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Highly cited articles in biomass research: A bibliometric analysis

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ABSTRACT

This study aimed to identify and analyze the characteristics of highly cited biomass articles in the Science Citation Index Expanded that were published between 1900 and 2013. Articles with at least 100 citations from the Web of Science Core Collection were selected, and the following characteristics were recorded: publication year, authors, institutions, countries/territories, journals, Web of Science categories, and citation life cycles. The results show that 3407 highly cited articles were published between 1966 and 2011, and the most highly cited biomass articles were published in *Ecology*. The USA produced 49% of all highly cited articles and contributed the most single, internationally collaborative, first-author, single-author, and corresponding-author articles. All of the top 13 most productive institutions were located in the USA. In addition, the Y-index was successfully applied to evaluate the publication characteristics of authors. Authors' publication intensities for highly cited articles in biomass research and their publication characteristics were analyzed.

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1. Introduction

The number of citations has been widely accepted as an indicator of the impact of an article [1]. In general, the best articles are published in peer-reviewed journals with high impact factors [2]. In recent years, bibliometric indicators of total citations have been broadly applied to evaluate most-cited articles [3], highly cited articles [4], and classic papers [5]. Since Garfield published "Highly Cited Works in Mathematics" in 1973 [6,7], the citation characteristics of highly cited papers has been analyzed in the fields of water resources [8], chemical engineering [9], environmental sciences [10], wetlands [11], social work [12], adsorption [13], and, in particular, medicine [14–16]. To evaluate countries, institutions, and authors, indicative categories such as independent, collaborative, first-author, corresponding-author, and single-author highly cited articles have been used [9,12]. The citation life cycles of highly cited articles are also important [17]. The citation histories of papers have been used to assess and identify characteristics of articles in water resources [18], chemical engineering [9], social work [12], psychology [19], medicine, and biochemistry [20], as well as to predict future citations on the basis of citation life cycles [21].

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Energy is very important to the world. We rely greatly on non-renewable fossil fuels such as petroleum and coal, but the combustion of fossil fuels causes greenhouse gas emissions worldwide [22]. Development of sustainable energy sources is necessary for our future energy use. The term "biomass" denotes all organic material from plants [23]. Biomass comes from land- and water-based vegetation (trees, crops, and algae) as well as all organic waste. The main components of biomass are the carbohydrate polymers cellulose $[C_6(H_2O)_5]_n$, hemi-cellulose $[C_6(H_2O)_4]_n$, and lignin $[C_{10}H_{12}O_3]_n$ [24]. Green plants convert CO_2 and H_2O to plant material with the help of sunlight through the process of photosynthesis. This process stores solar energy in the form of chemical energy in biomass. Because biomass is abundant and environment-friendly, it is extremely promising as a potential renewable energy resource.

Early biomass research began with the sea [25,26]. Biomass can produce biofuels, such as biodiesel and bioethanols. Biodiesel is produced by triglyceride feedstock from both plant and animal sources, such as vegetable oils, waste oils, and fat, through the transesterification process [27], and bioethanol is produced from starchy feedstock (including sugar) and lignocellulosic feedstock. Biomass as an alternative energy source has received considerable attention [23] because it is renewable [28].

In this study, all biomass-related journal articles with at least 100 total citations from time of publication to the end of 2013 in the Science Citation Index Expanded (SCI-EXPANDED) from 1900 to 2013 were selected and analyzed for the following characteristics: publication year, authors, institutions, countries/territories, journals, Web of Science categories, and citation life cycles. Five bibliometric indicators were used to evaluate publications from specific countries and institutions. A new indicator, the Y-index, was used to evaluate the performance and contributions of individual authors with highly cited articles.

