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Assessing Knowledge Production for Agrosilvopastoral Systems in South America☆

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ABSTRACT

In recent decades agroforestry has undergone significant development in Latin America. South America generates the most scientific research on the topic in the region. We conducted a comprehensive review and analysis of knowledge production for South American agroforestry that includes livestock grazing, known as *agrosilvopastoralism* (AS), examining how different sociopolitical factors such as sources of funding, institutional priorities, and international cooperation can bias the direction and objectives of scientific research. We assessed the major attributes of scientific publications on the topic (25 articles per country; overall $n = 210$) and the potential factors underlying the processes of research and development in the region. The tree component was the most studied, while the livestock component received less attention. Studies were mainly focused on the production of goods and services (monetary or nonmonetary approaches), except in Brazil, where conservation was the major study objective. Stakeholders were involved in more than half of the studies (60%), and they were mostly ranchers and local producers. More than half (70%) of the studies offered recommendations based on their results, and such recommendations were mostly concerned with the management of agrosilvopastoral system components. In general, studies were led just as often by local as foreign first authors and coauthored by more than three people as part of interinstitutional working groups. Brazil, Argentina, Colombia, and Chile had more frequent cooperation among institutions and countries but mainly used their own funding. In contrast, Bolivia, Ecuador, and Peru had almost 100% of their studies supported by foreign countries (North America and Europe). Countries with greater internal funding of research generated more long-term studies. Besides this, two clear trends were detected: 1) conservation and social aspects were mainly supported by sources from external countries led by foreign principal investigators, and 2) production issues were supported from sources within countries and supported high levels of cooperation among institutions.

Introduction

Extensive land clearing for livestock production and the associated land degradation have led to greater interest in integrating trees with agricultural crops and/or livestock rearing to improve production and environmental outcomes in pastoral landscapes (Nair, 1993; Mosquera-Losada et al., 2009). These management systems, widely known as agroforestry systems, are a valuable tool for maintaining or increasing production of preferred commodities while supporting conservation goals and enhancing ecosystem services and rural livelihoods (Jose et al., 2004; Bhagwat et al., 2008; Torralba et al., 2016). Much research has focused on agroforestry, but the factors underlying scientific knowledge generation for agroforestry in developing countries, as well as the science-based recommendations given for its implementation, have rarely been questioned or analyzed. We conducted a comprehensive review and analysis of knowledge production for South American agroforestry systems that include livestock production, known as *agrosilvopastoral systems* (ASs), to address these issues.

Agroforestry has developed significantly in Latin America in recent decades (Somarriba et al., 2012). Funding is allocated to agroforestry by the private sector, governments, nongovernmental organizations, and bilateral

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and multilateral cooperation agencies. Such production systems can enhance a wide range of provisioning services (e.g., food, raw materials), supporting and regulating services (e.g., erosion control), and biodiversity (Torralba et al., 2016). Concerns about agricultural expansion and pressures on natural ecosystems (e.g., soil erosion or biodiversity loss; Tscharntke et al., 2015) are international in scope. In Central and South America, 52% and 23% of agricultural lands, respectively, are in agroforestry (agricultural land with 10 − 30% tree cover, Zomer et al., 2009). Of the two regions, a higher proportion of the population in South America is rural (68 million, or 55% in 2015) and, at the same time, South America generates the most scientific research (69 739 papers representing 82% in 2013) (World Bank Data, 2017).The current knowledge about agroforestry in South America is unevenly distributed in terms of types of production systems, geographical coverage, and study topics. Depending on prevailing social-ecological and biophysical conditions, agroforestry shows strongly regional variation, with diverse objectives and rates of production, such as an organic system of coffee *(Coffea arabica)* plantations in association with native trees in the Brazilian Cerrado (Oliveira-Neto et al., 2017); silvopastoral systems combining *Pinus* sp. or *Eucalyptus* sp. plantations with native grasslands for cattle production on Chilean and Argentinean rangelands (Cubbage et al., 2012; Colcombet et al., 2015); yerba mate *(Ilex paraguariensis)* plantations under native timber overstory in Paraguay and Argentina (Eibl et al., 2000); and cattle, sheep and/or goats in combination with plantations of native tree species on rangelands in the Andean region of Venezuela (Torres, 2007). A considerable amount of research has been devoted to international commodities, such as shaded coffee *(Coffea arabica),* shaded cacao *(Theobroma cacao),* and oil palm *(Elaeis guineensis)* (Somarriba et al., 2012), mainly in the Amazonia biome (Brazil, Colombia, Ecuador). Despite this focus, research topics such as biodiversity conservation or habitat fragmentation have gained predominance over the past 2 decades (Di Marco et al., 2017). For example, several studies focused on the quantification of ecological impacts on natural ecosystems and ecological processes (Velasco et al., 2015; Di Marco et al., 2017).

International organizations (e.g., Food and Agriculture Organization and United Nations projects and initiatives) greatly support and prioritize key topics such as global climate change adaptation and mitigation, allocating funding to projects in Latin America (Tubiello, 2012; GEF, 2014) to support food security, rural livelihoods, and the provision of ecosystem services. However, one of the key problems identified at the regional scale (e.g., UNASUR) is the need to develop a joint strategy for the use of natural resources, accompanied by a permanent and systematic research program, to help shape development in the region (UNASUR, 2014). South American countries have identified the need for promoting international (regional) cooperation between research institutions within the region.

Misalignment between the interests of researchers and agroforest communities (CGIAR, 2015) can influence agroforestry planning and implementation (Robbins et al., 2015; Peri et al., 2016). Knowledge production and its direction can be biased by different sociopolitical factors such as the way funding is assigned by each country, institutional priorities, and constraints on international cooperation. The aim of this study was to synthesize and analyze the scientific literature on ASs generated across South America in order to understand the processes of knowledge generation and the potential impacts on these production systems. This literature review from a wide variety of sources was carried out to answer the following questions: 1) what are the main components of ASs investigated in South America? 2) who conducts and fund these studies? 3) which kind of recommendations are provided (e.g., management or policy)? and 4) which are the main factors affecting the research?

