
</tr>
<tr>
<td>Time to get benefit</td>
<td>+</td>
<td>36%</td>
<td>.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>64%</td>
<td>67%</td>
</tr>
<tr>
<td>Complexity</td>
<td>+</td>
<td>45%</td>
<td>16%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>36%</td>
<td>16%</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>36%</td>
<td>67%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>27%</td>
<td>33%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.</td>
<td>33%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>27%</td>
<td>16%</td>
</tr>
</tbody>
</table>
negative responses throughout the 7 categories of SPS characteristics. For the nonadopters group, 19 distinctive responses were collected, respectively 8 positive responses and 11 negative responses across 6 categories of perceived SPS characteristics; with the exception of observable changes on the farm. It was also notable that some of the responses overlapped in multiple categories since one distinctive perception might incorporate various aspects of SPS underlying it.

Discussing the responses in details, in terms of the cost category, the positive perception of SPS reflected the ease of obtaining seeds from local trees and tree donations from previous projects, thus the farmers did not necessarily buy the trees with their own financial resources and they perceived the cost as very low. However, depending on the quantity of trees needed for bigger farms, the number of trees received via donations or seeds from local trees may not be sufficient; thus, both adopters and nonadopters requiring high financial investment may perceive SPS negatively. Additionally, 18% of adopters group mentioned that their costs increased due to maintaining planted trees and protecting them against cattle, especially those trees dispersed across the paddock.

Regarding the recognized benefits of SPS, all 11 adopters were generally satisfied with their current SPS practices and indicated their willingness to continue or expand their SPS practices should there be any opportunity to participate in project or capacity building courses, or even independently. A number of positive responses regarding “Benefit” were recorded by adopters' group, among them, the principal benefits were recognized as higher humidity on the farm (55%)
and the provision of shade for improving animal wellbeing (55%). Specific benefits of SPS were also mentioned, including better soil and forage quality, additional animal feed, and tree byproducts. On the contrary, for the nonadopters group, the perceived benefits were not as great, in many cases as very abstract. Although benefits, such as shade for cows (33%), general benefits for the environment (16%), and timber provision (16%), were mentioned, these benefits did not convince these farmers to adopt SPS.

The perception regarding the time needed to obtain benefits from SPS showed obvious differences between adopters, with seven farmers perceiving the long time to wait after implementing the SPS negatively, while the remaining four farmers perceived it positively. The verified time to obtain benefits from SPS in the research area varied depending on the intensity of practices and utilized trees species, but average between 3 and 5 years. Farmers with positive perceptions recognized this time period as worthwhile for the environment, while the entire nonadopters group and the adopters with negative perceptions were discouraged and demotivated with respect to performing the activities.

In terms of SPS complexity, farmers showed different perceptions depending on each SPS practice. Living fences were considered as much easier to adopt, needing less skill to carry out. However, other SPS practices, like windbreakers and fodder banks, were perceived as requiring greater knowledge and skills. Moreover, both adopters and nonadopters group addressed the difficulty of maintaining trees during the initial phase, noting that farmers faced several issues when managing trees and the trees were resulted to have a low survival probability, given climatic conditions and protection from animals attacks. Due to this fact, many farmers remained confused when implementing further SPS practices, particularly the fodder bank.

Regarding the compatibility of conducting SPS, 64% of adopters showed negative perceptions since it required more time and labor investment, especially during the very initial stages of planting. Efforts also depended on the number of implementing practices and its scale. In addition, some farmers in the nonadopters group also mentioned the spatial issue as they rotated their pasture with cultivation and meadow for cattle on a regular basis or even rented spare pasture to other farmers, which was an impediment to placing dispersed trees across pastures or even as living fences.

Further, regarding the risk of implementing SPS, the responses gaining more than 70% among the 30 distinctive responses was “Climate condition incurs high risk.” It implies that due to repetitive and severe dry seasons, most adopters noted a high risk of implementing SPS, a point connected with the high complexity of SPS.

Last, but not least, the observability of changes on the farm after implementing SPS was asked to the adopters’ group, with more than half of farmers mentioning the improved animal wellbeing and the visual change in farm environment as more lively, with more animals.

3.4. Net perceptions
Table 6 summarizes the calculated net perceptions percentages for both groups of adopters in a low level and nonadopters in decision stage.