2. Methodology

The analysis provided in this study is based on the SCI-EXPANDED database of the Web of Science Core Collection from Thomson Reuters (updated on October 31, 2014). According to Journal Citation Reports (JCR) from 2013, it indexes 8539 journals with citation references across 176 Web of Science subject categories in the science edition. The keywords biomass, "bio-mass", biofuel, "bio-fuel", bioenergy, "bio-energy", biogas, "bio-gas", biooil, "bio-oil", biohydrogen, "bio-hydrogen", biomethane, biomethanation, biomethanol, biomethanization, biomethanator, biomethanogenesis, biomethanated, biomethanization, bio-methane, bio-methanated, bio-methanator, bio-methanization, bio-methanol, bio-methanation, bioethanol, "bio-ethanol", biobutanol, "bio-butanol", biodiesel, "bio-diesel", biogasoline, "bio-gasoline", biorefinery, biorefinement, biorefining, biorefiners, biorefine, biorefinering, biorefineries, biorefinary, biorefinely, "bio-refinery", "bio-refineries", and "bio-refining" were searched for in the topic field (including title, abstract, author keywords, and *KeyWords Plus*) in the Web of Science Core Collection from 1900 to 2013. We identified a total of 187,407 documents of 19 document types, including articles, proceedings papers, reviews, meeting abstracts, news items, editorial materials, notes, letters, corrections, book chapters, book reviews, reprints, discussions, additional corrections, biographical items, bibliographies, software reviews, and abstracts of published items. *KeyWords Plus* supplies additional search terms extracted from the titles of articles cited by authors in their bibliographies and footnotes in the ISI (now Thomson Reuters, New York) database, and substantially augments title-word and author-keyword indexing [29]. Only the document type "article" was considered. Two additional filters, TC_{2013} [8,18] and the front page [30], were employed to retrieve articles. Because citations' invariance will not be updated, TC_{2013} was applied [30]. The articles selected by $TC_{2013} \geq 100$ were deemed highly cited articles. The total number of times an article was cited from its publication until the end of 2013 was recorded as TC_{2013} [8,18]. The other filter, the front page, was used to identify articles with the indicated keywords on their front page, including the article title, abstract, and keyword section [30]. Articles that could be found only through *KeyWords Plus* were excluded. Ultimately, 3407 articles (1.8% of the 187,407 total articles) were selected as highly cited articles. These records were downloaded into spreadsheet software, and additional coding was manually performed using Microsoft Excel 2007 for calculation.

Articles from Hong Kong after 1997 were included in China [8]. Articles from Germany and "Fed Rep Ger" were, after manual inspection, reclassified as being from Germany [9]. Yugoslavia and Serbia were reclassified as Serbia. Czechoslovakia and the Czech Republic were reclassified as the Czech Republic [31]. In the SCI-EXPANDED database, the corresponding author is labeled as the reprint author; in this study, this person is identified as the corresponding author. In a single-author article for which authorship is not specified, the author is classified as both the first author and the corresponding author [9]. Similarly, in a single-institution article where affiliation is not specified, the institution is classified as both the first author's and the corresponding author's institution. If one author was assigned as the first author of an article, that article was considered a "first-author article" by that author, and if one author was assigned as the corresponding author of an article, that article was considered a "corresponding-author article" by that author. In terms of country/territory or institution, the term "first-author article" was assigned if the first author was from the country/territory or institution under analysis, and the term "corresponding-author article" was assigned if the corresponding author was from the country/territory or institution under analysis. *TP*, *FP*, and *RP* are the numbers of "total articles", "first-author articles", and "corresponding-author articles" for a country/territory, an institution, or an author, respectively.

