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Worldwide research trends on sustainable land use in agriculture

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ABSTRACT

Currently, 42% of the world's population depends on agriculture for its livelihood, and agriculture drives the economy of most developing countries. Therefore, human life on our planet depends on its sustainability. Research on sustainable land use in agriculture has been gaining increasing relevance since the term 'sustainable development' was coined with the Brundtland Report in 1987. The objective of this study is to analyse the evolution of this line of research worldwide to date. A bibliometric analysis of the existing articles from the period 1988–2017 was conducted. The results show that this topic has been gaining relevance in land use studies. Extensive cooperative networks and a high level of international collaboration exist between the different agents involved in land use studies. The analysis of key words has shown four main research lines of inquiry: agronomy, which focuses on soil processes and the study of different crops; sustainable water management for irrigation; the analysis of changes in land use, especially as related to the increase in population, the need for supplies, and the expansion of urban land; and sustainable development in new forms of agrarian management, such as organic farming, permaculture, and multifunctional systems. The regions serving as the object of these studies are mainly the Americas, Asia, Oceania, and Western Europe. This highlights a research gap in regions such as Russia, the Middle East, and Africa. Future research should examine the development of circular economic systems in agricultural activity, perceptions and preferences of stakeholders, inclusion of the sustainability objective in planning urban spaces, improvement in irrigation water use efficiency, use of non-conventional water sources in agriculture, and development of management practises and crops that can adapt to the impact of climate change.

1. Introduction

With the beginning of the Anthropocene (Ellis and Haff, 2009), the Earth entered an era of intensification and expansion of land use that satisfied livelihood demands for food, fibre, and bioenergy (MEA, 2005). The result of these human activities was the modification of 75% of the Earth's terrestrial surface (Ellis and Ramankutty, 2008), with agricultural activities occupying more than a third of the Earth's surface (FAOSTAT, 2010) while natural areas occupied less than a quarter (Ellis and Ramankutty, 2008). The expansion and intensification of industrial and technological agriculture have increased production, lowering the number of underfed people (Alexandratos and Bruinsma, 2012) and feeding increasing demand for richer and more resource-intense diets (Foley et al., 2011; Smith et al., 2010; Tilman et al., 2011). Industrial agricultural activities also generate employment, improve economic growth, and boost the service sector in industrial regions (Du Pisani, 2006; Thornton, 1973).

However, the intensification of agriculture is achieved via the application of high levels of input, such as fertilizers or herbicides, which can pollute the environment and impact the health of local livelihoods (Kirkhorn and Schenker, 2001; Tilman, 1999). It can also influence soil fertility and erosion if practises do not preserve soil characteristics (Cunningham et al., 2013; Foucher et al., 2014). On the other hand, the expansion of agriculture is the second largest global threat for biodiversity conservation (Maxwell et al., 2016), because of the deforestation practises that precede it. Currently, about three quarters of the world's forest have disappeared due to agricultural expansion practises (Kissinger et al., 2012), and the resilience of animal populations and

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other environmental impacts are at stake (Baudron and Giller, 2014; Hansen et al., 2013; Maxwell et al., 2016; Sanderson et al., 2002). Under the prospect of increasing future demand of agricultural production, balancing production with nature preservation while minimising trade-offs is a key challenge for future sustainable land management (Chaplin-Kramer et al., 2015; Grau et al., 2013; Alexandratos and Bruinsma, 2012).

The term 'sustainability' was coined after the Bruntland report by the World Commission on Environment and Development of the United Nations in 1987, which defined 'sustainable development' as, "Development which meets the needs of the present, without compromising the ability of future generations to meet their own needs" (Brundtland et al., 1987). Sustainable development integrates three dimensions of human-natural systems—social, environmental, and economic dimensions—and it persists as an ideal similar to democracy, justice, and liberty (Meadowcroft, 2007). To some scholars, both terms—'sustainability' and 'sustainable development'—are interchangeable (Holden et al., 2014). After this first report, other milestones have founded treaties for the sustainable development of the Earth, such as the Rio Declaration in 1992 (United Nations Educational, Scientific and Cultural Organization (UNESCO, 1992), which protects and promotes the sustainable use of the planet's biological resources; the Kyoto Protocol (United Nations Climate Change (UNFCCC, 2008), which commits the countries of the world to reduce greenhouse gas emissions; and the Millennium Development Goals of the United Nations (United Nations (UN, 2015), which gives guidelines for improving livelihoods and the environment globally.

Sustainable agricultural land uses or the sustainable intensification of agricultural activities can be defined in many ways (Yunlong and Smit, 1994) but are mainly those that intend to balance the production of high yields while preserving the environment and well-being of local livelihoods (Godfray and Garnett, 2014; Pretty and Bharucha, 2014). Several improvements have occurred since the industrial revolution to reduce the trade-offs from agriculture in nature-human systems. For example, technology has resulted in the improvement in yields; savings in the usage of resources such as water, fertilizer, and pesticides (Tilman et al., 2011; Mueller et al., 2012; Foley et al., 2011); and reduction in soil erosion (Smith, 2013). However, social concerns, regarding the manner in which agricultural production is conducted and land is conserved, suggest other forms of achieving sustainability, by reducing food waste (Kummu et al., 2012; Tscharntke et al., 2012), improving food accessibility (Borras and Franco, 2012), and changing diet (Alexander et al., 2015; Alexandratos and Bruinsma, 2012; Cassidy et al., 2013; Smith et al., 2010). Addressing consumer demand; trading and international agreements, such as certifications; and responsible political schemes, such as the Round Table for Responsible Soy, are other current forms of achieving sustainability in agricultural land use systems. Recent discussion about methods to promote sustainable future agricultural production has contrasted the idea of preserving some land, while devoting other areas to intensive production (land sparing) with the idea of integrating agricultural uses with the natural matrix (land sharing) (Phalan et al., 2011; Fischer et al., 2013). However, the integration of both may be optimal for securing the long-term balance between conservation and sustainable agricultural production on Earth (Mehrabi et al., 2018; Grau et al., 2013).

Research on sustainable land use in agriculture began after the Brundtland Report was published in 1987. Since then, this line of work has developed remarkably. Given the high volume of existing research on the sustainable use of agricultural land, a greater understanding of the evolution of this research is necessary, including advances in sustainable land management. In addition, knowledge gaps that persist in this field of study must be identified. Hence, this present work analysed the existing literature on the sustainable use of agricultural land based on the following objectives: 1) analyse the current state of research and identify the main drivers in this area of study; 2) highlight the main lines of investigation and detect the different research trends in each country; and 3) examine the existing literature to highlight areas that require further investigation. To achieve these objectives, the literature was systematically reviewed, and a bibliometric analysis was performed. The present study's main contribution relative to existing studies is that it combines both qualitative and quantitative literature review methods to enable greater objectivity in the results and analysis of a great number of articles, thereby avoiding potential biases in the review process.

2. Methodology

2.1. Bibliometric method

Bibliometric analysis uses statistical and mathematical methods and the mapping of data applied to bibliographic information available in different databases of scientific publications to analyse the evolution of research trends and evaluate the contribution in a thematic area (Giménez and Manzano-Agugliaro, 2017; Garrido-Cárdenas et al., 2018a). Introduced by Garfield and Sher (1963), this methodology is also used to identify the trends and principal drivers of a research topic, through the use of mathematical tools and statistical software (Li and Zhao, 2015), and allows the determination of publication quality (Garrido-Cárdenas et al., 2018b). Durieux and Gevenois (2010) defined the three categories of indicators used in bibliometric studies. Quantity indicators analyse the productivity of the different agents (authors, institutions, countries, and journals). Relevance indicators measure publication quality by the number of citations, H index, and journal classification. Structural indicators analyse the links of collaborations and the existence of networks in a research area. These indicators can be used in the different approaches of bibliometric analysis. Traditional approaches include co-citation, co-occurrence, and coupling analysis (Aznar-Sánchez et al., 2018).

For the development of this work, a classic approach based on co-occurrence has been selected and combined with the analysis of the three types of indicators (quantity, quality, and structure) (Suominen and Toivanen, 2016). First, the publication count is used to identify the most productive authors, institutions, countries, and journals in our subject of study. Second, the quality of the publications of these agents is evaluated based on citation count, H index, and the impact factor—the SCImago Journal Rank (SJR). The H index is the number of h documents with at least h citations (Padilla et al., 2018). The SJR gauges the number of weighted citations, based on the study area and prestige of the cited series. Quality analysis, especially for journals, is of great interest to researchers, offering an indication of the relevance of the journal in which their work is published (Malesios and Arabatzis, 2012). Third, mapping techniques have been used to analyse the network structure among the different agents and identify the main research trends in our study subject (Zhang et al., 2017).

