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A quantitative and qualitative historical analysis of the scientific discipline of agroecology

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At present, agroecology can be interpreted as a scientific discipline, as a movement or as a practice. In this paper we analyse the historical evolution of the scientific discipline of agroecology with a quantitative bibliometric analysis of 711 publications using the term agroecology and the derived term agroecological, as well as a qualitative analysis of definitions, topics and scales, where we also include further important works on agroecology. Agroecology emerged in the 1930s and the period up until the 1960s was the initial phase of agroecology. During the 1970s and 1980s, agroecology as a science expanded, and in the 1990s became institutionalized and consolidated. Since the 2000s, broader definitions have provided the basis for new dimensions in agroecology. During the last two decades the range of topics treated within agroecology grew enormously; also the publication rate has exploded within the last 10 years. The scale and dimension of scientific research in agroecology has changed over the past 80 years from the plot or field scale to the farm or agroecosystem scale and finally to the food system. Currently, three approaches persist: (1) the plot/field scale; (2) the agroecosystem/farm scale; and (3) the food system approach. In spite of a vague utilization of the term agroecology through its different meanings and definitions, the new views and dimensions brought to agroecology as a scientific discipline will probably facilitate efforts to respond to actual important questions on sustainable agriculture, global land use and climate change, or food security, due to increasingly applied systems thinking and interdisciplinary research approaches.

Keywords: agroecology, agroecosystem, agronomy, biodiversity, organic farming, rural development, sustainability

Introduction

In general, agroecology deals with different topics and questions related to agricultural production. In the last two decades, the term agroecology has been increasingly used with different meanings (Wezel *et al.*, in press). On the one hand it is used for the scientific discipline of agroecology, that will be the topic of this paper; but, on the other hand the term agroecology is also used in the sense of a movement or as an agricultural practice (Wezel, 2007; Wezel, *et al.*, in press). Environmental movements in the 1960s often emerged in opposition to industrialized agriculture, when public policies did not consider the environmental impact of agriculture, in particular pesticides, or the social aspects of rural development. Initially, the term agroecology was not used explicitly to describe a movement. It was only in the 1990s when the word started to be used in this sense, especially in the USA and in Latin America, to express a new way of considering agriculture and its relationship to society, and its place within it.

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At the same time there emerged a third usage, that is, for designing a set of agricultural practices. In general, agroecological practices are seen as new, re-invented or adapted practices or techniques within more environmentally friendly agriculture, organic or alternative agriculture, or within traditional agriculture in developing countries.

A historical analysis of the origin and evolution of agroecology seems to be necessary to understand the development of this discipline. Boulaine (1989) states that a good method to illustrate the historical evolution of a scientific discipline, in their case soil science, is to analyse the history of the people involved, and through this approach their ideas, concepts, methods and techniques become apparent. Using the ideas and research of an emerging field, here the case of ecology was mentioned, helps to explain why the past developed the way it did (Leopold, 1949 cited in Worster, 1990). Publication numbers can also give important clues about emerging disciplines. Dalgaard *et al.* (2003) state that an indication for a new or separate discipline, in their case agroecology, is that the numbers of references to agroecology have increased over recent years, indicating that more scientists feel that their work lies sufficiently far from existing scientific disciplines so that an alternative term is necessary.

In this paper we make use of both types of propositions for a historical analysis: analysing ideas and concepts, and the evolution of publication numbers. Thus, to critically analyse the history of agroecology, two main objectives will be considered: (1) to quantitatively analyse the number of publications per year, their authors, countries of origin and the main keyword associated with the term 'agroecology' and closely related terms; (2) to qualitatively analyse the historical evolution of the scientific discipline of agroecology and the different definitions or concepts employed. This includes also the study of the basic supporting scientific disciplines such as agronomy or ecology, as well as an examination of the emergence and evolution of different topics within agroecological research during the history of agroecology.

Methodology

The quantitative analysis was based on a literature review of agroecology using the database Scopus, where scientific articles and some proceedings contributions can be found. With Scopus, publications can be traced back to the 1950s. This work was complemented by a literature review carried out through the Virtual Catalogue of the University of Karlsruhe, Germany (www.ubka.uni-karlsruhe.de/kvk/kvk/kvk_en.html), where we checked library portals in Austria, France, Germany, Great Britain, Italy, Norway, Spain, Switzerland and the United States. Finally, the Internet was used to complete the search for publications (http://scholar.google.com). For the literature review all publications (articles, proceedings papers, books) with the English terms 'agroecology' and 'agro-ecology' as well its derived terms 'agroecological' or 'agro-ecological' were used. The latter were also considered in order to cover the whole spectrum of publications on agroecology, which is not possible with only the single term 'agroecology' since the syntax in titles or the combinations of words is in many cases only possible with the term 'agroecological'. In addition to the English terms, the French terms 'agroécologie', 'agro-écologie' or 'agro-écologique', the Spanish, Portuguese or Italian terms 'agroecologia' or 'agro-ecologia', and the German terms 'agrarökologie' or 'agrarökologisch' were used as well. In the following text, we use only the English term 'agroecology' and 'agroecological' for simplification. In the whole analysis we considered all publications that used the term 'agroecology' or 'agroecological' either in the title or in the keywords. Keywords were only included in publications since 1995, aside from a very few exceptions.