Materials and Methods

Literature Search and Study Selection

We performed a literature search in the Scopus database based on the following search string: *"agroforest*"* OR *"*silvopast*"* OR *"*silvicult*"* OR *"silvopascicult*."* To select only case studies from South America, the search was refined by adding the names of each country as search terms. There is wide consensus today about the use of the term *"agroforestry"* to refer to land use involving a deliberate mixture of woody perennials and herbaceous plant communities, often with domesticated or semiwild animals (*sensu* Nair, 1993; Jose et al., 2004), but we searched on diverse terms used to refer to agroforestry systems.

We performed the search in August 2014 and found 738 preliminary items. Within the obtained results we specified the following two inclusion criteria: a study had to include areas (study sites) under AS use (e.g., not just forested or just agricultural lands and including livestock), and the study had to describe at least two of the three main components of AS: trees (native species or exotic plantation), forage/crops (grassland, pasture, or crop), and domestic grazing animals (cattle, sheep, or goat). This means only production systems that included livestock were included, and therefore the possible systems considered were agrosilvo, agropastoral, silvopastoral, or agrosilvopastoral. The search was not exclusively focused on field-based studies; it included descriptive and theoretical articles. English and Spanish language manuscripts were considered. Given that knowledge generation is uneven among the countries (e.g., 48 000 scientific articles published for Brazil in total during 2013 while 89 articles were published for Bolivia; World Bank Data, 2017), we selected the 25 most recent articles from each country to balance the number of study cases for each. Furthermore, in the case of the larger countries (e.g., Brazil and Argentina), we attempted to cover different regions to include more diverse situations. When the search in Scopus was not enough to reach 25 articles for a given country, we additionally considered the documents provided by the Google Scholar search engine, giving priority to 1) indexed journals not found in Scopus, 2) not-indexed journals, 3) published graduate theses, or occasionally 4) book chapters. As result, we obtained 210 articles (Appendix A). Bolivia ($n = 19$) and Paraguay ($n = 16$) had fewer than 25 articles. Guyana, Suriname, and Uruguay were not included in this review since we found very few articles related to AS (1980 − 2014).

To characterize the context of AS literature, each publication was classified according to the general characteristics of the publication and the main attributes of the studies (Table 1). Each study was assigned one of the four main biomes represented in South America, following the classification proposed by Olson et al., (2001): temperate forest, temperate grasslands and shrublands, tropical forests, tropical grasslands and shrublands, or multiple options. Similarly, we extracted some of the underlying information (e.g., number of coauthors, cooperation among institutions, funding provenance) of research papers that are potential conditioning factors for the scientific knowledge about ASs in South America (see Table 1). We coded all information extracted from the studies in spreadsheets, where categories were pretested among reviewers to ensure repeatability.

Data Analysis

The information obtained from each publication was extracted using two types of variables: 1) binary data (yes/no), which were converted to dummy variables, and 2) categorical data (e.g., time scale of studies: <1, 1 − 5, >5 years long). We organized the information related to the main attributes and potential conditioning factors according to the groups mentioned earlier. We first calculated such variables as the percentage of articles per country ($n = 25$). However, many studies reported a combination of components under study, main objectives (e.g., production of goods and services and conservation), stakeholder involved (e.g., producers and NGOs), recommendations (e.g., management and conservation), or cooperative arrangements. Therefore we expressed such variables (both main attributes and potential conditioning factors) as the relative percentage of the overall results for South America. These analyses help us to gain deeper understanding of the situation of each country itself and each country within the region.

Table 1
Data extraction variables used to describe main attributes and conditioning factors of scientific research on agro-silvo-pastoral use in South America

Variable	Description or source	Classes
General characteristics of articles		
Type of publication	Type of publication	Article Book chapter Thesis
Year	Year in which the study was published	1983-2014
Type of study	Type of study	Research paper Synthesis (e.g., literature review) Theoretical paper (exploring theoretical concepts) Multiple
Spatial scale	Scale of the study area	Local National Regional (include >1 country) Multiple
Time scale	Duration of the study	1 year (or 1 season) 2-5 years >5 years
Type of system	Defines the scale of the productive system	Subsistence (families that consume their own products to survive) Small-scale (e.g., local farmers) Large-scale (e.g., industries, ranches) Multiple Undefined
Land property	Ownership of the land on which the productive system is developed	Communal Private State Reserves Multiple Undefined
Biome	Main biomes of South America, according to terrestrial eco-regions defined by Olson et al., 2001	Temperate forest Temperate grasslands and shrublands Tropical forests Tropical grasslands and shrublands Multiple
Main attributes		
Component studied	Main component under study	Tree (native forest or exotic plantation) Livestock (cattle, sheep, goats, horses) Forage/Crop (natural or implanted pastures, crops and fruit cultivation) Human (producers, local communities)
Study objective	Main objective pursued by the study based on four approaches	Productivity (including monetary and non-monetary valuation) Conservation (animals, plants or ecological processes) Restoration (environmental or economical values) Sociological (local human involved in AS)
Stakeholders involved	Stakeholders participating of the study and/or the application of AS	Producers (smallholders, ranchers, or large traders) Government (national, provincial, or local agencies) Professionals (Professionals (biologists, agronomists, veterinarians) from the private sector) NGOs Indigenous groups Others (Universities, tourism agents)
Recommendations	Guidance and/or suggestions based on the results provided in the study	Management Conservation Policies and decision-making
Conditioning factors		
First author	Nationality of the first author	Local (author same nationality as study area) North America Europe Other (Asia, Africa, Oceania, other Latin American countries)
Number of co-authors	Number of authors listed in the article	1 2-4 >4
Cooperation	Authors from one or more institutions and/or more than 1 country participating in the study, according to the affiliations indicated in the article	National (all co-authors from the same country, local or foreign) International (co-authors from different countries) Inter-institutional (co-authors belongs to different institutions)
Subject area	Subject area of the journal according to Scimago Journal Ranking	Agricultural and biological sciences Environmental sciences Social sciences Veterinary Multidisciplinary Others (Biochemistry, Economics, Medicine) Undefined (journals not included in SJR)
Funding	National or international projects, donations, etc., as explicitly stated in the article (e.g., acknowledgments)	Internal funding (funds from the same country as the study area) Europe North America International (international organizations or associations, or other countries) Undefined (no detailed or authors no received specific funding for the study)