2.2. Data processing

Given the existence of two main databases for bibliometric review, Scopus and Web of Science (WoS), the database to be used, was chosen in a step previous to the selection. An article review has been carried out to select the optimal database for this work. According to Mongeon and Paul-Hus (2016), Scopus has indexed a greater number of journals than WoS. The findings of Gavel and Iselid (2008) show that WoS includes 54% of the Scopus publications, whereas Scopus contains 84% of the WoS titles, suggesting that Scopus could better ensure that the selection of the sample of works is representative.

The search was conducted according to the following parameters: [TITLE-ABSTRACT-KEYWORD ("land use" OR "use of land") AND TITLE-ABSTRACT-KEYWORD (sustainability OR sustainable) AND TITLE-ABSTRACT-KEYWORD (agricultur* OR farm* OR crop* OR agroecosystem OR agro-ecosystem)]. These parameters were applied to the titles, abstracts, and keywords, as has been done in other studies

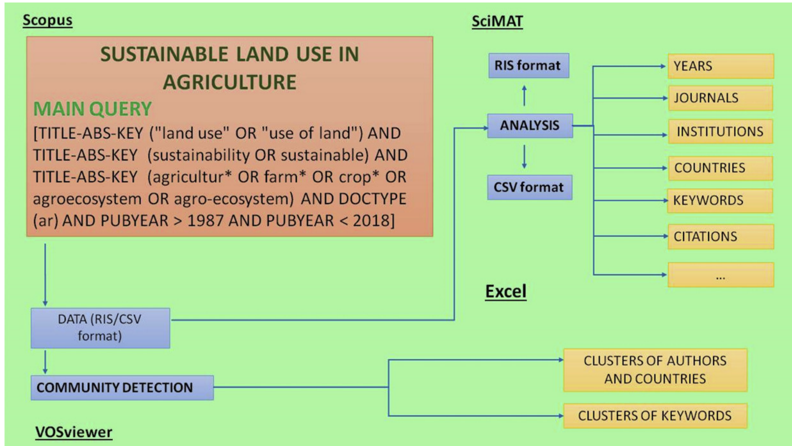

Fig. 1. Methodology flow chart.

(Zhuang et al., 2016). The period of study was between 1988 and 2017. Our starting point was 1988 because it follows the year of the 1987 Brundtland Report, a milestone considered as the main driver for current research on sustainability. To compare complete annual periods, only documents up to 2017 were included. It has become a usual practice in the research that preliminary results are introduced in a Congress which are published as a conference paper. Once, the research work has been concluded, this will be published as a Journal article. It is also common that an author compiles results from different works in a chapter book or in a whole book. Furthermore, a Journal article has undertaken a peer review process which is more rigorous than in the other document formats (Cossarini et al., 2014). For these reasons and in order to avoid duplicities within our sample, we have only included articles in our research. Notably, different search queries will lead to different results. Finally, the sample for this study consisted of 5502 articles. Fig. 1 shows a synthesis of the search procedure and methodology used for this research work.

The metadata extracted from the database and subsequently analysed were the number of articles per year, the different authors of the articles, the affiliation of all the authors of each article (institution and country), the different subject areas used for the classification of the articles, and the keywords for the articles. After the metadata had been downloaded in both the RIS and CSV file formats, the data were debugged to eliminate duplicates that could lead to errors when posting the records. Given that the same author and institution can be found in different formats, these data were reorganised so that an author or institution was not counted with different denominations more than once. Then, we proceeded to elaborate the different figures and tables that facilitate the visualisation and analysis of the data. For this purpose, Excel (version 2016, Microsoft, Redmond, USA), SciMAT (v1.1.04, University of Granada, Granada, Spain), and VOSviewer (version 1.6.7, Leiden University, Leiden, the Netherlands) were used. Finally, to extract the main lines of research in the study topic, an analysis of keywords was conducted, for which regrouping the terms was necessary to eliminate duplicates due to factors such as uppercase words, plurals, and hyphens (Cheng et al., 2018).

3. Results and discussion

3.1. Current status of research on sustainable land use in agriculture (SLUA)

Table 1 shows the evolution of the principal indicators for the research articles on sustainable land use in agriculture (SLUA), published during 1988–2017. The number of articles shows a trend of steady growth throughout the period analysed. The growth accelerated during the last five years, accounting for 44.87% of the articles in the sample.

Table 1
Characteristics of scientific research on sustainable land use in agriculture (SLUA).

Year	No. of articles	No. of authors	No. of authors per article[1]	No. of cites	No. of cites per cumulative articles[2]	No. of countries	No. of journals
1988	11	20	1.82	0	0.00	5	10
1989	11	17	1.55	3	0.27	6	10
1990	19	32	1.68	3	0.16	12	17
1991	32	53	1.66	9	0.28	11	28
1992	29	51	1.76	20	0.69	11	23
1993	54	81	1.50	43	0.80	17	45
1994	50	99	1.98	51	1.02	16	44
1995	56	110	1.96	98	1.75	20	44
1996	64	132	2.06	152	2.38	33	54
1997	88	157	1.78	234	2.66	34	64
1998	60	139	2.32	259	4.32	34	48
1999	80	207	2.59	353	4.37	31	67
2000	79	188	2.38	378	4.52	31	52
2001	117	315	2.69	503	4.44	40	85
2002	106	283	2.67	561	4.65	42	81
2003	126	306	2.43	769	4.97	49	77
2004	111	394	3.55	908	5.49	42	81
2005	144	395	2.74	1107	5.88	40	94
2006	161	532	3.30	1479	6.42	61	104
2007	220	708	3.22	1950	6.87	55	140
2008	204	686	3.36	2417	7.59	63	134
2009	280	979	3.50	3232	8.24	59	176
2010	295	1123	3.81	3866	8.97	76	193
2011	311	1242	3.99	4967	9.92	70	201
2012	325	1308	4.02	6488	11.16	77	220
2013	413	1594	3.86	8154	12.33	78	225
2014	455	1890	4.15	10011	13.59	82	232
2015	520	2217	4.26	11675	14.74	90	257
2016	488	2190	4.49	13371	16.12	90	240
2017	593	2455	4.14	15929	17.37	94	282

1: Total annual number of authors who published articles divided by the annual number of articles. 2: Total number of citations up to the present date divided by the total number of articles published up to the present date.

This line of research has gained interest from the beginning of this study, exhibiting exponential growth since 2006.

Fig. 2 presents a comparison between the growth trends in the number of articles on Land Use (LU) and that on SLUA. Logarithms were applied to homogenise the time series of the data. Considering 1988 as the starting point, we calculated the annual average growth rates of the number of articles on LU and SLUA, which were 8.28% and 14.74%, respectively. These data indicate that, within the research on LU, issues related to the sustainability of agricultural land are becoming increasingly important. From the work by Buter and Van Raan (2013)

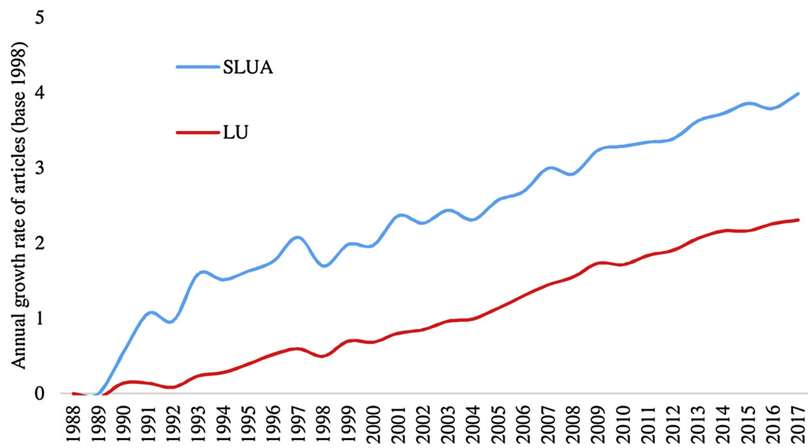

Fig. 2. Comparative trends in SLUA and LU research (in percent).

on the analysis of the highly cited knowledge base of sustainability science, we observed a growth rate of 11.77% in the number of articles on sustainability during 1999–2008. However, the growth rate in the articles on SLUA for that same period was 10.96%. These data show that the number of sustainability studies regarding the use of agricultural land during this period was below the average number of sustainability studies in other subjects.