In total, 711 publications were collected and analysed, 540 articles, seven proceedings papers, the remainder including books and a few other publications such as technical papers. A complete reference list was compiled and different analyses of the references were carried out, for example, number of publications per year, affiliation of the publishing authors, main publishing authors, chosen journals for publication or clusters of keywords affiliated with the term 'agroecology' or 'agroecological'. A number of references above the 711 already mentioned were found, but were discounted as no clear indication for the author could be found, or the publication was considered grey literature, such as institution or project reports.

For the analysis of the keywords, two parallel analyses were carried out. The first analysed the different words used in the title of the publication; the second considered the author keywords. These analyses

were intentionally carried out separately because there was (1) redundancy in using the same words in the title and for the author keywords; (2) author keywords often provide more information about the aim and topic of the publication than is obvious in the title only; and (3) author keywords are provided only for articles, but not for books. For the title keywords analysis, 711 titles from articles, proceedings papers and books were used. This included titles in English, French, Spanish, German, Portuguese and Italian. The keywords used in the different languages, with a higher frequency and with valuable information concerning the topic agroecology, are listed in Table 1. Different

Table 1 Title words (since 1928) and author keywords (since 1985) used for agroecology publications

	Title words n=711	***Author keywords n=348***		***Title words n=711***	***Author keywords n=348***
Agroecology	158	150	Biodiversity	21	24
Agroecological	354	92	Diversity	15	11
Agriculture	66	67	Environmental	15	12
Agricultural	49	29	Environment	14	9
Farming	23	33	Ecological	29	14
Cropping	16	8	Ecology	8	16
Rural	23	7	Agroecosystem	17	14
Farm	25	9	Landscape	17	12
Farmer	23	15	Soil	56	51
Production	43	20	Nitrogen	9	26
Yield	18	14	Fertility	9	10
Crop	38	19	Indigenous	10	8
Maize	27	14	Traditional	11	6
Cassava	17	9	Economic	18	10
Rice	12	16	Policy	18	16
Potato	13	5	Food	13	9
Weed	11	14	Poverty	7	4
Pest	11	16	Resource	20	13
Livestock	28	13	Development	41	17
Sustainable	50	39	Management	41	33
Sustainability	23	24	Organic	25	21
Conservation	20	21	Indicator	15	11

writings where summarized, for example, 'agroecosystem' for agroecosystem(s), agro-ecosystem(s) or agro ecosystem(s). The same was done for certain crops, for example rice includes rice and its scientific name *Oryza sativa*. Country names or general words such as 'analysis' or 'system' were not included.

The analysis of the author keywords was carried out on 348 articles. Here, some articles in languages other than English were included, when author keywords were provided in English. Author keywords have normally been provided for publications since 1995 only, except for few articles from 1985 to 1994.

To analyse the number of author keywords and title words used since 1980, different terms were selected to represent each one of the clusters of keywords in Table 1. Two terms were specified with a substantive, as the single words can be very broad in their meaning (agroecological, organic).

The analysis of country of affiliation for publications was carried out for articles only (and a few proceeding papers) since information about country affiliation of book authors was in most cases lacking. In total, 503 references were analysed. Country affiliation was not listed before 1980, except for five articles in the 1950s. The country affiliation provides information about the country in which the authors worked, within a certain research institution, at the time they were publishing their articles. It does not give any information about the nationality of the authors. If several authors were from the same or several institutions, but located in the same country, the country was counted only once for the respective publication. In some cases, country affiliation was provided only for the first author. Thus, the analysis only provides information about general trends. Nevertheless, these trends are, in our opinion, evident and show in which countries research about agroecology has been carried out so far.

Main publishing authors (all 711 publications) and the journals chosen for the publications (540 journal articles) were analysed for the period from 1928 to 2008.

For a thorough qualitative historical analysis of definitions, topics and scales within the scientific discipline of agroecology, other important works on agroecology were also considered where the term agroecology or agroecology was not present in the title or the author keywords. This included references cited by different authors as important publications in agroecology, but also publications that we considered as important work in agroecology from our own experience.

Results

Quantitative history of agroecology

Number of publications per year

The first publication with this word 'agroecology' or 'agroecological' was published in 1928; the next publications followed in 1930, 1935 and 1938. Further growth is presented in Figure 1, with 696 publications up to 2007. In the first five decades, publication rates remained very low, with three publications in the 1930s and another 13 during the 1950s and 1960s. In the 1940s and 1970s (except for 1979) nothing was published. From 1980 to 1987, the number of publications increased to about six per year. This level increased on average to 16 publications per year for the period 1988 to 1996. Since 1997, publication numbers increased significantly to about 37 per year. In 2006 and 2007, the publication rate exploded to around 75 per year. This was also found for the first 10 months of 2008. We can state a 100% increase of publication numbers for the four different periods from 1988 to 2007. This reflects a similar increase in numbers for publications with the term agriculture between 1980 and 1987, and 1988 and 1996 (51%) and 1988 and 1996, and 1997 and 2005 (133%). In contrast, over the last two years the increase slowed down to 20%. This slow down is also evident for publications with the term agronomy, ecology or biodiversity.