Characterization of the studied variables was approached through descriptive statistics. Hierarchical clustering analysis with Ward's method and squared Euclidian distance was applied to identify groups of similar countries according to the main attributes in scientific publications and potential conditioning factors. Finally, partial least squares (PLS) regression analyses were performed to investigate the association between the potential conditioning factors (X matrix: first author provenance, number of authors, cooperation, source of funding) and 1) the main component of AS under study (Y matrix: trees, livestock, forage/crop, human), 2) the main objective of each study (Y matrix: production, conservation, sociological), and 3) recommendations (Y matrix: management, conservation, policies, and decision making) for the nine South American countries included in the study.

Results

The first approach (894 items) showed that the annual number of studies about AS in South America has increased since 1982 (Fig. 1a). Some countries like Peru and Chile produced a large share of the publications coming out until the 1990s (23% and 21%, respectively) when their proportion declined (10% and 6%, respectively), though the absolute number of articles from those countries did not change. Other countries like Argentina, Brazil, and Venezuela produced a similar percentage of the annual publications (5 — 8%, 40 — 50%, and 4 — 5%, respectively) throughout the period studied (Fig. 1b), although in absolute numbers Brazil tripled its annual publications from 2004 to 2016. Colombia is another country that increased its scientific production, though its proportional representation within South America has been similar throughout the period.

The final 210 selected studies of AS were published in 91 different journals (25% in *Agroforestry Systems*), 1 Ph.D. thesis, and 2 book chapters. We found that most of the articles reported analytical studies (64%), while descriptive and theoretical works were less frequent (Fig. 2a). The local scale was the most frequent (64%), while regional or national surveys were less frequent (Fig. 2b). Knowledge of AS was generated mainly from seasonal or brief research (63%), while short- and long-term studies were less frequent (Fig. 2c). There were different sizes of production systems represented in the literature (Fig. 2d), from smallholders in 40% of articles to large-scale farmers in only 18% of articles. Private properties were the most common land tenure form represented in the literature (60%), followed by state lands in a lower proportion (Fig. 2e). Large portions of the studies were conducted in tropical and subtropical forest biomes (65%, Fig. 2f), denoting gaps in the knowledge available for temperate forests and temperate and tropical shrublands.

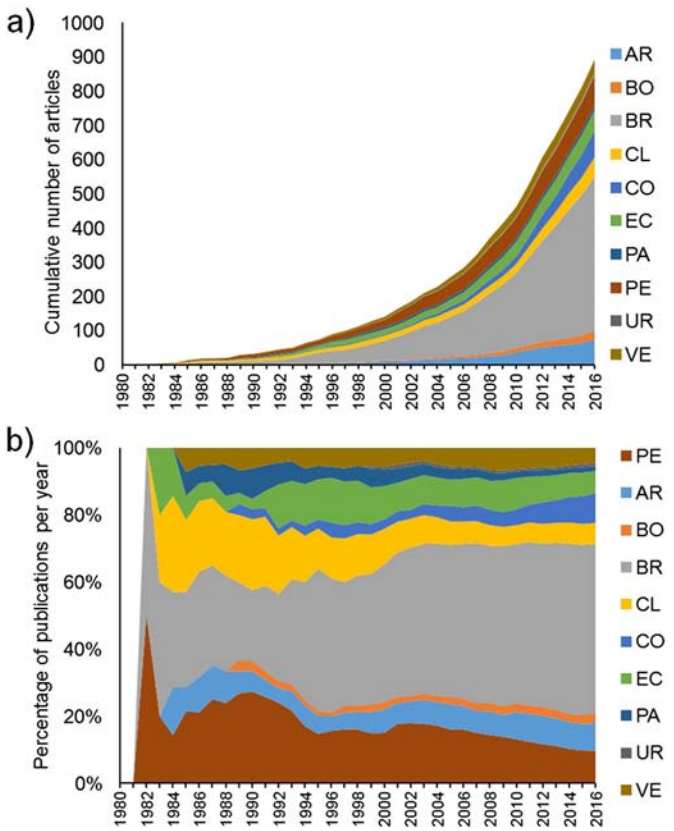

Figure 1. Publication rate of studies regarding agro-silvo-pastoral use in different countries of South America since 1980 until present (http://scopus.com, last accessed: February 2, 2017): a) cumulative number of articles per country; b) proportion of articles from each country per year.