The other indicators included in Table 1 also show the growing trend of this line of research. The number of authors that participated in the realization of the 5502 articles of the sample is 15,741. This number has increased annually, from 20 authors in 1988 to 2455 in 2017. The average number of authors per article has also increased from 1.78 in 1988 to 4.14 in 2017. The number of references included in the articles on SLUA has evolved in a similar way. For 1988, we found a total of 172 references, and an average number of references per article of 15.64 was found, while for 2017, these figures amounted to 28,902 total references and 48.74 references per article. During the entire period, the 5502 articles accumulated a total of 88,990 citations, for an average of 17.37 citations per article. The number of countries implicated in the production of work on SLUA increased from 5 in 1988 to 94 in 2017, indicating the international growth of this line of research and its increasingly global nature. The range of journals hosting articles on SLUA has increasingly expanded, from 10 in 1988 to 282 in 2017. The evolution of the journal number where SLUA articles are published follows a parallel trend to the one of the article number. These two variables show a strong proportionality relationship between them. So that an increase in the number of published articles mean a direct increase in the journal number and it is also directly observed when the number of published articles decrease.

The articles in the sample were published in 21 languages. The most common language was English, representing 89.90% of the total sample, followed by Chinese (5.23%), German (1.96%), and Portuguese (1.21%). The remaining languages were French, Spanish, Persian, Japanese, Hungarian, Polish, Turkish, Italian, Swedish, Arabic, Dutch, Slovenian, Estonian, Croatian, Czech, Russian, and Catalan, each representing less than 1% of the sample.

Regarding the evolution of the principal subject areas of SLUA, according to the Scopus classification (note that the same article can be indexed in several categories), throughout the period of analysis, the main subject category regarding this topic has been Environmental Science, monopolising the largest number of published works, with 59.61% of the total. This is followed by Agricultural and Biological Sciences with 45.87%, Social Sciences with 26.41%, Earth and Planetary Sciences with 15.76%, Energy with 8.47%, and Engineering with 6.05%. The remaining categories do not reach 4% of the articles analysed.

The Economics, Econometrics, and Finance category includes only 3.53% of the sample articles. This reveals a production shortage of research on SLUA with an economic approach, which indicates that most published articles offer only a partial analysis of sustainability. Schoolman et al. (2012), in their work on the multidisciplinary nature of sustainability studies, conclude that articles with an economic approach are the most multidisciplinary. However, few sustainability studies are of an economic nature. Given that the concept of sustainability encompasses environmental, economic, and social dimensions, this study subject should be addressed from different disciplines to achieve equitable economic growth, social welfare, and thriving ecosystems (Galdeano-Gómez et al., 2017). Similarly, publications regarding the categories Multidisciplinary and Decision Sciences represent only 1.49% and 1.05%, respectively, of the articles in the sample.

Table 2 shows the principal indicators of the 10 journals with the highest number of articles on SLUA published for the period studied. The first column includes the total number of published articles by a Journal and the second column, the number of SLUA related articles during the analyzed period. The percentage shows the meaning of this research field over the total number of published articles by the journal during the given period. The two journals with the highest percentages are specialized on land issues: Land Degradation and Development with a 6.7% and Land Use Policy with 5.6%. The journal with the largest number of articles is Land Use Policy with a total of 162. This journal published its first article on this subject in 1989, but in 2013, it became ranked number 1, followed by Agriculture, Ecosystems, and Environment with 135; Journal of Environmental Management with 109; Nongye Gongcheng Xuebao Transactions of the Chinese Society of Agricultural Engineering with 108 and Land Degradation and Development with 87. The journal with the highest SJR index is Land Degradation and Development with 1.761. Sustainability is the most recent journal to address this subject, publishing its first article in 2013. In only five years, this journal has grown to be ranked among the most prolific journals, and in the last 2 years, it has ranked in the first position, together with Land Use Policy. Regarding the impact of the publications, Agriculture, Ecosystems, and Environment has the highest number of total citations in articles on SLUA with 5025, followed by Land Use Policy with 3027, Journal of Environmental Management with 2523, and Land Degradation and Development with 1621. Agriculture, Ecosystems, and Environment also has the highest average number of citations per article with 37.2, followed by Journal of Environmental Management with 23.1, Agricultural Systems with 21.7, Environmental Management with 18.9, and Land Use Policy with 18.7.

Table 3 shows the quantity and quality indicators of the articles on SLUA of the 10 most prolific countries during 1988–2017. The USA was the most productive in the SLUA, with a total of 1027 articles during the entire period, representing 18.67% of the total sample, followed by

Table 2
Main journals in SLUA research.

Journal	Total No. of articles	No. of articles on SLUA[1]	SJR[2]	H index[3]	Country	No. of cites	No. of cites per article[4]	1st article	Last article
Land Use Policy	2888	162 (5.6%)	1.348 (Q1)	31	Netherlands	3027	18.69	1989	2017
Agriculture, Ecosystems and Environment	5460	135 (2.5%)	1.747 (Q1)	42	Netherlands	5025	37.22	1989	2017
Journal of Environmental Management	6720	109 (1.6%)	1.161 (Q1)	30	USA	2523	23.15	1988	2017
Nongye Gongcheng Xuebao Transactions of The Chinese Society of Agricultural Engineering	12375	108 (0.9%)	0.386 (Q2)	12	China	444	4.11	2005	2017
Land, Degradation and Development	1307	87 (6.7%)	1.761 (Q1)	25	USA	1621	18.63	1996	2017
Sustainability Switzerland	5114	84 (1.6%)	0.537 (Q2)	11	Switzerland	298	3.55	2013	2017
Environmental Management	3395	78 (2.3%)	0.921 (Q1)	23	Germany	1471	18.86	1991	2017
Shengtai Xuebao Acta Ecologica Sinica	8402	76 (0.9%)	0.180 (Q4)	11	China	262	3.45	2007	2017
Environmental Monitoring and Assessment	9057	75 (0.8%)	0.589 (Q2)	17	Netherlands	865	11.53	1995	2017
Agricultural Systems	2296	67 (2.9%)	1.156 (Q1)	24	UK	1454	21.70	1995	2017

1: Number of published articles on SLUA and their percentage over the total amount of published articles by the Journal during the period 1988-2017. 2: 2017 SCImago Journal Rank. All Journals are to be found in the Environmental Science category, except for Transactions of the Chinese Society of Agricultural Engineering y Agricultural Systems. For these two Journals the Agricultural and Biological Sciences categories have been considered. 3: Only SLUA articles. 4: Total number of citations per article during 1988–2017 divided by the total number of articles.

China with 925 (16.81%), Germany with 555 (10.09%), the UK with 413 (7.51%), and the Netherlands with 351 (6.38%). These 10 countries are also among the most relevant in research on climate change and agriculture (Aleixandre-Benavent et al., 2017), patterns of best management practises (Zhuang et al., 2016), sustainable and inclusive food systems (except India and Brazil) (Monasterolo et al., 2016), wastewater irrigation (except the Netherlands) (Maassen, 2016), sustainable water use in agriculture (except Brazil) (Velasco-Muñoz et al., 2018), and soil contamination (except France) (Guo et al., 2014). The number of articles per capita has been calculated to normalise the data to the size of the country. Based on this variable, the Netherlands is the most productive country with 20.48 articles per million inhabitants, followed by Australia with 10.44, Germany with 6.71, the UK with 6.25, and Italy with 3.88. In terms of quality indicators, the Netherlands also has the highest average number of citations per article with 27.76, followed by the USA with 27.01, the UK with 26.29, Australia with 23.34, and Germany with 22.43.

Table 4 shows the main structural indicators of the most prolific countries regarding the research in SLUA. The countries with the highest percentage of international collaborations are China, 72.54%; the Netherlands, 66.38%; France, 61.75%; the UK, 61.26%; and Germany, 52.25%. The USA has the largest network of collaborators, with a total of 95. In addition, the USA is a main collaborator for the other nine most prolific countries in this subject, being the main collaborator for six of them (China, Germany, the UK, India, Brazil, and Australia). The rest of countries with the largest international collaborative network are the UK, 92 collaborators; the Netherlands, 86; Germany, 82; China, 67; and Italy, 66. These high percentages and the extensive international collaborative networks highlight the global interest on this research subject. Articles produced through international collaboration exhibit a higher average number of citations than those without international collaboration in all countries except China, with an average of 24.33 citations, compared to 17.37 for articles without international collaboration.

Fig. 3 shows a structural map based on co-authorship, illustrating the network of collaborations between countries. The size of the circle is based on the number of articles, the thickness of the links depends on the number of co-authorships, and the different groups formed by the different countries are represented in different colours. The figure shows three large groups. The first group (red colour) consists of the most prolific countries in SLUA research from the Americas and Asia, with the USA and China at the head, leading large countries with similar types of agriculture, such as Canada and Brazil, or Mexico, Chile, and Argentina. For the USA, corn and soybeans are the most commonly harvested crops, generating the highest agricultural export sales. The USA stands out as one of the world's largest food producers.