Keywords

From 1928 to 2008 the most frequently cited keywords were 'agroecology' or 'agroecological' (Table 1). The latter is the most often used word of all, with a very high number appearing in article titles. It is often used in combination with zone(s) or region(s), indicating the area where the research was carried out, or it is mentioned in publications dealing with the land zoning approach. Agroecological is also often used in a general sense in combination with 'characterization, engineering or factors'. The first cluster of

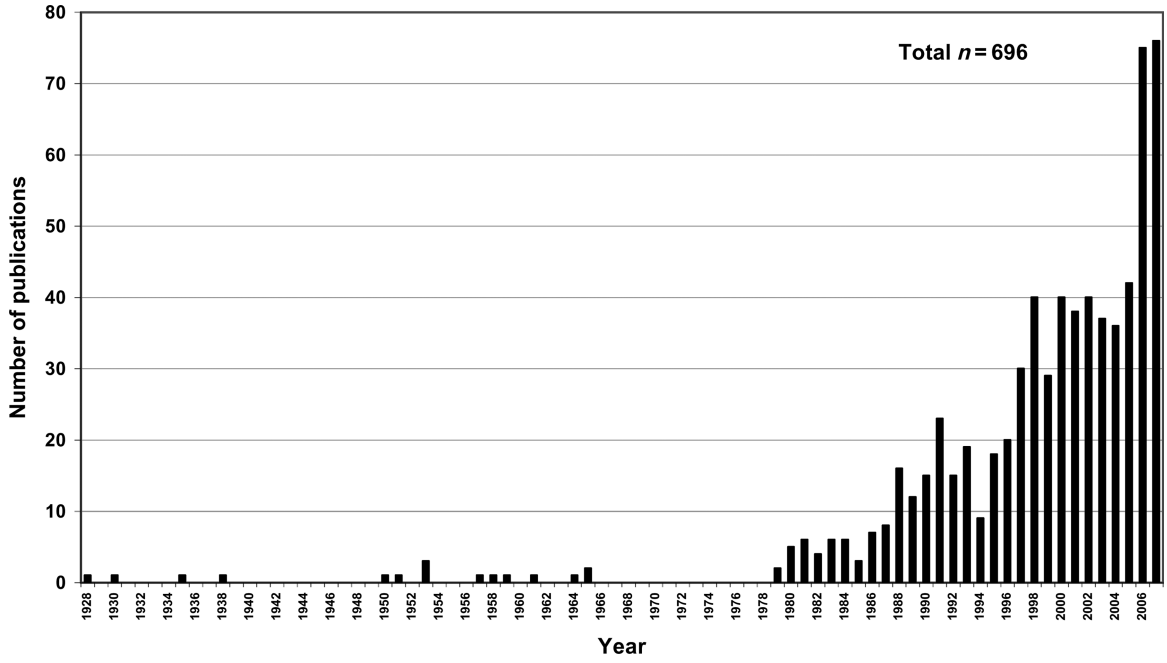

Figure 1 Number of publications using the word agroecology or agroecological in the title or in the author keywords from 1928 to 2007

keywords with the keywords 'agriculture, agricultural, farming, cropping, rural, farm, farmer and production' clearly indicates that the core topic in agroecology is agriculture and agricultural systems in general. Most often mentioned 'crops' were 'maize, cassava, rice and potato', but also topics around 'livestock' production play an important role (e.g. including the words cattle, cow, ruminant, grazing and others). In relation to this, 'weeds and pests', and how they can be

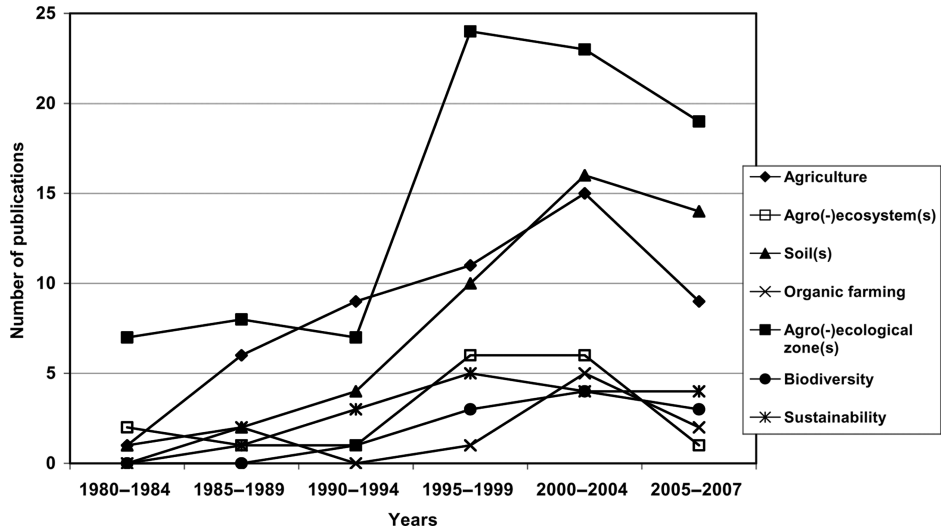

Figure 2 Evolution of selected title word clusters in publications from 1980 to present
Note: Time periods on the *x*-axis are five years, except 2005–2007 which is only three years