Main Attributes of Studies

The tree component of AS was the most studied in South America and within each country, while the livestock component received less attention (Table 2). Studies from Brazil covered multiple components. Consequently, tree, livestock, and forage/crop components were proportionally more studied there than for South America as a whole. Chile also included the forage/crop component in higher proportion than South America. The human component was proportionally more studied in Bolivia, Paraguay, and Peru. In general, the studies were mainly focused on production of goods and services (monetary or non-monetary approaches), except in Brazil, where conservation was the most frequent study objective (see Table 2). Compared with South America as a whole, studies carried out in Argentina, Chile, Peru, and Venezuela were more oriented to productivity; studies carried out in Bolivia, Brazil, and Peru were more oriented to conservation goals; studies carried out in Bolivia, Peru, and Venezuela were more oriented to restoration goals; and social goals were more studied in Bolivia and Paraguay. Stakeholders were involved in more than half of the studies (60%) and they were mostly represented by producers (see Table 2). Compared with South America as a whole, local producers were proportionately more involved in studies from Bolivia, Brazil, and Peru; government and professionals were most involved in Brazil and Venezuela, while nongovernmental organizations and indigenous groups were more involved in studies in Bolivia and Paraguay. Studies from Argentina and Colombia showed the lowest participation of stakeholders. Moreover, 70% of studies provided recommendations derived from their results, and such recommendations were mostly concerned with management of AS components (see Table 2). Compared with South America as a whole, studies carried out in Brazil made more recommendations for management (along with Bolivia) and conservation (along with Colombia). Studies from Argentina, Brazil, Colombia, and Paraguay included the highest proportion of recommendations for policies and decision making. Studies from Peru and Venezuela showed the lowest proportion of recommendations.

Potential Conditioning Factors for Agroforestry Research

In general, studies were led by local first authors (same country for the author's affiliation and the study area) (Table 3). The proportion of local first authors was greater in Argentina, Brazil, Chile, Colombia, and Venezuela. By contrast, Paraguay and Peru showed the highest proportion of studies led by North American authors, and Bolivia and Ecuador showed the highest proportion of studies led by European authors. Most of the studies, except in Paraguay, were coauthored by > 4 people (see Table 3), which indicated interinstitutional work. Publications by national groups (local or foreign) were proportionally greater in Brazil, Colombia, Paraguay, and Venezuela, while international cooperation was proportionally greater in Bolivia, Chile, and Peru. Interinstitutional working groups were proportionally high in Argentina, Brazil, and Peru compared with the overall proportion for South America. The subject areas of

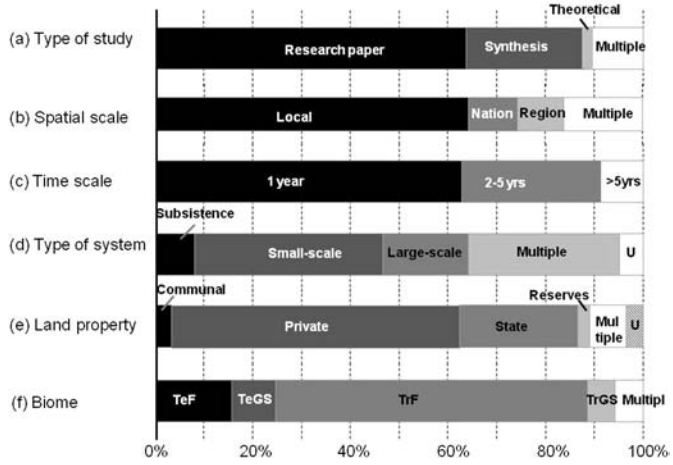

Figure 2. Percentage of case studies following different analytical approaches. TeF = temperate forests, TeGS = temperate scrublands, TrF = tropical and subtropical forests, TrGS = tropical and subtropical scrublands. U = Undefined.

journals were mainly "Agricultural Science" and, to a lesser extent, "Environmental Science." The funds supporting research came from South American countries (internal funding) but also from Europe and North America (see Table 3). Research supported by internal funding comprised the largest share of studies in Argentina, Brazil, Chile, Colombia, and Venezuela. Studies supported by Europe occurred in the highest proportion in Bolivia and Ecuador, while studies supported by North America occurred proportionately more often in Paraguay and Peru than in South America overall.

Cluster analysis of case studies based on the main attributes of the AS and on conditioning factors identified two main groups (50% of maximum distance) with different subclusters: 1) Argentina and Chile linking with Brazil, and them linking with Colombia and Venezuela; and 2) Bolivia linking with Ecuador and Peru, and them linking with Paraguay at a greater distance (Fig. 3).

PLS analysis undertaken to assess the association between the conditioning factors and the main component under study explained 87.2% of the variability in the first two PLS components (Fig. 4A). The most explanatory variables on component 1 were local first author and foreign (North America and Europe together) first author, while component 2 added national and international author teams (Table 4). Publications that studied the tree or forage/crop components of AS were associated with interinstitutional cooperation and international author teams, while studies about livestock were more associated with local first authors and internal funding. Studies about the human component were associated with foreign first authors and external funding.

PLS analysis to assess the association between the conditioning factors and the main objective of publications explained 83.0% of the variability in the first two PLS components (Fig. 4B). The most explanatory variables on component 1 were first local author and foreign (North America and Europe together) first author, while component 2 added national and international author teams (see Table 4). Publications targeting conservation, restoration, and productivity were associated with interinstitutional cooperation and international author teams, while publications with sociological perspectives were associated with foreign first authors and external funding.

Finally, PLS analysis to assess the association between the conditioning factors and the recommendations of publications explained 89.8% of the variability in the first two PLS components (see Fig. 4B). The most explanatory variables on component 1 were internal (own country) and external (North America and Europe together) funding, while component 2 added national and international author teams and interinstitutional cooperation (see Table 4). Publications making recommendations for management and conservation were associated with local first authors and internal funding, while recommendations for policies and decision making were associated with national authorship teams.