According to the results, farmers with low adoption levels perceived the “Risk” of SPS as its most negative characteristic, followed by “Compatibility” and “Time to obtain benefit”; meanwhile they simultaneously perceived huge benefits of SPS and its observable changes. Compared to this, it is found that farmers who did not adopt SPS perceived the “Complexity” of SPS as its most negative characteristic, followed by “Time to obtain benefit” and “Compatibility.”
Table 6. Net perception of adopters and nonadopters for each characteristic of SPS

<table>
<thead>
<tr>
<th>Category</th>
<th>Net perception mean percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adopters</td>
<td>Nonadopters</td>
</tr>
<tr>
<td>Cost</td>
<td>27%</td>
</tr>
<tr>
<td>Benefit</td>
<td>227%</td>
</tr>
<tr>
<td>Time to obtain benefit</td>
<td>-27%</td>
</tr>
<tr>
<td>Complexity</td>
<td>-9%</td>
</tr>
<tr>
<td>Compatibility</td>
<td>-27%</td>
</tr>
<tr>
<td>Risk</td>
<td>-64%</td>
</tr>
<tr>
<td>Observability of change in farm</td>
<td>182%</td>
</tr>
</tbody>
</table>

Source: Author’s own calculation

3.5. Nonadopter group before knowledge

Among the 27 interviewed farmers, 10 were categorized as nonadopters before knowledge, which means they were not aware of SPS or had very little knowledge of it. Interviews with these farmers sought to clarify the potential of their adoption of SPS practices and general recognition of functions of trees on the farm.

Above all, 60% of farmers recognized that trees can provide shade to the cattle, which may be very beneficial during the dry season with its strong sunlight, although they believed it can be achieved with a small number of trees rather than building a complete SPS. Further, under circumstances where they cannot see the benefits of implementing the new system, farmers were reluctant to adopt it since it will require more time and labor to do so (60%); in particular dispersed trees were identified as the SPS practice that has most negative perceptions since farmers had the idea that the trees are not beneficial for the pasture and are incompatible with cultivation.

4. Discussion

4.1. Barriers of adopting SPS and the enabling conditions to scale-up the adoption

Constructing enabling conditions requires demonstrating the potential of embedded, collaborative approaches by identifying the constraints and challenges in specific locations by designing proper political programs and institutional environments (FAO, 2006). Based on the identified main barriers to adopting and integrating SPS on the farm, the following enabling conditions are recommended for policy implementation.

The first identified barrier is the high complexity and high risk that are the most negatively perceived characteristics of adopting SPS by both the nonadopters’ group and low-level adopters’ group of farmers, respectively. It is notable that there are two common factors—the climate conditions and further SPS practices such as fodder bank and dispersed trees in the paddocks—identified as underlying the perceived complexity and risk of SPS, inferring that its high complexity is linked to the perception that SPS is highly risky.

Climate conditions in the study area were emphasized by all farmers, revealing the difficulty of managing pasture and initiating SPS practices. In the research area, precipitation amounts decrease by 75% in the dry season compared to the wet season (IDEAM, 2018). In an additional question posed to all 27 farmers, they were asked if they perceived any climate change compared to the past; over 90% acknowledged that the dry season period had been prolonged, with both the dry and wet seasons experiencing more intense levels of precipitation and sunlight. Since climate conditions are an external variable, farmers mostly showed a pessimistic attitude toward integrating trees into their farming due to the risk associated with the low survival rates of planted trees as
well as slow growth rates and highly complicated work to overcome these barriers until the trees become more resistant to various shocks.

Additionally, as the existing literature addresses (Braun et al., 2016; Dagang & Nair, 2003; Mahecha, 2003), the inherent drawback of SPS is the innately long-term process needed to obtain its benefits, thus aggravating the complexity and the risk of adopting SPS. Braun et al. (2016) noted that producers often expect short-term benefits and express low personal interest when considering the opportunity costs associated with agroforestry, even though the final economic result is very attractive.

Another remarkable point is that the nonadopters group did not perceive enough benefits of integrating SPS practices on their farm, even thinking that trees in a paddock may harm pasture growth. Traditionally, pasture is maintained without trees due to the belief that the trees might take all the nutrients from the soil instead of growing nutrient forage; further, tree roots will expand too much, which is not conducive for good pasture. From a question about the slow diffusion of SPS, which was asked of the 17 farmers with knowledge of SPS, over 75% noted the traditional thinking to create pasture by cutting down all the trees. This dominate belief underlines the lack of consciousness about sustainability, discouraging farmers from implementing SPS practices, causing them to miss the potential benefits of integrating trees and forage shrubs into their pastures, including improved cattle productivity (Murguetio et al., 2010). Orefice et al. (2017) note that farmers, whose primary farm income is cattle-based, would perceive the benefits of SPS management in terms of cattle production and wellbeing, rather than advantages from the additional revenues generated by tree byproducts, like crops or timber.