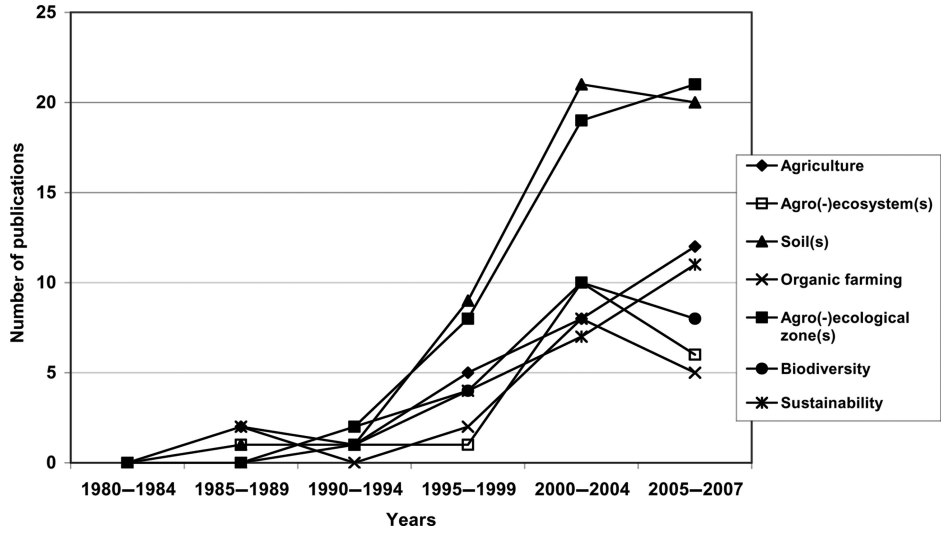

Figure 3 Evolution of selected author keywords cluster in publications from 1980 to present
Note: Time periods on the *x*-axis are five years, except 2005–2007 which is only three years

managed are mentioned fairly frequently. Many other publications deal with questions on 'sustainability, sustainable agriculture or sustainable development', and to a lesser degree with 'conservation, biodiversity and diversity'. Closely connected to these themes are the keywords 'environmental, environment, ecological and ecology'. As agroecological research increasingly takes into account spatial scales larger than the field or the farm scale, the words 'agroecosystem and landscape' appear quite often in publications as well. A very often used keyword is 'soil'. Although publications on this topic can vary quite considerably from soil 'fertility', soil management, soil fauna, soil water to soil erosion, this clearly indicated the importance of soils within agroecological topics. The term 'nitrogen' is often related to soils, but also to other topics such as nutrient cycling and livestock production of biological fixation. Some publications deal with 'indigenous/traditional' knowledge, agriculture, agricultural practices or breeds/varieties. 'Economic' or socio-economic questions and economic benefits as well and impact of 'policy' on different agricultural systems also feature in several publications. Finally, in some publications the issue of 'food' production and food security is important as well as 'poverty' in general, but more precisely poverty reduction.

Country affiliation of publications

As mentioned previously, this analysis does not give any information about the nationality of the authors. The country affiliation provides information about the country in which the authors worked, within a certain research institution, at the time they were publishing their articles. In total, 503 references were analysed. Publications originated from 79 different countries. Many articles that use the term 'agroecology' or 'agroecological' in the title or the author keywords were written by authors from research institutions in the United States (133). This was followed by the United Kingdom (39), France (37), Germany (34) and the Netherlands (30). Other countries with higher numbers are Nigeria (26), China (23), India (18), Canada (15), Italy and Brazil (14), as well as Kenya (11) and Denmark (10).

Main publishing authors

So far, M. Altieri is the author who has published, often together with other authors, the most articles or books (28) where the term agroecology or agroecological appeared in the title or in the author keywords. He is followed by C. Francis (11) and S. Gliessman (10), as well as N.T. Uphoff (six), B.M. Bensin, W. Tischler and P.M. Rosset (five each) and T. Dalgaard, D. McKey and J.R. Porter (four each). Around 45 authors have published three agroecology articles so far.

Journals used for agroecology publications

For the publication of the 540 articles, 292 different journals were used. This includes non-English language journals. By far the most articles were published in *Agriculture, Ecosystems and Environment* (39), followed by *Agricultural Systems* (13), *Journal of Crop Improvement* (10), *Eurasian Soil Science* (nine), *Journal of Ecology* (nine), *Journal of Applied Ecology* (eight), *Ecological Engineering* (seven) and *Environment, Development and Sustainability* (seven). Most of the other journals were related to agriculture. To a lesser degree, articles were published in journals dealing with (1) ecology, environment and biodiversity, (2) soils, nutrient cycling and fertilizers and (3) development and policy.

Qualitative history of agroecology

Starting phase of agroecology: 1930s to 1960s

The year 1928 was the beginning of the history of agroecology. The first publication was a book published by Bensin (1928), a Russian agronomist, who later worked in the United States. According to López i Gelats (2004), it was Bensin who traced back the term agroecology to 1928 from the Czechoslovak Botanical Society. Bensin (1930) suggested the term 'agroecology' to describe the use of ecological methods on commercial crop plants. Agroecology would hence be preliminarily defined as the application of ecology in agriculture. Two further publications were also published by Bensin (1935, 1938), the latter dealing with agroecology as a basic science of agriculture.

In the 1950s, several articles written by the German ecologist/zoologist Tischler (1950, 1953, 1959, 1961) were published in which he used the term agroecology. In these papers, he presented the results of his agroecological research, in particular on pest management, and discussed unsolved problems concerning soil biology, insect biocoenosis interactions and plant protection in agricultural landscapes, including non-cultivated habitats. His book, published in 1965, was probably the first to be actually titled 'agroecology' (Tischler, 1965). He analysed the different components (plants, animals, soils and climate) and their interactions within an agroecosystem as well as the impact of human agricultural management on these components. This approach combined ecology (interactions among biological components at the field level, or agroecosystem) and agronomy (integration of agricultural management). Further publications in the 1950s and 1960s dealt with pest management and zoology (Boness 1953, 1958; Heydemann, 1953; Valdek, 1964), field crops (Vavilov, 1957) and agroecological cartography (Bensin 1951; Thran & Broekhuizen, 1965).