Discussion

Compared with previous reviews of AS (Cubbage et al., 2012; Somarriba et al., 2012; Montagnini et al., 2013; Casanova-Lugo et al., 2016), our study took a broader perspective by covering multiple aspects of AS, from the specific component under study to stakeholder involvement and recommendations. We focused our review in South America to assess indicators of the economic, social, and cultural context and to gain better insight about the process of generating information in this region. Our study followed an integrated process of exploring the

Table 2
Main attributes of case studies on agro-silvo-pastoral use in South America classified by the components under study, main focus of research, stakeholders participation and recommendations. Each percentage is related to the total publication number of each country or total analyses, where one case study can include more than one component

	Overall (n = 210)		AR (n = 25)		BO (n = 19)		BR (n = 25)		CL (n = 25)		CO (n = 25)		EC (n = 25)		PA (n = 16)		PE (n = 25)		VE (n = 25)	
	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Component studied																				
Tree	146	70%	12	48%	12	63%	22	88%	12	48%	18	72%	18	72%	7	44%	21	84%	24	50%
Livestock	36	17%	3	12%	2	11%	8	32%	1	4%	1	4%	0	0%	2	13%	2	8%	17	17%
Forage/Crop	103	49%	11	44%	1	5%	19	76%	13	52%	8	32%	12	48%	2	13%	15	60%	22	76%
Human	55	26%	2	8%	11	58%	5	20%	4	16%	5	20%	4	16%	7	44%	10	40%	7	26%
Study objective																				
Productivity	139	66%	22	88%	11	58%	15	60%	18	72%	11	44%	14	56%	11	69%	18	72%	19	99%
Conservation	98	47%	7	28%	12	63%	19	76%	7	28%	11	44%	13	52%	4	25%	15	60%	10	28%
Restoration	68	32%	6	24%	9	47%	9	36%	5	20%	6	24%	3	12%	3	19%	12	48%	15	36%
Sociological	57	27%	2	8%	12	63%	4	16%	2	8%	6	24%	7	28%	9	56%	8	32%	7	28%
Stakeholders involved																				
Producers	119	57%	2	8%	13	68%	22	88%	12	48%	6	24%	24	96%	8	50%	25	100%	7	28%
Government	24	11%	2	8%	1	5%	13	52%	0	0%	2	8%	1	4%	0	0%	1	4%	4	16%
Professionals	19	9%	2	8%	0	0%	6	24%	1	4%	1	4%	2	8%	0	0%	2	8%	5	20%
NGOs	22	10%	0	0%	3	16%	6	24%	1	4%	1	4%	2	8%	6	38%	1	4%	2	4%
Indigenous groups	41	20%	0	0%	10	53%	4	16%	4	16%	2	8%	6	24%	7	44%	5	20%	3	12%
Others	2	1%	0	0%	0	0%	1	4%	0	0%	0	0%	0	0%	0	0%	0	0%	1	4%
Recommendations																				
Management	106	50%	8	32%	8	42%	24	96%	20	80%	11	44%	12	48%	9	56%	5	20%	9	28%
Conservation	48	23%	5	20%	2	11%	15	60%	5	20%	10	40%	6	24%	3	19%	2	8%	0	0%
Policies and decision-making	44	21%	7	28%	2	11%	7	28%	4	16%	7	28%	5	20%	5	31%	2	8%	5	20%

AR = Argentina, BO = Bolivia, BR = Brazil, CL = Chile, CO = Colombia, EC = Ecuador, PA = Paraguay, PE = Peru, VE = Venezuela.

Table 3
Potential conditioning factors classified by first author provenance, number of co-authors, cooperation, subject area in SJR and funding provenance

	All (n = 210)		AR (n = 25)		BO (n = 19)		BR (n = 25)		CL (n = 25)		CO (n = 25)		EC (n = 25)		PA (n = 16)		PE (n = 25)		VE (n = 25)	
	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
First author																				
Local	118	56%	18	72%	0	0%	23	92%	18	72%	23	92%	3	12%	7	44%	2	8%	24	96%
North America	36	17%	5	20%	3	16%	1	4%	2	8%	2	8%	4	16%	8	50%	11	44%	0	0%
Europe	46	22%	1	4%	14	74%	1	4%	4	16%	0	0%	17	68%	1	6%	7	28%	1	4%
Other	10	5%	1	4%	2	11%	0	0%	1	4%	0	0%	1	4%	0	0%	5	20%	0	0%
Number of co-authors																				
1	25	12%	2	8%	2	11%	1	4%	2	8%	1	4%	1	4%	9	56%	5	20%	2	8%
2-4	110	26%	10	40%	8	42%	16	64%	10	40%	5	20%	6	24%	1	6%	8	32%	11	44%
>4	75	36%	13	52%	9	47%	8	32%	13	52%	19	76%	18	72%	6	38%	12	48%	12	48%
Cooperation																				
National	118	56%	14	56%	7	37%	16	64%	10	40%	19	76%	14	56%	14	88%	6	24%	18	72%
International	92	44%	11	44%	12	63%	9	36%	15	60%	6	24%	11	44%	2	13%	19	76%	7	28%
Inter-institutional team	133	63%	19	76%	13	68%	21	84%	16	64%	14	56%	12	48%	3	19%	19	76%	16	64%
Subject area (SJR)																				
Agricultural Sc	151	72%	19	76%	15	79%	15	60%	21	84%	18	72%	15	60%	8	50%	22	88%	18	72%
Environmental Sc	31	15%	3	12%	1	5%	9	36%	4	16%	6	24%	6	24%	1	6%	1	4%	0	0%
Social Sc	4	2%	0	0%	0	0%	1	4%	0	0%	0	0%	1	4%	1	6%	1	4%	0	0%
Veterinary	4	2%	2	8%	0	0%	0	0%	0	0%	1	4%	0	0%	0	0%	0	0%	1	4%
Multidisciplinary	3	1%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	1	4%	2	8%
Others	6	3%	1	12%	0	0%	0	4%	0	0%	0	4%	3	8%	0	6%	0	8%	2	12%
Undefined	11	5%	0	0%	3	16%	0	0%	0	0%	0	0%	0	0%	6	38%	0	0%	2	8%
Funding																				
Internal funding	98	47%	17	68%	0	0%	22	88%	15	60%	16	64%	0	0%	5	31%	0	0%	23	92%
Europe	50	24%	0	0%	14	74%	2	8%	3	12%	3	12%	19	76%	1	6%	7	28%	1	4%
North America	29	14%	3	12%	1	5%	1	4%	1	4%	2	8%	4	16%	8	50%	9	36%	0	0%
International	23	11%	5	20%	1	5%	0	0%	6	24%	4	16%	1	4%	1	6%	4	16%	1	4%
Undefined	10	5%	0	0%	3	16%	0	0%	0	0%	0	0%	1	4%	1	6%	5	20%	0	0%