3. Results and discussion

3.1. Publication year

A total of 3407 highly cited biomass related articles ($TC_{2013} \geq 100$) were published in SCI-EXPANDED. The articles were published between 1966 and 2011. The maximal value of TC_{2013} was 3335, and the average value was 177. Fig. 1 illustrates the distribution of these 3407 highly cited articles over decades, and their citations per publication ($CPP = TC_{2013}$/year). Time is necessary to accumulate citations. No highly cited articles have yet emerged in the most recent two years (2012–2013). However, only 6.1% of the highly cited articles were published before the 1990s, and 44% and 49% of the highly cited articles appeared in the 1990s and the 2000s, respectively. Thus, time may not be a significant reason that an article is highly cited. In particular, the decade of the 1970s, with 41 articles, had the highest *CPP* (285), which can be attributed to the articles entitled "Physiological method for quantitative measurement of microbial biomass in soils" [32] by Anderson and Domsch in 1978, with a TC_{2013} of 1579, and "Effects of biocidal treatments on metabolism in soil. V. Method for measuring soil biomass" [33] by Jenkinson and Powlson in 1976, with a TC_{2013} of 1498. The *CPP*s of the other five decades ranged from 147 in the 2010s to 285 in the 1970s. The earliest highly cited article, published in 1966, is entitled "Studies on decomposition of plant material in soil. II. Partial sterilization of soil and soil biomass" [34] and has a TC_{2013} of 182. The most recent highly cited article, "Driving forces enable high-titer anaerobic

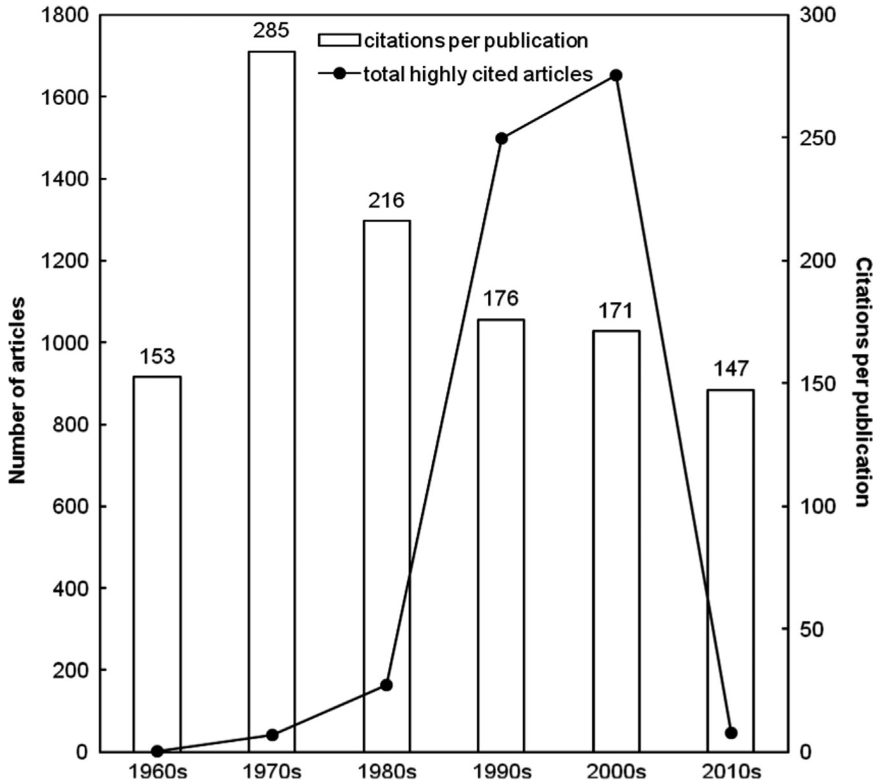

Fig. 1. Number of articles and citations per publication by decade.

1-butanol synthesis in *Escherichia coli*" [35], was published in 2011 and has a TC_{2013} of 110.

3.2. Performance of authors

Given the central role of an author's name in evaluating scientific productivity and the trend toward obfuscation of authorship credit, both the number of authors on an article and their positions in the byline need to be taken into account when determining author contribution [36]. The first author actually made the greatest contribution, and should receive a greater proportion of the credit [37]. The corresponding author supervised the planning and execution of the study and the writing of the paper [38]. In addition, authors with most highly cited articles were more likely to be listed as first authors [16] and non-first authors were assumed to have made smaller contributions [39]. The recently developed Y-index [12] has used to evaluate the performance of authors in, for example, the most-cited articles in chemical engineering [9], the most-cited research articles in the Science Citation Index Expanded [31], and the most-cited articles in adsorption research [13]. The Y-index (j, h) was applied to evaluate authors' publications. This index is related to the numbers of first-author publications (FP) and corresponding-author publications (RP), as defined below [12,31].