The second cluster (green colour) consists of European countries of medium size, compared to the previous group, also with similar agricultural production systems. In this group, Germany leads countries such as the UK, Denmark, Switzerland, and Poland. In Germany, the main crops are potatoes and cereals, but the agricultural sector, besides being small in Gross Domestic Product (GDP), has a strategic role, from the political point of view. However, it is quite singular, as it is the country with the longest tradition of organic agriculture and marketing of dietetic products. Finally, in blue, the group is led by the Netherlands, France, and Belgium, which have great relationships with

Table 3
Main countries in SLUA research.

Country	No. of articles	Articles per capita[1]	No. of cites	No. of cites per article[2]	H index[3]	1st article	Last article	Ranking position[4] (No. of articles)		
								1988–1997	1998–2007	2008–2017
USA	1027	3.153	27733	27.00	80	1988	2017	1 (71)	1 (211)	2 (745)
China	925	0.667	10679	11.54	50	1996	2017	14 (5)	2 (163)	1 (757)
Germany	555	6.711	12450	22.43	56	1993	2017	7 (12)	3 (143)	3 (400)
UK	413	6.255	10859	26.29	56	1989	2017	3 (23)	5 (77)	4 (313)
Netherlands	351	20.487	9745	27.76	56	1988	2017	2 (27)	4 (90)	6 (234)
India	322	0.240	3327	10.33	33	1988	2017	3 (23)	7 (71)	7 (228)
Brazil	283	1.352	5351	18.91	38	1988	2017	9 (9)	9 (38)	5 (236)
Australia	257	10.448	5999	23.34	40	1991	2017	8 (11)	6 (75)	10 (171)
Italy	235	3.881	3497	14.88	32	1992	2017	20 (3)	12 (28)	8 (204)
France	217	3.233	4676	21.55	37	1993	2017	10 (6)	10 (31)	9 (180)

1: This variable was estimated as the total number of articles among each country's total population in 2017. The result is shown as the number of articles per million inhabitants. 2: Total number of article citations during 1988–2017 divided by the total number of articles. 3: Only SLUA articles. 4: Ranking of each country by number of SLUA articles per subperiod.

Table 4
Primary relationships between countries in SLUA research.

Country	Percentage of international collaboration[1]	No. of partners	Main partners	No. of cites per article	
				International collaboration[2]	No international collaboration[3]
USA	47.52	95	China, Brazil, UK, Germany, Australia	31.60	22.84
China	72.54	67	USA, Germany, Netherlands, Canada, Australia	9.19	17.77
Germany	52.25	82	USA, Netherlands, UK, China, Austria	26.99	17.45
UK	61.26	92	USA, Germany, Netherlands, Brazil, France	27.08	25.06
Netherlands	66.38	86	Germany, USA, UK, China, Kenya	28.30	26.70
India	24.22	46	USA, UK, Netherlands, Germany, France	19.55	7.39
Brazil	49.82	45	USA, UK, France, Germany, Netherlands	24.74	13.12
Australia	44.75	58	USA, China, UK, Germany, Netherlands	29.62	18.26
Italy	42.98	66	UK, USA, Netherlands, Spain, Germany	20.21	10.87
France	61.75	63	UK, USA, Netherlands, Brazil, Germany	26.07	14.24

1: Number of published articles resulting from collaboration with another country (or countries) divided by the total number of articles. 2: Total number of citations of published articles resulting from international collaboration during 1988–2017 divided by the total number of published articles resulting from collaborations. 3: Total number of citations of articles without international collaboration during 1988–2017 divided by the total number of published articles without collaboration.

other European countries, such as Ireland and Hungary. Agriculture accounts for 10% of the Netherlands' GDP and is the strongest economic sector in the country. The Netherlands aims for sustainable agriculture, with a focus on horticulture. On the other hand, France is the greatest agricultural power of the European Union, being the second largest exporter of food products in the world, after the USA.

Table 5 shows the main indicators for the articles of the most prolific institutions in SLUA research. China stands out because it contributes half of the ranking institutions. Notably, Sweden and Kenya have a place among the most prominent institutions in terms of SLUA publications, despite not being among the most prolific countries in this area. Regarding quantity indicators, the Chinese Academy of Sciences ranks first with a total of 381 articles. In 2000, for the first time, it reached the top in terms of the number of articles published on this subject, but in 2005, it established its leadership, increasing the distance from the remaining institutions: the Wageningen University and Research Centre (the Netherlands) with 210, the Institute of Geographical Sciences and Natural Resources Research Centre with 109, China Agricultural University with 72, and Beijing Normal University with 65, which followed in this ranking (the last three are Chinese institutions).

Regarding the quality of the research, the Wageningen University and Research Centre has the highest number of citations with 6085, followed by the Chinese Academy of Sciences, 5641; Universität Bonn (Germany), 2695; World Agroforestry Centre (Kenya), 1831; and Ohio State University (USA), 1434. However, the highest average of citations per article is held by Universität Bonn with 52.8, followed by the World Agroforestry Centre with 35.9, Wageningen University and Research Centre with 29.0, Ohio State University with 24.7, and the Swedish University of Agricultural Sciences with 20.6. The average number of citations per article from Chinese institutions is below the average of the most prominent institutions. This means that Chinese institutions are highly competitive regarding the number of articles, but their publications have lower impact.

Regarding the structural indicators of the main institutions, the World Agroforestry Centre produced 92.16% of its articles through international collaboration, followed by Universität Bonn, 78.43%; Wageningen University and Research Centre, 70.48%; Swedish University of Agricultural Sciences, 68.63%; and Ohio State University, 55.17%. Chinese institutions have the lowest international collaboration in their research, with less than 35% overall. All institutions have a higher average number of citations when their articles are produced

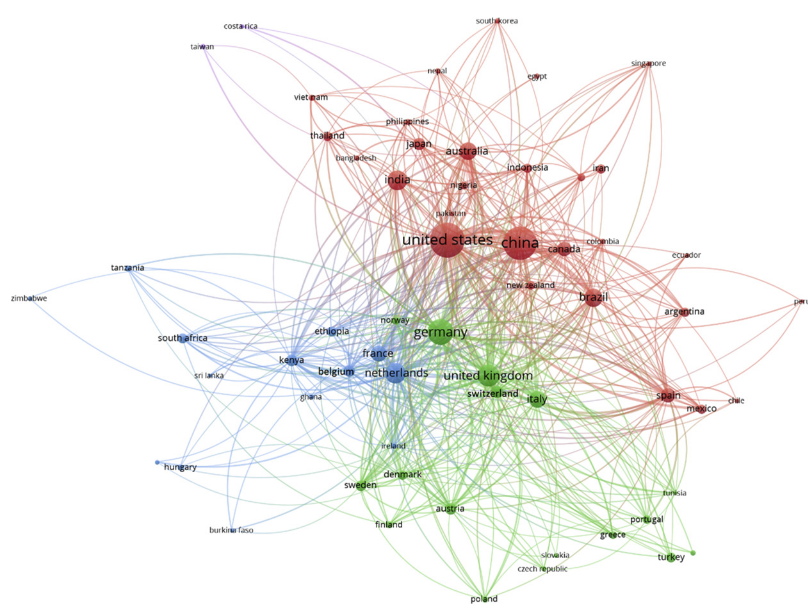

Fig. 3. Cooperation between countries in SLUA research based on co-authorship.

Table 5
Primary institutions in SLUA research.

Institution	Country	No. of articles	No. of cites	No. of cites per article[1]	H index[2]	Percentage of international collaboration[3]	No. of cites per article International collaboration[4]	No international collaboration[5]
Chinese Academy of Sciences	China	381	5641	14.81	42	29.13	20.36	12.52
Wageningen University and Research Centre	The Netherlands	210	6085	28.98	43	70.48	29.44	27.87
Institute of Geographical Sciences and Natural Resources Research	China	109	1327	12.17	19	26.61	19.86	9.39
China Agricultural University	China	72	513	7.13	14	33.33	6.50	7.44
Beijing Normal University	China	65	858	13.20	16	24.62	06.17	11.94
Ministry of Education China	China	60	511	8.52	14	20.00	15.42	6.79
Ohio State University	USA	58	1434	24.72	19	55.17	20.81	29.54
Empresa Brasileira de Pesquisa Agropecuaria - Embrapa	Brazil	53	932	17.58	18	43.40	26.74	10.57
Research Centre for Eco-Environmental Sciences	China	53	934	17.62	20	28.30	24.73	14.82
Universität Bonn	Germany	51	2695	52.84	20	78.43	63.50	14.09
Swedish University of Agricultural Sciences	Sweden	51	1050	20.59	21	68.63	26.00	8.75
World Agroforestry Centre	Kenya	51	1831	35.90	24	92.16	35.13	45.00

1: Total number of article citations during 1988–2017 divided by the total number of articles. 2: Only SLUA articles. 3: Number of articles resulting from collaboration with institutions in another country (or countries) divided by the total number of articles. 4: Total number of citations of articles resulting from international collaboration during 1988–2017 divided by the number of articles resulting from collaboration. 5: Total number of citations of articles without international collaboration during 1988–2017 divided by the number of articles without collaboration.