AR = Argentina, BO = Bolivia, BR = Brazil, CL = Chile, CO = Colombia, EC = Ecuador, PA = Paraguay, PE = Peru, VE = Venezuela.

main attributes of AS publications, as well as the conditioning factors behind scientific research in South America. Our approach is particularly focused on the contextual factors that guide scientific studies in different countries. However, we recognize there are some limitations as a result of the methods used. First, we selected only 25 papers within each country. By doing this, much research—mostly papers from countries with high scientific output such as Brazil—was neglected. The conclusions, geographic patterns, and biases implied at the continental scale should be taken cautiously as a result. Our decision to select an equitable number of articles within each country was to avoid bias from those countries with greater scientific development (e.g., Brazil) over less developed countries (e.g., Bolivia, Paraguay). Less research does not necessarily mean less knowledge. Moreover, our objective was not to describe and/or compare different farm practices and current research trials of AS in South America because this has been achieved by previous studies (Cubbage et al., 2012; Somarriba et al., 2012). Our main interest was to disentangle how knowledge is built across the continent, and for this we needed a representative sample of all countries and diverse situations. Another limitation of our review is the timeline of the studies because those in Brazil correspond to 2012 — 2013, while those in Bolivia or Paraguay correspond to 1980 — 2010. The problem here is the comparison of conditioning factors behind each study because they probably change over time (e.g., political decisions regarding investment on science within each country, international relationship). This would be a fruitful area for additional research.

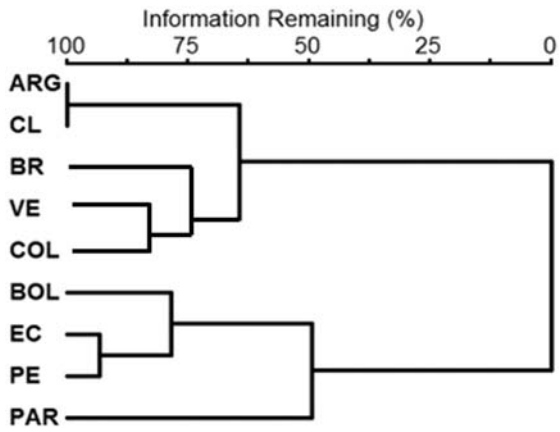

Figure 3. Cluster analysis using the major attributes and conditioning factors identified in publications (Table 2 and 3) to determine similar groups of countries.

Research regarding AS has been carried out in almost all South American countries save Uruguay and Guyana using a broad range of disciplinary approaches, spatial and temporal scales, and engagement with the human components of AS systems. Most of the reviewed studies denoted the importance of tree presence in the functionality and performance (yield) of these productive systems. Recently, many countries have incorporated native tree species in combination with crops or domestic animals in order to promote the use and conservation of local flora (Somarriba and Beer, 2011; Brandt et al., 2014; Vebrova et al., 2014). In contrast, livestock in general, but animal management in particular, received less attention in the reviewed literature despite livestock production being the main source of annual income in some silvopastoral systems in South America (Peri et al., 2016). Nevertheless, meat production has historically been carried out in pastures and steppe biomes throughout South America. Although open pastures continue to be the most widespread livestock farming systems, silvopastoral systems combining animals and trees have proven to be more efficient than traditional management in terms of high-performance meat production (Ayerza, 2010; Peri et al., 2016). However, technical factors, lack of extension work with farmers, and scarce technical and training