$$j = FP + RP \quad (1)$$

$$h = \tan^{-1}\left(\frac{RP}{FP}\right) \quad (2)$$

An author with a higher j has more first- or corresponding-author articles, playing a leadership role. h differentiates the nature of that leadership role. Values of $h > 0.7854$ indicate more corresponding-author articles, and values of $h < 0.7854$ indicate more first-author articles. When $h = 0.7854$, the author has the same number of first-author articles and corresponding-author articles. When $h = 0$, j = the number of first-author articles, and when $h = \pi/2$, j = the number of corresponding-author articles.

We analyzed 9670 authors contributing to 3093 (91% of 3407 articles) highly cited articles with both first- and corresponding-authors' names in the Web of Science Core Collection. Of these authors, 7235 (75% of 9670 authors) authors and 7361 (76%) authors did not have first-author articles or corresponding-author articles, respectively. In total, 6831 (71%) authors did not have any first- or corresponding-author articles ($j = 0$). Excepting authors with $h = \pi/2$ or $h = 0$, 1905 (20%) authors with both first-author and corresponding-author articles included 84 authors (0.87%) with $h > 0.7854$, 32 authors (0.33%) with $h < 0.7854$, and 1789 authors (19%) with $h = 0.7854$. Fig. 2 displays the distribution of the top 51 authors ($j \geq 8$) with their Y-index values. These 51 authors contributed the most highly cited articles as first authors or corresponding authors in biomass research. Each dot in Fig. 2 represents a Y-index (j, h) that could represent one or more authors. In an analysis of 3093 highly cited articles with first and corresponding authors' names in the Web of Science Core Collection, D. Tilman contributed the most biomass articles, with 21 articles, followed by D.J. Jacob (18 articles), E. Baath (17), and Y.J. Kaufman (15). However, A. Demirbas had the highest value of j ($j = 26$), with the same number of first- and corresponding-author articles ($h = 0.7854$), followed by G. Knothe with a Y-index (18, 0.7854). The author with the highest value of j would not always have the same value of h in different research fields. For example, top authors in the adsorption field had values of $h < 0.7854$ [13], and top authors in the chemical engineering field had values of $h > 0.7854$ [9]. In addition, most of the top authors in social work field had values of $h = 0.7854$ [12]. The publication characteristic h could yield a different ratio of first-author articles to corresponding-author articles. This is especially helpful when the j values of authors are too close or are the same and their different contributions cannot be distinguished. For example, the j values of Logan, Fierer, and Canakci were all nine, but their h values were