Table 6
Primary authors in SLUA research.

Author	No. of articles	No. of cites	No. of cites per article[1]	H index[2]	Country	Institution	1st article	Last article
Lal, Rattan	39	1150	29.49	16	USA	Ohio State University, Carbon Management and Sequestration Center	1989	2017
Salvati, Luca	35	264	7.54	11	Italy	Council for Agricultural Research and Economics	2012	2017
Cerri, Carlos Eduardo	18	308	17.11	10	Brazil	Universidade de Sao Paulo, Department of Soil Sciences	2007	2017
Smith, Peter JS	18	600	33.33	10	UK	University of Aberdeen, Institute of Biological and Environmental Sciences	2007	2017
Verburg, Peter H.	15	462	30.80	10	The Netherlands	Vrije Universiteit Amsterdam	2007	2017
Liu, Yansui	14	162	11.57	8	China	Institute of Geographical Sciences and Natural Resources Research	2005	2017
Cerri, Carlos C.	13	265	20.38	10	Brazil	Universidade de Sao Paulo, Centre for Nuclear Energy in Agriculture	2007	2017
Lambin, Eric F.	12	393	32.75	9	USA	Stanford University	2011	2017
Kuemmerle, Tobias	11	291	26.45	11	Germany	Humboldt-Universität zu Berlin, Department of Geography	2012	2017
Van Ittersum, Martin K.	11	1133	103.00	11	The Netherlands	Wageningen University and Research Centre	1997	2014

1: Total number of article citations during 1988–2017 divided by the number of articles. 2: Only SLUA articles.

through international collaboration, except China Agricultural University, Ohio State University, and World Agroforestry Centre. The articles produced in collaboration with foreign institutions obtain an average of 25.5 citations, whereas those without international collaboration obtain an average of 16.6 citations.

Table 6 shows the main indicators for the most prolific authors in this subject. Most of them joined this line of research at the beginning of the 21 st century. Each author has more than ten articles, and they all published articles on this subject in 2017 except Martin van Ittersum. Rattan Lal has the highest number articles, with a total of 39. This researcher, affiliated with the Carbon Management and Sequestration Center at Ohio State University, has been publishing the longest in this area of research; he published his first article on SLUA in 1989. In addition, he has the highest H index (16) and the highest number of citations accumulated (1150). Luca Salvati, with 35 articles; Carlos Eduardo Cerri and Peter Smith, with 18; and Peter Verburg, with 15, follow in this ranking. Martin Van Ittersum has the highest average number of citations per article at 103.1, followed by Peter Smith at 33.3, and Eric Lambin at 32.8. The authors who have joined this line of research most recently are Luca Salvati and Tobias Kuemmerle, with their first articles published in 2012. Even so, in only 6 years, these two authors have managed to have a place among the most prolific in this line of research.

As seen in Table 6, some of the most prolific institutions (Table 5) have none of the most prolific authors on this subject. This is due to several factors. First, there are institutions that host a large number of authors, with none having published a large number of articles. For example, the Chinese Academy of Sciences has a large number of authors, but most of them (more than 80%) have only published one article on this subject. The author from the University of Bonn with the largest number of articles has a total of seven. However, other institutions, such as the Universidade de Sao Paulo, have fewer authors but a large number of articles. Second, some institutions have a departmental structure in which each department has its own affiliation in Scopus; this occurs in the case of the Chinese Academy of Sciences. Third, some authors, such as Salvati, show affiliations with different institutions for the works that they publish.

Fig. 4 shows a structural map based on co-authorships, which represents the cooperation network among the different authors. The size of the circle is based on the number of articles, the thickness of the lines depends on the number of cooperative publications, and the colour differentiates the clusters formed by the authors. The results show the set with the greater number of relations and articles. Note the central core mainly consists of different groups of mostly Asian authors. Yansui Liu stands out as the leader, in terms of the number of articles. Among his main collaborators are Li, Y.; Chen, Y.; Yang, Z.; and Gong, J. Among the peripheral clusters that stand out is the one led by Lal, R., which includes Lambin, E.; Meyfroidt, P.; Shukla, M.K.; Velayutham, M.; and Phalan, B., among others. In the Salvati cluster, we find Perini, L.; Bajocco, S.; and Corona, P., while Cerri, C.E. and Cerri, C.C. share a group with Cherubin, M.R.; Davies, C.A.; Tormena, C.A.; and Easter, M., among others. As main collaborators of Smith, P., we find Koroleva, P.V. and Lisovoi, N.V., among others. Verburg and Kuemmerle share a group with Levers, C.; Müller, D.; and Erb, K. The group of van Ittersum, M.K. is represented by Rabbinge, R.; Rossing, W.A.H.; Wolf, J.; and Groot, J.

3.2. Analysis of research trends

Keywords were analysed to show the main research trends in SLUA (Li and Zhao, 2015). The terms had to be regrouped, as many of them are written in different formats (e.g., in capital letters, with hyphens, with synonyms, plural). Subsequently, 21,329 different keywords were obtained from the sample of 5502 articles. As in other similar studies (Li et al., 2008; Wang et al., 2011, 2013), the frequency of the appearance of keywords used in this research line was fitted to a power-law distribution. In this context, this law explains the existence of a reduced central core of terms that is repeated with high frequency in a substantial number of articles analysed, whereas the remaining terms do so in only a few or even in only one article. Thus, 66.53% of the keywords appeared in a single article, 93.03% of the keywords were used in fewer than 10 articles, and 0.65% were repeated on at least 100 occasions.

Table 7 includes the 20 most repeated key words in the sample articles for the period 1988–2017, and in the three 10-year subperiods in which it was divided. These terms represent the research hot spots for this subject. The terms used for the selection of the sample of articles were eliminated from the analysis to avoid distorting the results, but their possible combinations were maintained. During the entire analysis period, the 20 most frequent keywords were repeated a total of 10,660 times. These data show the general research trends during 1988–2017 (Li and Zhao, 2015). The most frequent term in the entire period is 'sustainable development', which appears in 24.48% of the articles. Although our study object is agricultural land, the forest agroecosystem stands out as a form of agricultural exploitation. The main focus of attention is on the land, both from the perspective of management and planning as well as environmental protection and conservation. The main drivers of change are climate change, environmental impacts, changes in land use, and deforestation. Most studies analyse

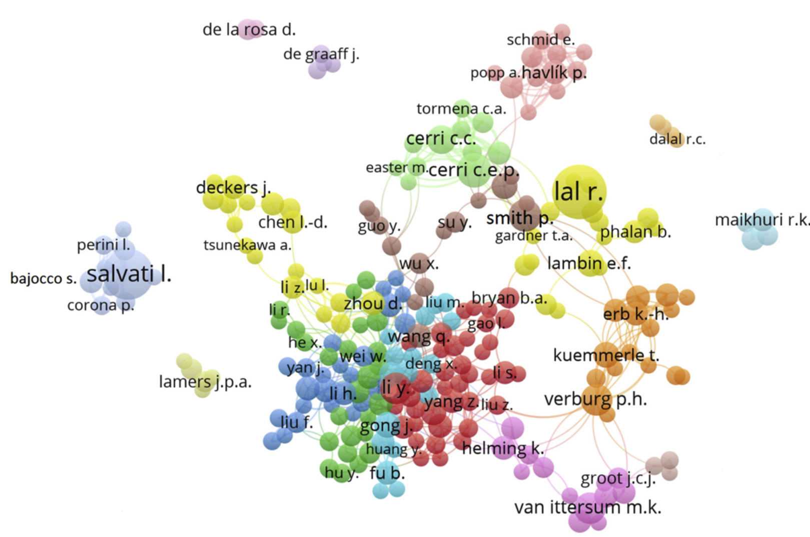

Fig. 4. Cooperation between authors in SLUA research based on co-authorship.

Table 7
Primary keywords in SLUA research.