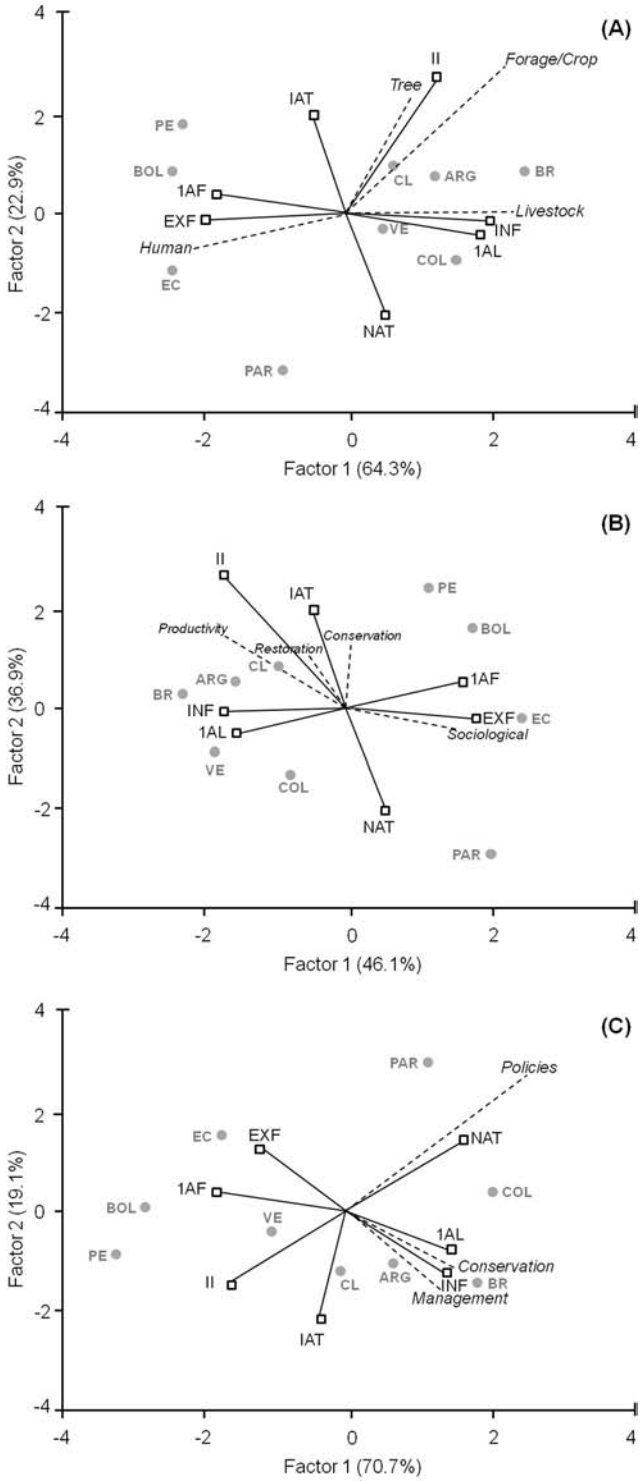

Figure 4. Partial Least Squares (PLS) regression diagrams showing the relationships between conditioning factors of publications with: A) main component (tree, forage/crop, livestock, human) of agro-silvo-pastoral systems under study, B) main objective of study (productivity, conservation, restoration or sociological issues), and C) recommendations (management, conservation or policies and decision-making). 1AL= local first author; 1AF= foreign first author; II=inter-institutional cooperation; IAT= international author team; NAT= national author team; EXF= external funding; INF= internal funding.

support for local producers have limited the technology development and application of AS (Clavero, 2012; Somarriba et al., 2012).

Information reported in scientific articles, theses, technical reports, or book chapters is the main source of up-to-date knowledge for agroforestry extension officers and practitioners (Somarriba et al., 2012). This

Table 4
Beta coefficients for PLS analyses according to A) main component of agro-silvo-pastoral systems under study, B) main objective of study, and C) recommendations

Response	Variable	Component 1	Component 2
A: Main component	Local first author	**5.33**	-15.94
	Foreign first author	**4.71**	-13.74
	Internal funding	-3.35	0.23
	External funding	-2.27	-2.43
	National author team	-6.85	**21.76**
	International author team	-7.70	**21.42**
	Inter-institutional cooperation	1.00	-0.10
B: Objectives	Local first author	**9.26**	-12.3
	Foreign first author	**9.34**	-9.41
	Internal funding	-3.19	3.56
	External funding	-3.56	-0.28
	National author team	-4.78	**6.12**
	International author team	-4.85	**6.08**
	Inter-institutional cooperation	-0.23	-0.93
C: Recommendations	Local first author	-0.90	0.67
	Foreign first author	-0.25	-0.94
	Internal funding	**3.65**	-0.07
	External funding	**2.43**	1.15
	National author team	0.55	**3.62**
	International author team	0.84	**2.65**
	Inter-institutional cooperation	-0.20	1.97

knowledge should serve as the foundation for technical and training support, as well as for decision makers and management policies. Most case studies reviewed concluded with recommendations—sometimes stated in a general way, sometimes giving details for application in practice—which are critical to ensuring the usefulness of science and for helping to generate tools and policies for management and conservation in the region. In this sense, authors (Somarriba et al., 2012; Vessuri et al., 2013) recognize the need to review, summarize, and communicate current knowledge in the field of agroforestry for practitioners.

The bulk of knowledge about AS in South America is published in English, presenting a language barrier for Latin agroforesters, as the so-called "international" or "core" journals do not belong to this region. This indicates, on the one hand, the growing acceptance of science produced in South America in top-tier journals (Holmgren and Schnitzer, 2004). The encouragement and funding from various international organizations (FAO, UNASUR) also help to increase international scientific, technological, and academic cooperation by those in the region with countries in the north hemisphere, as well as in South-South bilateral relations. On the other hand, the dominance of English may be evidence of the effect of journal rankings derived from the SCI (Vessuri et al., 2013; Anderson et al., 2015), and the competitive pressure under which Latin scientists (or any "peripheral" region of the world, *sensu* Dunn et al., 2000) operate if they wish to elevate the reputation of their research—they need to publish in high-impact, high-prestige journals, and such journals are mainly in English and reluctant to publish highly specific local studies. The current challenge is to find a research strategy that supports the improvement of the level of science in Latin America while preserving the possibility of addressing problems relevant to the region.

Knowledge Production in South America Shaped by International Collaborations

Despite the abundance of natural resources in South America, it is still the most unequal region in the world (CEPAL 2016). Moreover, as the global economy has contracted, foreign direct investment into Latin American natural resources has decreased (IMF, 2016). In this context, it is important to understand to what extent local or foreign countries orient funding toward scientific research and technological development (R&D) in AS, as well as what influence they exert as a result of what is studied, and thus to develop a long-term strategy

from South American countries integrating social, economic, and political dimensions.

Our review about AS in South America reveals the strong influence of foreign interests, except in those countries with policies that generate internal financial support for R&D such as Brazil and Argentina. Moreover, countries with more internally funded research generated more long-term studies. Our results highlighted two clear research trends: 1) conservation and sociological issues supported by external countries occurred most in Bolivia, Peru, and Ecuador; and 2) research on the production of goods and services (including monetary and nonmonetary approaches) was supported within countries with high cooperation among institutions including Brazil, Venezuela, Chile, and Argentina.