Between the 1930s and 1960s other works (without using the word agroecology or agroecological in the title) were published, and are considered as agroecology publications for the purposes of this paper. The first book concerning agroecology was published by the German zoologist Friederichs (1930), who also worked in the Tropics, with his book on agricultural zoology and related ecological/environmental factors for plant protection. This book also presented different pest management strategies, including biological control and the role of natural habitats for pest management, and evaluated the economic impact of pest damage. His approach was very similar to Tischler's. A second important book on agroecology was published by the American agronomist Klages (1942), whose article in 1928 (Klages, 1928) was one of the first papers dealing with agroecology without using the term explicitly. This article dealt with the distribution of crop plants on a physiological basis. He also analysed the ecological, technological, socio-economic and historical factors influencing their production. Although Klages (1942) only once used the term agroecology in his book, his contribution, along with Friederichs (1930), can be seen as the basis for further publications about agroecology. These pioneers in agroecology were rooted in the biological sciences, particularly zoology (Friederichs, 1930) and agronomy/crop physiology (Bensin, 1928, 1935; Klages, 1928, 1942).

At the end of the 1960s, the French agronomist Hénin (1967) defined agronomy as being 'an applied ecology to plant production and agricultural land management' – which is very close to Bensin's definition – without actually using the word 'agroecology'. Something similar can be stated for the Italian author, Azzi (1956). He defined 'agricultural ecology' as the study of the physical characteristics of environment, climate and soil, in relation to the

development of agricultural plants (quantity and quality of yield and seeds); however, he did not include entomological aspects in his analysis. The foundations of his work were already laid 30 years beforehand (Azzi, 1928, 1942).

Expansion of agroecology as a science: 1970s to 1980s

During the 1970s almost no publications can be found using the term agroecology in the title, except for two publications in 1979 (Figure 1). In the 1980s many publications dealt with agroecological zones or zoning (e.g. Henricksen, 1986; Moss, 1980; Richards & Agalawatte, 1981; Sooryanarana, 1985) based on a concept for the determination of land potential or land suitability, disseminated by the FAO (e.g. Higgins & Kassam, 1981). Other publications analysed agricultural production relating to different crops or to livestock (e.g. Altieri & Trujillo, 1987; Moss, 1980). At the end of the 1980s, sustainability and sustainable development became topical within agroecology (e.g. Altieri, 1989; Dover & Talbot, 1987; Oram, 1988) as well as alternative agriculture (Altieri, 1987).

Since the beginning of the 1980s, agroecology has emerged as a distinct methodology and conceptual framework for the study of agroecosystems (e.g. Puia & Soran, 1984). Agroecology at that time was defined as the global study of agroecosystems protecting natural resources, with a view to design and manage sustainable agroecosystems (Altieri, 1989). The key concept 'agroecosystem' emerged in the 1970s. It was formerly suggested by the ecologist Odum (1969, quoted in Altieri, 1995), who considered agroecosystems as 'domesticated ecosystems', intermediate between natural and fabricated ecosystems. Brauns (1985) broadened the agroecological view of agroecosystems by analysing industrialization and environmental impacts such as herbicides, fertilization, water pollution in agroecosystems and their agrobiocoenosis. Another new orientation in agroecology was research into traditional farming systems and agroecosystems in tropical and subtropical developing countries (Arrignon, 1987; Mendoza, 1981). In these countries, researchers started to recognize that different examples of traditional management of agroecosystems have to be seen as ecologically based management for agricultural production, often illustrated by a strong link between crop and animal production, as well as natural resources.

Another important agroecology publication (without using the word agroecology or agroecological in the title) in the 1970s and 1980s was, for instance, Cox and Atkins (1979). They provided a very broad overview and in-depth analysis of different factors and dynamics in agroecosystems, but also raised political, economic and energy-related questions regarding agricultural systems in developing as well as in developed countries. In relation to research on agroecosystems, Altieri *et al.* (1983) and Conway (1987) should be mentioned. The latter further developed the concept of agroecosystems and identified four main properties: productivity, stability, sustainability and equity. More publications on traditional tropical and subtropical farming systems and agroecosystems are provided by Gliessman *et al.* (1981), Altieri and Anderson (1986) and Hecht (1995).

Institutionalization and consolidation of agroecology: 1990s

During the 1990s, agroecological research enlarged and consolidated, and several important textbooks were published (e.g. Altieri 1995; Carroll *et al.*, 1990; Gliessman, 1990, 1997), and academic research and education programmes were launched (in particular in the USA). The number of publications dealing with agroecological zones, characterization, zoning or land use classification, land use planning and Geographical Information Systems (GIS) increased enormously (Figures 2 and 3).

Publications on sustainability and sustainable agriculture also significantly increased (e.g. Cruces, 1996; Edwards *et al.*, 1993; Power, 1999; Ruiz & Morales, 1995; Thomas & Kevan, 1993; Vosti & Reardon, 1997). This might also be related to the United Nations Conference on Environment and Development, held in Rio de Janerio, Brazil in 1992, which raised awareness of this topic on the world's agenda. Consequently, the theme biodiversity emerged in the 1990s within agroecology-related publications (e.g. Alard, 1994; Altieri, 1993, 1999; Hidaka, 1998).

At the end of the 1990s the word 'soil' started to be used increasingly in agroecology publications under various topics such as soil fertility, conservation, productivity or zonation. As in the 1980s, the

term agroecosytem continued to be present in the title or the keywords of different publications (e.g. Altieri, 1999; Johns, 1998), but to a lesser degree in comparison to the words 'sustainable', 'sustainability' or 'biodiversity'.