1988–2017		1988–1997		1998–2007		2008–2017	
Keyword	%	Keyword	%	Keyword	%	Keyword	%
Sustainable Development	24.48	Developing Country	26.09	Eurasia	22.07	Land-Use Change	28.12
Land-Use Change	23.23	Sustainable Development	18.12	Sustainable Development	19.50	Sustainable-Development	26.70
Agricultural Land	12.21	Sustainable Agriculture	16.67	Asia	15.68	Agricultural Land	06.15
China	12.05	Land-Use Planning	10.39	Land-Use Change	12.78	China	13.26
Biodiversity	9.40	Deforestation	8.94	China	11.62	Biodiversity	10.71
Land-Use Planning	9.31	Land-Use Change	8.45	Far-East	8.05	Land-Use Planning	10.17
Geographic Information Systems	9.01	Environmental Protection	8.21	World	8.05	Geographic Information Systems	9.99
Soils	8.65	Agricultural Practice	7.00	Soils	7.97	Ecosystems	9.71
Ecosystems	8.34	Agroforestry	7.00	Sustainable Agriculture	7.97	Climate-Change	9.63
Forestry	8.20	Environment	6.28	Geographic Information Systems	7.88	Soils	9.53
Environmental Protection	8.16	Man-Environment Relations	6.28	Biodiversity	7.30	Economics	9.19
Climate Change	7.74	Resource Management	6.28	Forestry	6.97	Forestry	8.96
Eurasia	7.62	Environmental Management	6.04	Europe	6.80	Environmental Protection	8.70
Economics	7.49	Africa	5.80	Agricultural Land	6.56	Remote Sensing	8.55
Remote Sensing	7.16	Natural Resources	5.56	Eastern Hemisphere	6.56	Ecosystem Service	7.93
Conservation of Natural Resources	6.85	Land Management	5.31	Environmental Protection	6.39	Conservation of Natural Resources	7.65
Environmental Impact	6.13	Agricultural Development	5.07	Africa	6.31	Land Cover	7.11
Land Management	6.09	Agricultural Sustainability	4.83	Farming System	6.14	Environmental Impact	6.82
Deforestation	5.83	Land Degradation	4.83	Land-Use Planning	6.14	Land Management	6.41
Ecosystem Service	5.80	Policy	4.83	Environmental Management	6.06	Alternative Agriculture	6.08

%: percentage of appearance in SLUA articles by period.

sustainability at the level of biodiversity, ecosystem, and the services they provide. The country object of study in terms of largest number of articles is China, whereas at the regional level, Eurasia stands out. In the methodological approach, economic studies are prominent, along with geographic information systems and remote sensing. These data disagree with the results of the analysis by subject, revealing a shortage of articles of an economic nature. This fact may be due to the transversal nature of the economy. Some of the economic analysis tools are widely used by other disciplines. For example, cost-benefit analysis, input-output analysis, or life cycle assessment are the bases for calculating some of the indicators most used in agronomic and environmental studies as efficiency indicators, the water footprint and carbon footprint (Aznar-Sánchez et al., 2018). In addition, numerous studies assessed ecosystem services, using some type of economic analysis, although these works are usually classified as environmental.

The analysis by subperiod allows the evolution of research trends to be assessed through terminology preferences. The period 1988–1997 is influenced by the 1987 Brundtland Report and the Intergovernmental Panel on Climate Change of 1988. Since the beginning of the period, the environment is the predominant focus. Deforestation, resource management, the human-environment relationship, and agricultural practices are the central axes of research. The regulatory and political framework on sustainability is a priority issue. Most studies are conducted in developing countries.

The most important milestones during the period of study are the establishment of Millennium Development Goals in 2000, the implementation of the Kyoto Protocol and the report of the Millennium Ecosystems Assessment in 2005, the Stern Review in 2006, and the revision of the Montreal Protocol in 2007. The main transformations from the previous period are threefold. First, the phenomenon of globalisation is important for this line of research. For the first time, the term ‘world’ stands out. Second, in terms of methodology, this decade witnessed the development of geographic information systems and their application to land studies and its uses. Third, the analysis focuses on the level of the farming system, and the emphasis is being placed on biodiversity.

During the last decade of the period analysed (2008–2017), multiple milestones drove the execution of SLUA studies. The Economics of Ecosystems and Biodiversity of 2010 stands out, as well as the Rio +20 of 2012, the United Nations Sustainable Development Summit of 2015, and the Paris Agreement on Climate Change of 2016. Among the methodology, the discipline of economics stands out. The development of remote sensing facilitates its application in SLUA studies. Therefore, the analyses included both uses and land cover through geographic information systems and remote sensing. New sustainable forms of agriculture are emerging, such as organic farming, permaculture, and multifunctional agroecosystems.

The analysis of keywords also makes it possible to reveal the countries that have been the main object of study. These are mainly countries located in the Americas, Oceania, Asia, and Western Europe (Fig. 5). Similar to what Fig. 6 showed in co-authorship cooperation, Russia, the Middle East, and Africa are regions with research gaps in SLUA (Fig. 5).

Fig. 6 shows a structure map based on co-occurrences of the main keywords used in the articles on SLUA during the period 1988–2017. The size of the circle is based on the number of articles, the thickness of the lines depends on the number of co-occurrences, and the colour identifies the different clusters, which correspond to the main lines of research for this subject (Maaz et al., 2018). The most prominent terms in the figure correspond to the main keywords in Table 7. The figure shows the link between those terms considered hotspots for this research area, with four main groups identified. Agriculture currently faces many challenges. Among these challenges is the need to increase food production to meet the demands of a growing population worldwide. The use of agricultural crops to produce biomass for biofuels is another increasingly widespread activity. These practices, along with expanding urban land use, compete for an increasingly limited area. The loss of biodiversity associated with agriculture is another concern reflected in the many related legislative initiatives worldwide. Environmental conservation is an additional priority for both the general population and governments of most countries. Finally, the effects of climate change are a limiting factor for agricultural development and represent a threat to the entire planet. Sustainable agricultural land use would contribute to solving these challenges, guaranteeing the food supply for all populations, promoting regional economic development, and contributing to the conservation of natural resources for future generations. The lines of research identified here would comply with these objectives.

In the red cluster, the term ‘sustainable development’, which gives its name to this research line, is the term that is highlighted. It incorporates organic farming and multifunctional systems that combine agriculture, livestock, and agroforestry. Economic analysis and land

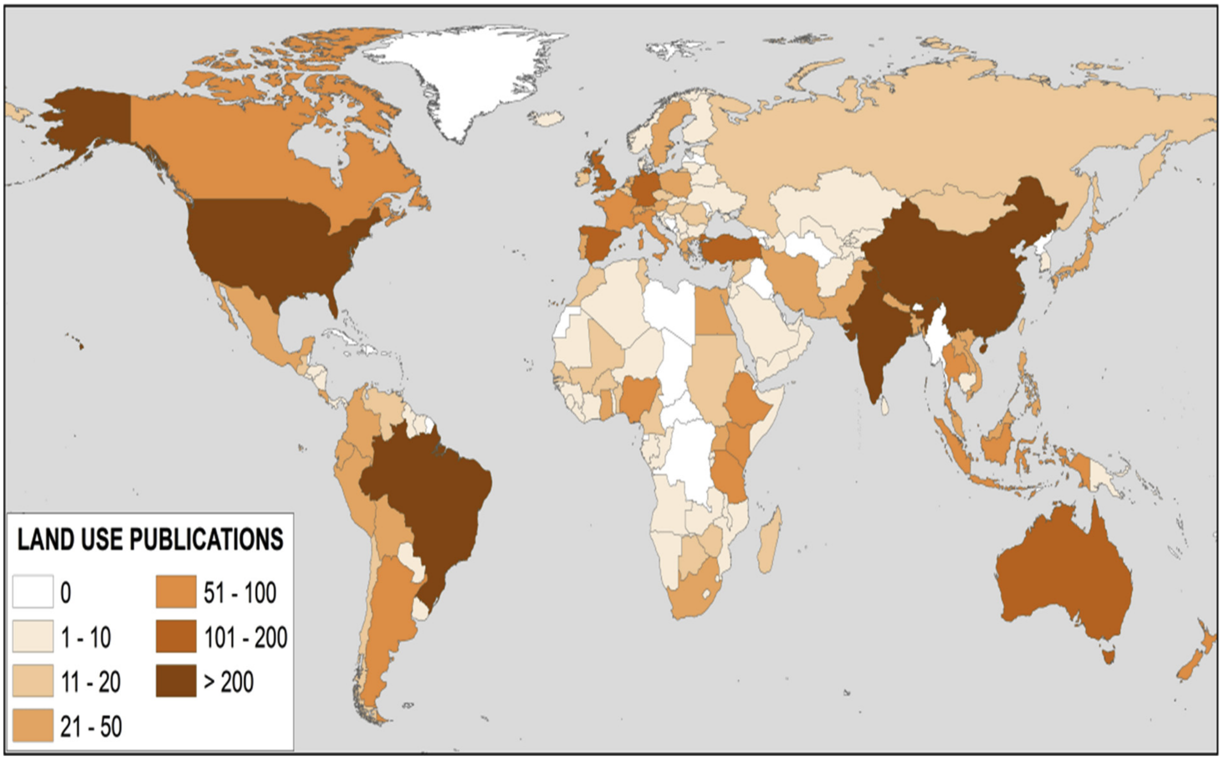

Fig. 5. Study area for SLUA research.