Thus, it is a crucial mission to strengthen farmers’ motivation to adopt a new system that has high complexity and risk under the given conditions by highlighting the benefits that can be gained by implementing SPS. In this sense, long-term extension services with financial and technical support is indispensable to reducing the risk of failure by facilitating their understanding of SPS. It is also paramount that projects and agents should grasp the principal benefits of SPS that farmers could believe to be the most crucial for their livelihoods. These should be based on their needs, keeping in mind the current situation, such that SPS adoption can be promoted, emphasizing those specific benefits. Given climate conditions in research area, the environmental benefits from adopting SPS could be considered as a positive externality for the farmers, since the farmers are already aware of how environmental degradation is linked to actual productivity loss, thus mitigating its impact by adopting SPS could also motivate farmers who are struggling with low productivity during the dry season.

In addition, farmers’ participation in SPS courses underlines the varying awareness of the concept of sustainability and environmental conservation. It could make a different starting point for accepting new agricultural innovations and help farmers realize the detrimental consequences of the conventional cattle farming system, meaning that more projects and courses should be encouraged and actively promoted to fill the knowledge gap for farmers, thus facilitating the acceptance of SPS practices. Moreover, organizing communal tree nurseries or setting-up demonstration farms that show the community the best management practices regarding livestock, trees, and forages, are also observed as an option both to increase farmers’ collective participation and to visibility show the benefits of SPS to the entire community.

The second barrier, especially for farmers leasing farmland and pasture or those who are employed, highlights the challenges related to land tenure status, which severely affects the farmers’ decision to adopt SPS. Farmers without land ownership typically use unsustainable land use systems because there is no financial or labor incentive for them to implement SPS. In the study area, since it is easy accessible from Bogotá, numerous farmers might lease their farm or work as employee, while the land owners live in the city. Within such a land tenure system, high
transaction costs are generated and planting trees will cause various issues with respect to land rental agreements and also ownership of tree products (Rioux, 2012).

In this context, recognizing farmers’ socio-economic background, including land tenure and production types, is vital for comprehending the current capability of farmers to adopt new agricultural innovations and design proper projects. The results show that one of the main factors preventing farmers from integrating SPS is farm and land ownership, which often is incompatible with adoption. Land tenure is crucial for promoting sustainable land use systems (FAO, 2002), since tenant farmers, with short-term leases, will not see the long-term benefits of SPS, which requires an initial investment of capital and labor. Moreover, tenant farmers will need permission from the landowner to change land usage. This external and critical obstacle prevents the scaling-up of not just SPS adoption, but also expanding all kinds of sustainable land use systems. Thus, to strengthen the impact of SPS projects, facilitating lease agreements that provide incentives or rewards at the end of the lease period and intervening to develop effective leases that distribute the benefits and costs between tenant and landowners is necessary (FAO, 2002).

Last, but not least, a lack of knowledge regarding how to implement SPS is identified as one of the principle barriers. SPS requires specific tree species and most farmers indicated that they are unaware of the appropriate trees for SPS, which ones can function as fodder banks and wind-breakers: this is related to the lack of knowledge from the initial stage of implementation. Limited information about new systems create high uncertainty that discourages farmers from trying new agricultural practices (Wilson, 2008) and generates high costs due to its low efficiency.

For this, selecting appropriate tree species adapted to each local context, especially the fodder shrub for SPS, is critical (Murgueitio et al., 2010). In high altitude tropical lands, under dynamic climate conditions, like the research area, careful selection of tree species is especially important, as ensuring that trees are resistant to cold temperatures will facilitate better tree growth. In this sense, native tree species will play a key role in mitigating the high risk of tree survival and enhancing ecosystem services in the pastoral landscape, while also helping to lower the farmers’ cultural, technological, and financial barriers related to planting trees (Murgueitio et al., 2010). The main species with high potential for use under SPS identified in the study area are: Saucito (Sambucus nigra), Aliso (Alnus Acuminata), Arboloco (Montana quadrangularis), Cedro (Cedrela montana), Roble (Quercus Humboldtii), and Sauce (Salix babylonica), among others. These trees were also recommended and donated by previous projects and capacitación courses managed by local governments and organizations, given their characteristics of easy acquisition, better resistance to the given climate conditions, and relatively rapid growth. Each species has adequate purposes and functions while the strategic and systematic mixture of trees for implementing each SPS practice is necessary to ensure a successful implementation of SPS.