More agroecological special research topics on crop and livestock production, or on pest management, were published, in particular since 1998. In many cases the word agroecology appeared in the keywords. This might be due to the fact that agroecology became more well known globally through the books of Altieri (1995) and Gliessmann (1997), and through growing presence on the Internet. Thus, writers would often list the word among the author keywords. Since the 1990s, agroecology was also increasingly considered as a subject for higher education (Altieri & Francis, 1992; Ferrera-Cerrato & Lizaola, 1993; Francis & Altieri, 1992) and education programmes were put into motion, in particular in the USA.

In contrast to the preceding decades, since the 1990s it is not possible to evaluate other publications that do not use the term agroecology in the title or in the author keywords for the qualitative history analysis of agroecology. Publication numbers increased so enormously, in particular those using the different keywords in Table 1 as well as in Figure 2 and 3, that finding all other publications on agroecology was no longer feasible. To mention only a few works would not give a balanced overview, thus, from the 1990s onwards the qualitative history analysis on agroecology carried out in this paper considers only publications with the term agroecology or agroecological in the title or in the author keywords.

New dimensions in agroecology: 2000 to present

At the beginning of the 21st century, new definitions for agroecology appeared. For some authors agroecology moved beyond agroecosystems toward food systems. The most recent definition is provided by Francis *et al.* (2003: 100) with agroecology defined as 'the integrative study of the ecology of the entire food systems, encompassing ecological, economic and social dimensions, or more simply the ecology of food systems'. Gliessman (2007) provided a similar definition for agroecology (see discussion). Ten new dimensions of agroecology, compared to traditional agronomic approaches, are presented by Clements and Shrestha (2004): new philosophy of agriculture, systems thinking, local adaption, non-crop biota, crop autecology, encompassing the agricultural landscape, closing the materials cycle, technology and ecology, human ecology, and the natural dimension.

Publications dealing with sustainability and sustainable agriculture increased even more compared to the 1990s (Figures 2 and 3), but now dealing also more often with sustainable development. Furthermore, publications related to biodiversity increased, including the new terms agrobiodiversity and biodiversity conservation. A new topic appearing since the 2000s connected to agroecology was organic farming/agriculture. Higher education with agroecology expanded and several masters or semester courses were established around the world (for some examples see Francis *et al.*, 2003, Wezel, 2007). In addition, development of agroecology curricula evolved and new learning modes and methods for agroecology were proposed (Lieblein *et al.*, 2007a, 2007b; Waldenström *et al.*, 2008).

Discussion

The roots of agroecology and present agroecology leaders

The historical analyses show that early (i.e. 1930s–1960s) agroecology article and book publications were almost exclusively written by researchers in Germany and in the USA. Thus, these two countries might be called the founders of agroecology. In looking at the disciplinary roots of agroecology, that is, plant geography, zoology (entomology), ecology, crop physiology or agronomy, we realize that these disciplines have an important tradition in these countries. In Germany, for instance, ecology and plant geography as a scientific discipline had already been established since the mid 19th century with scientists such as von Humboldt, Haeckel, Schouw, Griesebach, Schimper and Drude (for examples and titles see Klages, 1928, 1942). The word ecology, for example, was first proposed by the German biologist Ernst Haeckel in 1869 (Odum & Barrett, 2005). The term landscape ecology was first introduced by the German researcher Carl Troll (Troll 1939). In the 19th century, agronomy was also already well developed

in Germany, for example, with von Liebig (1843) and Thaer. In the USA, ecology started in the 1900s, with more well established ecology publications appearing in the 1930s (Odum & Barrett, 2005). Klages (1942) cited some authors' works in the 1920s on agronomy and ecology in the USA, such as Ball, Bensin, Clements and Livingston.

Since the 1980s, publication work on agroecology has expanded to many more countries. Nevertheless, the USA still dominates the publication rate, partly due to the many publications of Altieri, Francis and Gliessman. In the last two decades new 'agroecology countries' emerged such as Nigeria, China, India and Brazil, in addition to traditional research countries such as the United Kingdom, France, Germany and the Netherlands. This countries analysis should always to be interpreted with some caution, as the case of Nigeria shows. The higher number of agroecology publications from Nigeria is mostly due to international researchers working at IITA, the International Institute for Tropical Agriculture, based at Ibadan, Nigeria. Nevertheless, we think that general trends, where most agroecological research is carried out can be derived from the analysis. A more detailed country analysis of agroecology in the USA, Brazil, France and Germany is presented by Wezel *et al.* (in press).

Today's variation in definitions and scales

The word agroecology emerged at the beginning of the 20th century. Thereafter, both its definition and scope as a scientific discipline evolved significantly. An interesting aspect in the different concepts and in the realization of research in agroecology is the change of focus on different scales and dimensions over the past 80 years. In looking at the different definitions and descriptions in the publications, it is evident that agroecology changed from the plot or field scale (1930s to 1960s) to the farm or agroecosystem scale (1970s to 2000s) (Figure 4), although the smaller scale approaches are also still used up to the present. In some publications, the farm is seen as equivalent to an agroecosystem, but other publications see an agroecosystem at the somewhat larger end of the scale of a local or regional landscape where agriculture is practised. At present, the definitions of agroecology given by Francis *et al.* (2003) and Gliessman (2007) go beyond this by leaving the concrete spatial scale and entering the full dimension of the food system. This dimension includes local, regional, national and global geographical scales, as well as the food production systems, society, the economy and politics, that can not be attributed directly to a certain scale, but which are connected and interwoven in different ways (Figure 5a). Although not directly discussing agroecology, Pretty (2008) shows clearly that it is necessary to simultaneously consider and analyse natural, social, human, physical and financial capital dimensions to shape concepts for agricultural sustainability, the core topic of agroecology.