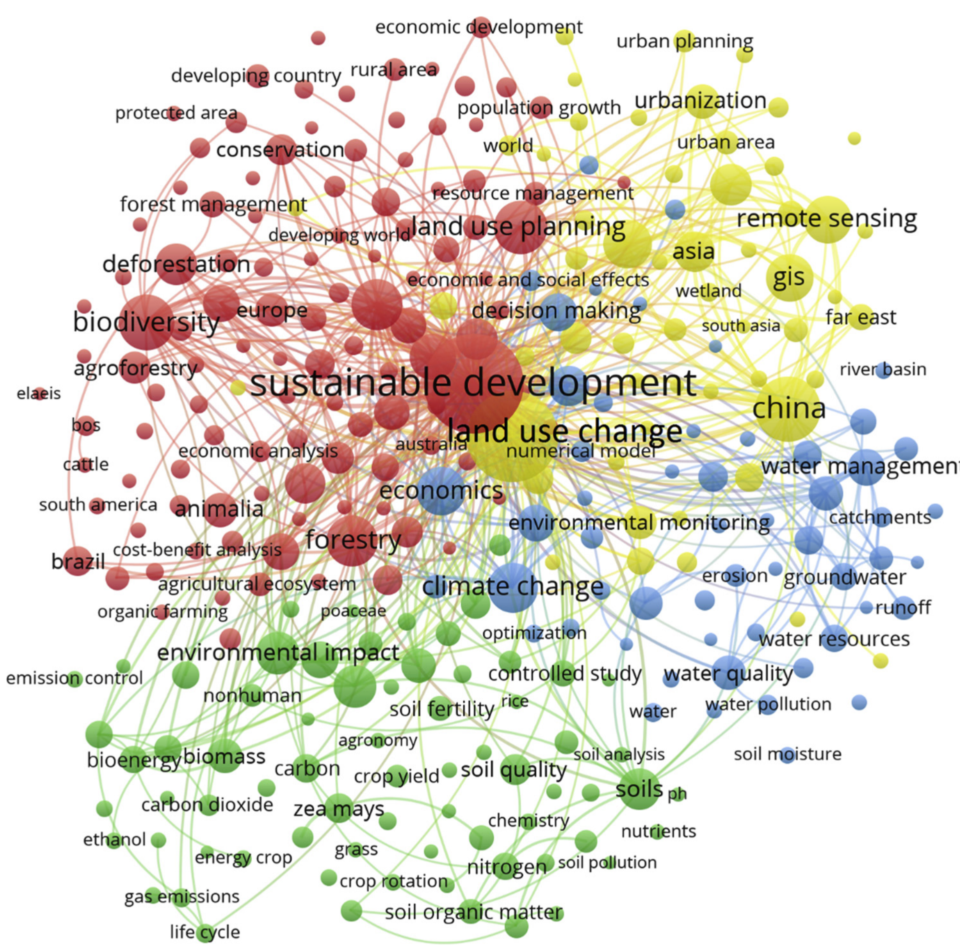

Fig. 6. Mean keyword co-occurrence network in SLUA research.

Table 8
Main keywords in SLUA research by country.

Blue-cluster countries	Keyword	Land-Use-Change	Sustainable-Development	Biodiversity	Agricultural-Land	Africa
	%	24.40	23.09	14.05	11.76	10.57
Red-cluster countries	Keyword	Sustainable-Development	Land-Use-Change	China	Agricultural-Land	Ecosystem
	%	25.67	25.09	18.70	12.23	9.34
Green-cluster countries	Keyword	Land-Use-Change	Sustainable-Development	Biodiversity	Agricultural-Land	Climate-Change
	%	25.54	25.54	14.56	14.14	10.44
USA	Keyword	Land-Use-Change	Sustainable-Development	Ecosystem	Climate-Change	Biodiversity
	%	27.44	25.70	12.95	11.79	11.21
China	Keyword	Sustainable-Development	Land-Use-Change	Agricultural-Land	Remote-Sensing	Environmental-Protection
	%	34.38	31.46	19.03	13.51	12.22
Germany	Keyword	Land-Use-Change	Sustainable-Development	Biodiversity	Agricultural-Land	Crops
	%	26.48	23.08	15.74	15.56	10.02
UK	Keyword	Sustainable-Development	Land-Use-Change	Biodiversity	Ecosystem	Climate-Change
	%	27.08	24.23	18.29	14.96	14.49
Netherlands	Keyword	Sustainable-Development	Land-Use-Change	Biodiversity	Land-Management	Land-Use-Planning
	%	26.05	21.29	14.01	11.20	10.92
India	Keyword	Remote-Sensing	Sustainable-Development	GIS	Land-Use-Change	Land-Cover
	%	17.85	17.54	16.92	15.08	9.85
Brazil	Keyword	Land-Use-Change	Sustainable-Development	Deforestation	Soil	Amazon
	%	28.17	19.72	17.25	12.32	10.21
Australia	Keyword	Sustainable-Development	Land-Use-Change	Biodiversity	Agricultural-Land	Climate-Change
	%	26.64	21.24	15.83	11.20	10.42
Italy	Keyword	Sustainable-Development	Land-Use-Change	Agricultural-Land	Climate-Change	Biodiversity
	%	30.08	25.42	14.83	14.83	12.71
France	Keyword	Land-Use-Change	Sustainable-Development	Biodiversity	Agricultural-Land	Farming-System
	%	28.57	19.82	17.51	13.82	12.90

%: percentage of appearance in SLUA articles.

management are used to assess rural development, environmental protection, and the conservation of ecosystems and biodiversity. This line is developed mainly in Europe, the Americas, and other developing countries. The line of research represented by the red cluster addresses responses to agricultural challenges by implementing high-yield, environmentally friendly production systems that combine, for example, different livestock ranching, forestry, and agricultural practices into a single production system. In this way, various products can be supplied from smaller areas, thereby contributing to the conservation of biodiversity and the environment. These practices would benefit from circular economic systems, capable of connecting all production phases. For example, excess animal excrement from livestock ranching could be sold as a sub-product or used as an agricultural fertiliser. However, circular production systems are mostly non-existent. Consequently, numerous livestock operations in developed countries must limit their number of animals given the difficulty of waste management, while fertilisation continues to represent much of the costs to agricultural farmers. Hence, among the lines of future research, development of circular production systems that connect different agricultural activities should be examined. Ecological production systems have been shown to be high-yield alternatives that can reduce the use of pesticides and inorganic fertilisers that contaminate the environment. Despite the benefits of alternative agricultural production systems, these systems continue to represent only a small portion of the production systems in many agricultural regions. This is due to many factors, among which is farmer reluctance to shift to this type of production given the possibilities of losses in crop yield, increased production costs, and reduced demand for ecological products. Hence, more in-depth research should be conducted on the perceptions and preferences of farmers after introducing this type of production system. Similarly, greater knowledge is needed regarding consumer preferences and the willingness to pay for not only healthy foods but for foods that have been produced in an environmentally friendly manner, while lacking distinguishing organoleptic properties.

The yellow cluster corresponds to the second research line, focusing on land uses and their evolution. The main factor of change is population growth and urbanisation processes. This line of research is developed mainly in Asia, especially in China. Remote sensing techniques and geographic information systems are very useful for research. Land transformation resulting from shifting land use, which is mainly related to urban expansion, represents a great challenge. Traditionally, agriculture has been the main factor responsible for converting natural ecosystems to managed ones. However, the more recent tendency of rural populations to migrate to urban centres has resulted in the growth of cities and new land-use conversion processes. The lack of adequate planning and development of urban centres has additional consequences, including the loss of natural ecosystems and contamination of the surrounding environment. Therefore, systems that sustainably manage urban waste should be investigated. Furthermore, land-use planning systems that can integrate elements such as forests and urban gardens, contributing to the production of goods and mitigation of pollution levels in cities should be developed.

The third research line refers to sustainable water use (blue colour). This resource is essential for the life of the entire ecosystem but particularly for the development of agricultural activity. Given the threat posed by the effects of climate change and the fact that agriculture is the main consumer of water worldwide, the study of sustainable water management in agriculture is highly relevant. Water is the main limiting factor for agricultural activities in much of the world. The expansion of agricultural land and poor conventional production practises have led to contamination of soil and water bodies worldwide. Hence, production systems must be developed that efficiently use water and polluting inputs (fertilisers and pesticides). In addition, greater knowledge is needed regarding the use of alternative water resources for irrigation (e.g., desalinated water, recycled water, and rainwater capture systems).