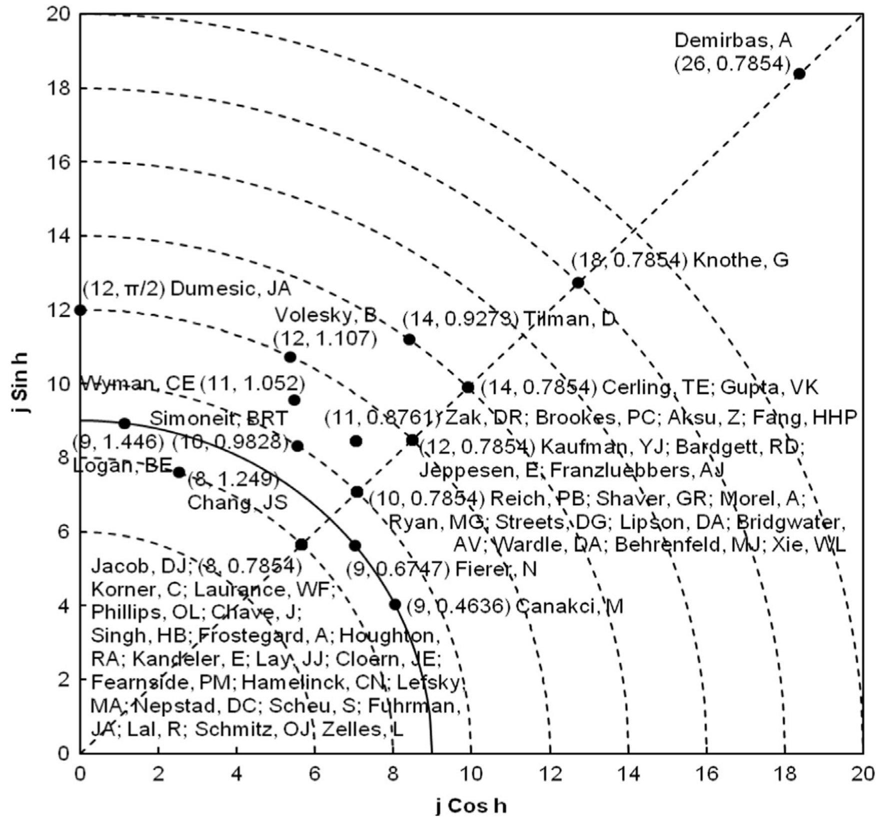

Fig. 2. Distribution of the top 51 authors with their Y-index values ($j \geq 8$).

different, at 1.446, 0.6747, and 0.4636, respectively. Of these three authors, Logan from Pennsylvania State University (USA), had the highest ratio of corresponding-author articles ($RP = 8$) to first-author articles ($FP = 1$). Canakci from Kocaeli University (Turkey) had the greatest ratio of first-author articles ($FP = 6$) to corresponding-author articles ($RP = 3$). Fierer from the University of California Santa Barbara (USA) also had a high ratio of first-author articles ($FP = 5$) to corresponding-author articles ($RP = 4$). Canakci ($h = 0.4636$) and Fierer ($h = 0.6747$) were the only two authors with values of $j < 0.7854$ in Fig. 2. Thirty-eight authors had values of $h = 0.7854$, on the boundary line with the same number of first-author articles and corresponding-author articles. Eleven authors had more corresponding-author articles than first-author articles ($h > 0.7854$), including Dumesic, who published only corresponding-author articles. These results indicate that the top authors contributing to the most-cited articles were more likely to be designated corresponding authors, and probably contributed most to the initial conception and supervision of their studies [40]. Similar distributions were found in the fields of adsorption [13] and chemical engineering [9].

3.3. Performance of Institutions

We found 10 and 143 highly cited articles in biomass research without first-author and corresponding-author affiliations in the Web of Science Core Collection, respectively. Of all articles with author affiliations, 1598 (47%) were single-institution articles, and 1799 (53%) were inter-institutionally collaborative articles. Table 1 shows the top 21 productive institutions, and displays the rankings and percentages of six indicators including total number of articles and numbers of first-author, corresponding-author, single-institution, inter-institutionally collaborative, and single-author articles. Sixteen of the 21 (76%) most productive institutions were in the USA, two institutions were in Canada, and one each was in each of Australia, Spain, and Sweden.

The National Aeronautics and Space Administration (NASA) ranked first in the total number of highly cited articles with 102 (3.0%), followed by Oregon State University with 78 (2.3%) and the University of Washington with 57 (1.7%). NASA also ranked first in inter-institutionally collaborative highly cited articles, and ranked 271st (the last position) in single-institution highly cited articles. However, McGill University (Canada) and Oregon State University (USA) ranked first in single-institution highly cited articles (21 articles, 1.3% of 1598 single-institution articles), followed by the University of Wisconsin, the University of California Davis, and the Indian Institute of Technology (IIT) (19, 1.2%). As for inter-institutionally collaborative highly cited articles, the second institution after NASA was Oregon State University, accounting for 3.2%, and the third was the United States Forest Service (USA) with 2.7%. NASA also had more collaboration in aerosol research [41]. A bias appeared because the IIT has branches in different cities. At present, publications from IIT were pooled as one heading, and publications divided into branches would result in different rankings. *FP* rankings were similar to *RP* rankings for institutions. Oregon State University had the most first-author and corresponding-author highly cited articles, followed by the United States Department of Agriculture, the Agricultural Research Service (USDA ARS), and NASA.