The change of definitions and scale can be related mainly to the evolution of the two basic disciplines from which agroecology is derived, agronomy and ecology. However, other disciplines such as zoology,

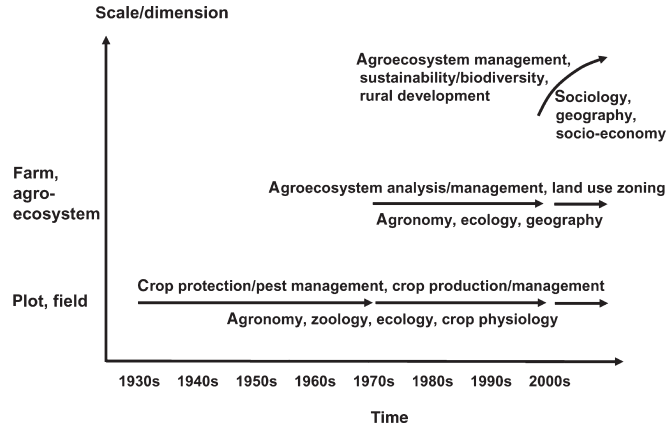

Figure 4 Temporal changes in scale and dimension in the definitions of agroecology as well as related main topics and basic disciplines for research applied (arrows above: main topics; arrows below: basic disciplines)

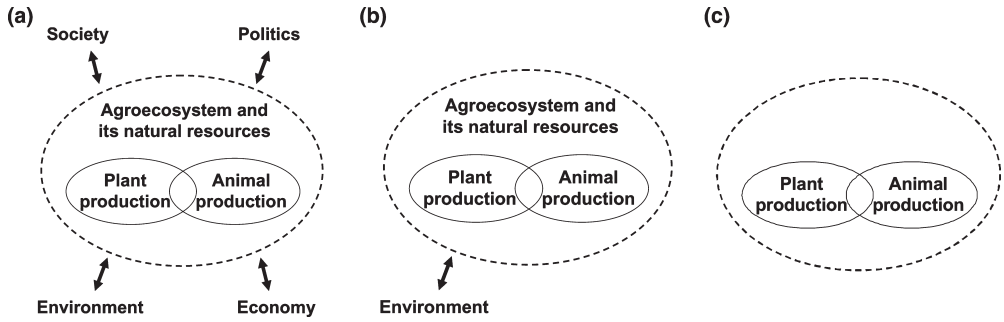

Figure 5 The different definitions and views of agroecology in today's research: (a) food systems approach, (b) agroecosystem approach, (c) plot or field approach

botany/plant physiology, and their applications in agricultural and environmental issues, also play an important role (Figure 4). With larger scales and over time, more disciplines have become involved, for example, geography or socioeconomics. Main topics and objectives vary according to the different scales and where they are applied in agroecological research. In particular, with the food systems approach many more new topics have become part of agroecology.

As mentioned previously, the broadest definition of agroecology was given by Francis *et al.* (2003: 100), who stated it is 'the integrative study of the ecology of the entire food systems, encompassing ecological, economic and social dimensions, or more simply the ecology of food systems'. We think that the politics/policy dimension should also be included in this definition, as the different political decisions and policies are an important issue to be considered (Figure 5a). Gliessman (2007: 369) provided a similar definition for agroecology giving it as 'the science of applying ecological concepts and principles to the design and management of sustainable food systems', but with certain emphasis on practical application. These two definitions are based on former definitions and descriptions of Altieri (1989, 1995, 2002). Schilke (1992) considered agroecology in the same way as Francis *et al.* (2003) who somewhat later defined it as the ecology of food systems. Although Schilke (1992) did not provide any definition of agroecology and this publication is considered a text written for high school education, he presents the classical ecological factors within an agroecosystem alongside the economic and political influences on agriculture, as well as the social impacts for rural populations. Ruiz-Rosado (2006) called agroecology a trans-discipline, because of its systems thinking and systems approach, using methods and advances from various disciplines and taking into account local knowledge where ecological, social and economic concepts and principles were applied in a reasonable manner. Agroecology as an interdiscipline is described by Buttel (2007) to include the social and human sciences as well as the ecological and agricultural sciences. Dalgaard *et al.* (2003: 42) defined agroecology as 'the study of the interactions between plants, animals, humans and the environment within agricultural systems' in covering 'integrative studies within agronomy, ecology, sociology and economics' and drew an analysis from which they concluded that agroecology could be clearly considered as a scientific discipline.

Nevertheless, for all these new definitions and approaches in agroecology, be it called a new scientific discipline, an interdiscipline or a trans-discipline, it has become clear that agroecology is a scientific discipline that integrates different disciplines to finalize a more systemic approach. Still, it is difficult to outline clear concepts and new operational tools as they are still under development. A new possible theoretical approach could be the holon approach of Bland and Bell (2007), even if it remains difficult to translate it into reality. Due to the need to tackle the problems of boundaries and change that are evident for all agroecological research questions, they argue that agroecologists need to take into account how intentionalities seek to create holons (an intentional entity) that persist amid the ever changing ecology of contexts, and how boundaries can be recognized based on

how intentionalities draw and act upon them. Another example of a new concept is that productivity of variability should be a key principle in agroecology instead of mostly seeking to limit the variability of productivity (Bell *et al.*, 2008).