Fourth, in green, we find the line of agronomic research. This line of research focuses on different types of crops, soil conditions, management techniques, and agricultural impacts. In addition to the changes in precipitation patterns, global climate change has led to an increase in the earth's temperature. This has resulted in consequences for crops, including changes in flowering periods. Technological and genetic advances in agronomy have enabled the commercialisation of transgenic products, such as transgenic papaya, and the production of crops under extreme conditions, such as cultivating tomatoes in the Sahara Desert. Future research should involve how crops adapt to new conditions in different climates.

Table 8 shows the five most utilised keywords in SLUA research

Table 9
Main keywords in SLUA research by institution.

Chinese Academy of Sciences	Keyword	Land-Use-Change	Sustainable-Development	Agricultural-Land	Asia	Eurasia
	%	37.57	32.28	22.49	19.31	19.31
Wageningen University and Research Centre	Keyword	Sustainable-Development	Land-Use-Change	Biodiversity	Eurasia	Farming-System
	%	25.35	18.78	12.21	12.21	11.74
Institute of Geographical Sciences and Natural Resources Research	Keyword	Land-Use-Change	Sustainable-Development	Agricultural-Land	Asia	Eurasia
	%	38.53	34.86	22.94	14.68	13.76
China Agricultural University	Keyword	Sustainable-Development	Land-Use-Change	Crops	Soil	Agricultural-Land
	%	22.86	15.71	12.86	12.86	11.43
Beijing Normal University	Keyword	Land-Use-Change	Sustainable-Development	Land-Use-Planning	Asia	Climate-Change
	%	36.92	36.92	18.46	16.92	16.92
Ministry of Education China	Keyword	Land-Use-Change	Agricultural-Land	Sustainable-Development	Gis	Urbanization
	%	48.33	35.00	31.67	16.67	15.00
Ohio State University	Keyword	Soil-Quality	Soil	Organic-Carbon	Soil-Carbon	Zea-Mays
	%	26.32	22.81	21.05	19.30	17.54
Empresa Brasileira de Pesquisa Agropecuaria - Embrapa	Keyword	Land-Use-Change	Soil-Carbon	Greenhouse-Gas	Soil-Organic-Matter	Crops
	%	45.28	18.87	16.98	16.98	15.09
Research Centre for Eco-Environmental Sciences	Keyword	Sustainable-Development	Land-Use-Change	Agricultural-Land	Asia	Eurasia
	%	37.74	35.85	33.96	33.96	33.96
Universität Bonn	Keyword	Sustainable-Development	Land-Use-Change	Agricultural-Land	Africa	Land-Use-Planning
	%	25.49	23.53	17.65	13.73	13.73
Swedish University of Agricultural Sciences	Keyword	Land-Use-Change	Biodiversity	Eurasia	Agricultural-Land	Ecosystem-Service
	%	23.08	19.23	19.23	13.46	13.46
World Agroforestry Centre	Keyword	Africa	Agroforestry	Climate-Change	Land-Use-Change	Biodiversity
	%	28.57	26.53	18.37	18.37	16.33

%: percentage of appearance in SLUA articles.

studies in different geographic areas. These areas include the main identified clusters of Fig. 3, as well as the main countries investigating on which appear in Table 3. In Table 8 we have also added the article percentage in which the keywords are used. Since articles have more than one keyword the percentage may be higher than 100% when summed up. In addition to these keywords, the 10 most important terms, included in at least 8% of the studies, were analysed. This analysis enabled the discovery of the preferred approaches by country and a comparison with those of joint research studies or collaborations. First, Fig. 3 presents the terms that characterise the research in the clusters formed by the different countries. In the three groups, the terms 'land use change', 'sustainable development' 'agricultural land', 'land use planning' and 'forestry' are highlighted. The blue cluster is dominated by the Netherlands and includes much of the African countries, for which 'Africa' stands out as one of the most utilised terms. The same occurs in the green cluster in which most of the European countries are included; thus, the term 'Europe' is among the main key terms. The red cluster includes the most countries, mainly in America and Asia, and the most utilised geographic term is 'China'. The African and European clusters have had the most studies on 'biodiversity' and 'climate change'. However, Africa had more soil studies with a management focus, whereas Europe showed greater interest in economic studies of ecosystems and crops. The Asian-American cluster stands out for soil and ecosystem studies focused on environmental protection and the use of remote-sensing methods. These results are consistent with those obtained from analysing the general tendencies (Fig. 6).

Regarding the analysis of the most utilised keywords by the main countries, we found a common group of terms: 'sustainable development' and 'land use change'. The additional terms used in studies in almost all countries are 'agricultural land', 'biodiversity', and 'ecosystems'. However, some marked differences were noted. Studies from the US focused on 'crops', 'forestry', and deforestation processes, paying special attention to the effects of climate change and environmental protection. Studies from China focused on urbanisation processes from 'ecological' and 'economic' approaches, and the use of remote-sensing methodologies. Studies from Germany addressed 'forestry', 'ecosystems', and 'crops', focusing on land-planning processes based on adequate cultivation practices and the effects of climate change. Studies from the UK stood out for their focus on conserving natural resources and ecosystem services. Studies from the Netherlands centred on land planning and management at the farming-system scale and the corresponding evaluation of environmental impacts, agricultural production, and agricultural sustainability. Studies from India used methods involving geographic information systems and remote sensing to analyse land use and *Triticum aestivum*. Brazil was the only country in which studies emphasised deforestation processes and the greenhouse gas effect, particularly in the Amazon. Studies from Australia centred on land-use planning, considering the consequences of climate change and environmental protection and impacts. Studies from Italy analysed ecosystem planning and management from an economic approach. Studies from France highlighted the impacts of climate change on farming systems, alternative agricultural practices, and ecosystem services.

It has been used the same procedure to compare research preferences on SLUA by the main institutions included in Table 5. The prevailing terms in most cases are "sustainable development", "land use change" and "agricultural land". Institutions highlight also terms referring the geographical area where the work has been conducted. Main institutions focus their work on Asia and Eurasia. Only the Universität Bonn and the World Agroforestry Centre study Africa. Chinese institutions are similar regarding their topic preferences. The Wageningen University and Research Centre, the Swedish University of Agricultural Sciences and the World Agroforestry Centre pay their attention to questions related to biodiversity. The former one works on the farming system. The Swedish institution concentrates specifically on ecosystem services. The World Agroforestry Centre is rather devoted to agroforestry systems. The Ohio State University and the Empresa Brasileira de Pesquisa Agropecuaria are, at the time, focused on coal and greenhouse gases (Table 9).

4. Conclusions

This work has shown the evolution of the research on sustainable land use in agriculture over the past 30 years, as well as the main quantity, quality, and structural indicators of the agents driving this research line (authors, institutions, countries, and journals). Despite its relatively recent origin, this research line has been gaining increasing interest in recent years. An exponential growth trend in the number of articles has occurred since 2006. Our results reveal that research on the sustainability of agricultural land use is becoming relevant for land use studies.

The three subject areas most linked to SLUA studies are Environmental Sciences, Agronomic and Biological Sciences, and Social Sciences. A shortage of works from Economic Sciences has been detected. However, the keyword analysis has reflected how economic methodologies are among the most prominent for studies on this subject, along with remote sensing and geographical information systems. We consider that this apparent contradiction may be due to the widespread use of economic methodologies in other disciplines. Extensive collaborative networks and a high level of international collaboration exist among the different agents involved in this line of research. The need for international collaboration derives from the global nature of the impacts due to changes in land use. These impacts are especially related to processes of deforestation and loss of vegetation cover, which limits carbon assimilation and the emission of greenhouse gases.

The keyword analysis has shown four main research lines and their geographical focus. The agronomic line of research focuses on soil processes and the study of different crops; research on sustainable water management focuses on efficient use of irrigation water and contamination of water bodies due to agricultural practices; research analysing changes in land use, particularly regarding population increase, focuses on the need for supplies and the expansion of urban land; and research on sustainable development focuses on new forms of agrarian management, such as organic farming, permaculture, and multifunctional systems.

Future lines of research should address the development of circular economic systems in agriculture, the study of the perceptions and preferences of stakeholders regarding the implementation of sustainable production systems and consuming agricultural goods, the objectives of sustainability in planning urban spaces to construct green cities that contribute to the production of agricultural goods while minimising impact to ecosystems, the improvement of the efficiency of irrigation water use and the use of nonconventional water sources in agriculture, and the development of management practices and crops that can adapt to the effects of climate change. Geographically, research on SLUA highlights research gaps in Russia, the Middle East, and Africa. In this area of research, the approaches used by researchers from different countries also differed significantly. In addition, these approaches varied based on whether the studies were conducted by researchers from a single country or by groups of researchers collaborating internationally.

Finally, we conclude that research on sustainable land use in agriculture is a growing line of research worldwide. The results of this work can be used for the development of future research and the evaluation of scientific production in this field of study.

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