In Brazil, Venezuela, Colombia, and Argentina, R&D activities are predominantly financed by public funds (e.g., national government, universities). These countries have national science and technology bodies (e.g., MINCyT, CONICET, CONICYT, MCTI) that invest in human resources training, scholarships, and projects and prioritize research related to specific national priorities (Anderson et al., 2015). The success of Brazil in R&D is not just the result of a spontaneous process but of a deliberate state policy to improve postgraduate education and research in a planned and guided way with dependable public funding and institutionalization of a systematic evaluation process (Neves, 2007). In the same way, Venezuela has passed laws (e.g., Ley Orgánica de Ciencia, Tecnología e Innovación 2006) to ensure that R&D funding is partially provided by companies (e.g., mandatory contributions of between 0.5 — 2% of their gross income for scientific projects). This is how Venezuela obtained 94.8% of R&D funding from the business sector (Lemarchand, 2010). In Argentina over the past decade, CONICET (the National Scientific and Technical Research Council) has prioritized funding national scholarships for graduate study but also providing financing for short research periods abroad for Ph.D. students and postdoctoral researchers.

Funding from the United States and Europe is still an important source of R&D funding in some countries of the region such as Bolivia, Peru, and Ecuador. In this review there were no internally supported studies in such countries. In such places, scientific-technological development depends on external financing but is also conducted by foreign researchers and institutions, which has been attributed to the lack of enough trained researchers, equipment, and technical supplies (Holmgren and Schnitzer, 2004). South American publications with more European Union and US funding tend to be led by European or North American authors, as occurs in other countries and in multiple disciplines (Salager-Meyer, 2008). It is rather obvious that richer countries are able to invest more resources in science and therefore account for the largest number of publications. The point is what kinds of recommendations or conclusions foreign authors highlight on the basis of their scientific results from AS studies in South America. According to our results, external funding and foreign first authors were negatively associated with the provision of science-based recommendations from studies. Among the few cases we found, foreign-led studies in Bolivia, Ecuador, and Paraguay formulated recommendations mainly oriented toward conservation and management of local tree species (Ibisch, 2002), smallholder-oriented forestry (Grossman, 2014), and growing trees to generate rural income and rehabilitate degraded lands (Hoch et al., 2009, 2012) with the participation of smallholders and indigenous communities. In studies from Brazil, by contrast, concern is focused on developing sustainable production models (e.g., silvopastoral use, multifunctional systems) to replace traditional systems or monocultures (de Souza et al., 2012; Sambuichi et al., 2012; Lapola et al., 2014).

Linking Policy and Science

According to Follis and Nair (1994), Somarriba et al. (2012), and Robbins et al. (2015), institutional support and appropriate local and regional policies are as important as the biological performance of any promoted technologies. Currently, one of the major dilemmas for the agricultural sciences is the research agenda definition, as there is a permanent conflict between local/regional strategic issues and the priorities imposed by developed countries. For example, there is a general (worldwide) consensus that agriculture and forestry are vital sectors for meeting the challenge of climate change due to their potential for C capture and accumulation (Montagnini, 2015). Climate change reveals how different perceptions lead to different priorities and perceptions of what the key problem is. On one hand, international organizations perceive that climate change is a real problem for our region. Their main argument is generally that climate change effects will reduce food production in this region, mainly in Bolivia, Ecuador, and Paraguay, among others (ECLAC, 2016). On the other hand, South American countries are also concerned about poverty reduction, so regional priorities focus on strengthening local producers, adoption of new technologies, water resource management, land tenure, and production schemes with added value (UNASUR, 2013).

It is possible to identify an increasing profile of scientific collaborations within South America. This region is one of the most dynamic players in the exchange of knowledge and experiences via South-South cooperation. Cooperative initiatives have been led mainly by Argentina, Brazil, Chile, Mexico, and Uruguay (85% of total bilateral South-South cooperation projects), while Ecuador, Bolivia, and Uruguay are the main countries looking for cooperation (SEGIB, 2016). Increasing such cooperation could be the key to fostering regional integration and generation of regional public goods.

Future Challenges in AS Research

Since the concept of *Agroforestry Systems* was adopted by the technical-scientific community, agroforestry has been perceived as part of several disciplines (Nair, 1993), but in practice it belongs to none. This confusion is also observed in the reviewed scientific literature. Most scientific studies deal with a single component of AS, whether focused on agriculture, silviculture, rural development, trade, or finances. The future challenge is to enhance the understanding of multifunctionality in an integrated way. Since there are positive and negative interactions among trees, crops or pastures, and livestock (Peri et al., 2016), AS practices need to encourage positive interactions to ensure long-term sustainability. There are some parallels at political and administrative levels. Agroforestry issues are currently being coordinated by different (and geographically separated) governmental agencies, such as rural development agencies, institutes of agriculture or forestry, and ministries of environment, at local and national levels. While this avoids overlapping responsibilities, it reduces the capacity to coordinate activities from a broader perspective and enhance synergies for AS.

As for public policies, we propose the following for broadening perspectives for the promotion of AS. Policymakers should focus on the biological efficiency of technology and also analyze economic feasibility, as well as social acceptability. Within this framework, social components will be especially important: It is essential that the design of the research and extension programs pay special attention to the needs of the beneficiaries to ensure that the programs are relevant, applicable, and practical. Finally, the capacity that each country has for funding its own research projects will be one of the main challenges, as well as the development of a regional strategy in South America for science specifically related to AS use.

Appendix A. Supplementary Data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.rama.2017.12.006.

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