3.4. Performance of countries/territories

The 3397 highly cited articles were published by 2240 institutions in 98 countries/territories. In total, 2584 (76%) were single-country articles and 813 (24%) were internationally collaborative articles. The characteristics of the top 20 countries are illustrated in Table 2. The leading country was the USA (1657 articles), accounting for 49% of all articles, followed distantly by the UK

Table 1
Characteristics of the 21 most productive institutions.

Institution	TP	*TP R* (%)	*IP R* (%)	*CP R* (%)	*FP R* (%)	*RP R* (%)	*SP R* (%)
National Aeronautics and Space Administration (NASA), USA	102	1 (3.0)	271 (0.063)	1 (5.6)	3 (1.2)	3 (1.3)	N/A
Oregon State University, USA	78	2 (2.3)	1 (1.3)	2 (3.2)	1 (1.5)	1 (1.5)	2 (2.5)
University of Washington, USA	57	3 (1.7)	23 (0.63)	4 (2.6)	11 (0.77)	10 (0.77)	61 (0.31)
University of Minnesota, USA	56	4 (1.6)	11 (0.88)	7 (2.3)	4 (0.85)	5 (0.86)	11 (0.93)
University of Wisconsin, USA	56	4 (1.6)	3 (1.2)	10 (2.1)	4 (0.85)	4 (0.89)	61 (0.31)
University of California Berkeley, USA	55	6 (1.6)	11 (0.88)	9 (2.3)	8 (0.79)	7 (0.83)	24 (0.62)
United States Forest Service, USA	55	6 (1.6)	45 (0.38)	3 (2.7)	21 (0.62)	18 (0.64)	11 (0.93)
United States Department of Agriculture, Agricultural Research Service (USDA ARS), USA	55	6 (1.6)	6 (1.1)	10 (2.1)	2 (1.3)	2 (1.3)	1 (3.1)
University of Maryland, USA	54	9 (1.6)	19 (0.75)	7 (2.3)	14 (0.74)	15 (0.7)	24 (0.62)
University of California Santa Barbara, USA	53	10 (1.6)	7 (1.0)	10 (2.1)	11 (0.77)	13 (0.74)	11 (0.93)
National Oceanic and Atmospheric Administration (NOAA), USA	50	11 (1.5)	110 (0.19)	4 (2.6)	64 (0.29)	72 (0.28)	24 (0.62)
Harvard University, USA	48	12 (1.4)	87 (0.25)	6 (2.4)	20 (0.65)	18 (0.64)	61 (0.31)
Cornell University, USA	44	13 (1.3)	27 (0.56)	14 (1.9)	6 (0.82)	10 (0.77)	11 (0.93)
Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia	43	14 (1.3)	8 (0.94)	22 (1.6)	8 (0.79)	7 (0.83)	11 (0.93)
Duke University, USA	42	15 (1.2)	66 (0.31)	10 (2.1)	72 (0.26)	72 (0.28)	61 (0.31)
Colorado State University, USA	40	16 (1.2)	34 (0.50)	17 (1.8)	21 (0.62)	25 (0.58)	N/A
Consejo Superior de Investigaciones Científicas (CSIC), Spain	40	16 (1.2)	11 (0.88)	26 (1.4)	16 (0.71)	13 (0.74)	24 (0.62)
McGill University, Canada	39	18 (1.1)	1 (1.3)	47 (1.0)	6 (0.82)	5 (0.86)	4 (1.2)
Swedish University of Agricultural Sciences, Sweden	39	18 (1.1)	15 (0.81)	26 (1.4)	21 (0.62)	28 (0.55)	4 (1.2)
University of British Columbia, Canada	39	18 (1.1)	45 (0.38)	15 (1.8)	21 (0.62)	18 (0.64)	24 (0.62)
University of Colorado, USA	39	18 (1.1)	27 (0.56)	20 (1.7)	21 (0.62)	25 (0.58)	N/A

TP: total highly cited articles; *IP*: single-institution highly cited articles, *CP*: inter-institutionally collaborative highly cited articles; *FP*: first-author highly cited articles, *RP*: corresponding-author highly cited articles; *SP*: single-author highly cited articles; *R*: rank; N/A: not available

Table 2
Characteristics of the top 20 contributing countries.