The second major, but more restricted approach in agroecology, is the agroecosystem approach (see Figure 5b). Here, ongoing research dominates the agroecosystem scale, including exchange with, and impact on the environment (see, for example, Martin & Sauerborn, 2006). Normally, interactions with society, politics and economy are not taken into consideration. A definition that summarizes this quite well is provided by the Department of Crop Science (Section of Agroecology) at the University of Göttingen (2008): 'Agroecological analyses focuses on plant and animal communities, food web interactions, and conservation biology in temperate as well as tropical agricultural landscapes and agroecosystems'. Within agroecosystem approaches the definitions and concepts might vary depending on the definition of what an agroecosystem is. Sometimes, the farm is seen as equivalent to an agroecosystem, for others an agroecosystem is at the larger end of the scale, that is, a local or regional landscape where agriculture is practised. According to the variation in scale, applied research methods might also vary considerably.

The third agroecological approach is restricted to the plot or field scale (Figure 5c). Here, research almost exclusively analyses crop–pest and crop–weed interaction with a particular emphasis on natural processes. In some cases the impact of pesticides on crops and natural flora and fauna is also analysed. Research on animal production with this restricted approach focuses often on the single animal, or the resources from single or several pastures, but does not really consider the interactions and implications for the agroecosystem or the environment.

Changing topics in agroecology

The topics discussed during the different periods of the history of agroecology have increased over time. Some topics, such as the core topics agriculture, farming or cropping, as well as the topic of soil have persisted throughout the whole period. Others appeared later on, due to changes in definitions or due to new definitions and scale approaches. Here, the topics agroecosystems or food and poverty can be mentioned. In particular, in the last two decades new topics such as biodiversity, sustainability and rural/sustainable development were considered with agroecology. The future core topic of agroecology will probably be agricultural sustainability/sustainable agriculture, as these terms subsume and bring together most other topics. These new topics received increasing attention in many different scientific disciplines because they became topics of global importance (for example, see the list of sub-disciplines at the intersection of nature and culture by Pretty *et al.*, 2008). The vast variety of topics presently considered within agroecology well reflects the different scale approaches and definitions employed today in agroecology. This is also clearly reflected in the diversity of journals used today for publication, although journals that have broader aims and scopes predominate. An ever increasing variety in topics can be assumed in the next few years, as agroecology becomes more than ever used with different meanings as a science, movement or practice (Wezel, 2007; Wezel *et al.*, in press). This has already become apparent in our analysis, for example, in keywords or the number of publications. It was often not possible to distinguish clearly between publications considering agroecology as a scientific discipline or as a movement or as a practice. In addition, as mentioned previously, since the 1990s it is no longer possible to qualitatively evaluate all publications relevant to agroecology that do not use the term in the title or in the keywords. Publication numbers increased in such a way that it is now impossible to evaluate all new topics considered as related to agroecology, for example, biodiversity or sustainability. Pretty *et al.* (2008) provide a list with a wide variety of sub-disciplines that have emerged in recent years. All these sub-disciplines are concerned with the intersection of nature and culture, and are clearly part of agroecology, if we look at the keywords in the list, with many of them also worked out in the present literature analysis. In future, agroecology might function as an umbrella science for all these (sub-)disciplines that have appeared in recent years at the intersection between agriculture and nature, biodiversity, culture, food production, sustainable development and policy.

Conclusions

The historical evolution of the scientific discipline of agroecology seems to show typical constraints of a 'new' scientific discipline. It emerged in a limited number of countries and was not really recognized during its first 50 years. But, it then expanded enormously because of new broader definitions used, enlargement of scale for agroecological research as well as new topics that are considered to be within the agroecology framework. Today, we think that agroecology is well established as a scientific discipline. But still, two main different approaches prevail, the agroecosystem versus the food systems approach, which might not be reconciled with eachother in the near future. The new topics of research and the enlargement of definitions, with quite different meanings and their application, created in the last two decades a vague or even confused agroecology environment, because agroecology is no longer seen only as a scientific discipline, but also as a type of a movement or as a practice. Sometimes it even seems to be a mixture of all of these. Although all these different meanings and uses have all their justification, it will be difficult in the near future to discuss and interpret agroecology without providing a precise definition of agroecology in the respective cases. To really consider agroecology as a new scientific discipline, the basic considerations for future agroecological research should be always to ask what effect, impact or change creates an innovation on the plot level, for example, a new crop rotation or a new type of biological control on the agroecosystem level, but also in the food systems level. Without trying to anticipate potential changes in the environment, on the local population or the economic situation of a single farmer or a group of farmers, such an agroecological research approach would be nothing more than what has been often applied before: restricted research approaches of single basic scientific disciplines.

Although clear concepts and new operational tools are still lacking or underdeveloped, it is fascinating how far agroecology has already evolved in the last few years, and how it has already changed peoples' attitudes and the research approaches applied. The new views and dimensions brought to agroecology as a scientific discipline, such as a new philosophy of agriculture, systems thinking, interdisciplinarity or human ecology, will probably facilitate the efforts of many research groups, together with the public and policy makers, to respond to present important questions on sustainable agriculture, global land use, climate change and food security.

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