4.2. Limitations of research
This research has certain limitations regarding the data-collection process, the sample size, and unbalanced samples for each category of farmers, all clear constraints to capturing greater heterogeneity and deriving more general results. Collecting samples across scattered sites represented the diversity of farmers, but differences across communities were neglected in the data analysis.

Further, in the study area, the levels implemented SPS practices were shown to be limited, with only a small number of practices, carried out at low intensities, such that the applicability of this perception analysis might be limited to farmers who are in the initial stage of adopting SPS, in other words, it might show different perception patterns among farmers implementing the whole system at an intensive level.

Moreover, this study did not emphasize the costs of implementing SPS practices, even though a lack of financial resources is frequently cited as a very significant factor affecting SPS adoption (Calle et al., 2009; Mahecha, 2003; Manuel et al., 2016). Since most farmers integrating SPS have
received assistance in the form of the donations of trees by previous projects and implementing SPS at a low level, the captured perceptions toward cost of implementing SPS might be biased to be as a noncritical barrier.

5. Conclusion
This study explores the reasons underlying the low adoption rate of the silvopastoral system (SPS), despite abundant research favoring SPS and promotions to scale-up its adoption. It is found that numerous inhibiting factors exist, comprising both external and internal SPS factors, thus hindering the integration of SPS on farms and slowing further diffusion. The internal inhibiting factors of SPS, such as the long-term investment required to obtain benefits, highly perceived complexity are still the main barriers hindering the potential adoption of SPS. Simultaneously, it turns out that the external factors also have considerable influence on farmers’ decisions to adopt SPS regardless of their willingness. The external SPS factors encompass the farmers’ socio-economic background related with land tenure status and production types, all causing farmers to perceive low compatibility. Moreover, the dynamic climatic conditions of tropical land at high altitude induces high risks for implementing SPS, which is less highlighted in existing research since the climate conditions depend on the specific local context.

Nevertheless, various general benefits of SPS and their observable changes to farms are perceived by farmers who adopted some SPS practices, all leading to a positive willingness toward more intensive SPS. It implies that further adoption and diffusion would continue if the enabling conditions, including the land tenure system, various tools to motivate farmers, provision of necessary information, and long-term support, are appropriately created to overcome the barriers that farmers face and promoted with proper strategies in each respective local context.

Based on findings, recommendations for further research are as follows: since the results might be utilized as preliminary study of recognizing farmers’ perceptions and barriers to adopting SPS, an impact analysis of the empirical programs or policies should help determine effective ways to scale up the adoption of SPS. Additionally, further technical research regarding the implementation of SPS and its impact on the environment and cattle productivity, specifically focusing on tropical lands at high altitude, would be indispensable to improving adoption levels in the research area. Moreover, initial adoption does not necessarily lead to permanent implementation; in other words, there might be many cases where the farmers initially adopted SPS with support but subsequently stopped implementation for one of the aforementioned reasons. In this sense, the analysis of perceptions and barriers over time, throughout the whole process of implementing SPS until permanent adoption, should be meaningful.

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References


Nature Sustainability. (2020). Make the most of qualitative research. Nature Sustainability, 3, 73. https://doi.org/10.1038/s41893-020-0482-0


Roux, J. (2012). Opportunities and challenges of using agroforestry for climate change mitigation: A case study of
Rogers, E. (2003). Diffusion of Innovations (Fifth ed.). Free Press,
UPRA. (2015). INFORME DE GESTIÓN PLAN DE ACCIÓN 2015 SEGUNDO SEMESTRE. https://www.upra.gov.co/documents/10184/40597/Informe+de+Gesti%C3%B3n+2015+versi%C3%B3n+publicaci%C3%B3n.pdf/c204814a-a98c-4eb9-81af-20ceef307046
Wilson, G. A. (2008). From ‘weak’ to ‘strong’ multifunctionality: Conceptualizing farm-level multifunctional transi-
Zabala, A. (2013). Motivations and incentives for pro-
environmental behaviour: the case of silvopasture adoption in the tropical forest frontier (Doctoral the-
esis). https://doi.org/10.17863/CAM.16432