Country	TP	*TP R* (%)	*IP R* (%)	*CP R* (%)	*FP R* (%)	*RP R* (%)	*SP R* (%)
USA	1657	1 (49)	1 (47)	1 (55)	1 (43)	1 (43)	1 (45)
UK	369	2 (11)	2 (6.7)	2 (24)	2 (7.2)	2 (7.1)	2 (6.8)
Germany	283	3 (8.3)	4 (4.3)	3 (21)	4 (5.5)	4 (5.6)	2 (6.8)
Canada	274	4 (8.1)	3 (5.6)	4 (16)	3 (5.7)	3 (5.7)	5 (5.6)
Netherlands	199	5 (5.9)	5 (3.9)	6 (12)	5 (4.2)	5 (4.3)	6 (3.7)
France	166	6 (4.9)	10 (2.1)	5 (14)	8 (2.6)	8 (2.6)	9 (2.2)
Australia	139	7 (4.1)	6 (2.8)	7 (8.1)	6 (2.9)	6 (2.9)	7 (3.4)
Sweden	133	8 (3.9)	8 (2.6)	7 (8.1)	9 (2.6)	9 (2.5)	7 (3.4)
China	126	9 (3.7)	9 (2.6)	9 (7.4)	10 (2.4)	10 (2.5)	25 (0.31)
Spain	121	10 (3.6)	7 (2.7)	12 (6.4)	7 (2.8)	7 (2.8)	18 (0.62)
Japan	97	11 (2.9)	12 (2.0)	13 (5.7)	12 (1.8)	12 (1.9)	14 (0.93)
Denmark	93	12 (2.7)	13 (1.9)	15 (5.4)	11 (1.9)	11 (1.9)	13 (1.5)
Switzerland	87	13 (2.6)	16 (1.2)	11 (6.8)	14 (1.6)	14 (1.6)	10 (1.9)
Italy	81	14 (2.4)	15 (1.4)	14 (5.5)	15 (1.6)	15 (1.5)	10 (1.9)
Brazil	71	15 (2.1)	26 (0.50)	10 (7.1)	23 (0.53)	23 (0.55)	14 (0.93)
India	71	15 (2.1)	10 (2.1)	23 (2.2)	13 (1.7)	13 (1.8)	18 (0.62)
Austria	62	17 (1.8)	20 (0.70)	15 (5.4)	19 (0.88)	19 (0.92)	14 (0.93)
New Zealand	59	18 (1.7)	17 (1.2)	18 (3.4)	16 (1.3)	16 (1.4)	10 (1.9)
Finland	52	19 (1.5)	18 (0.89)	17 (3.6)	18 (1.0)	18 (1.0)	25 (0.31)
Belgium	44	20 (1.3)	21 (0.62)	18 (3.4)	22 (0.59)	22 (0.61)	18 (0.62)

TP: total highly cited articles; *IP*: single-country highly cited articles, *CP*: internationally collaborative highly cited articles; *FP*: first-author highly cited articles, *RP*: corresponding-author highly cited articles; *SP*: single-author highly cited articles; *R*: rank; N/A: not available.

(369 articles), Germany (283 articles), and Canada (274 articles). The USA ranked first in six indicators. The G7 (USA, UK, Germany, Canada, France, Japan, and Italy) had the majority of the highly cited articles (74%), ranking 1st, 2nd, 3rd, 4th, 6th, 11th, and 14th, respectively. This finding was consistent with the studies by Suk et al. [42] and Chen et al. [43], who found that the G7 industrial countries published the majority of total world publications on helicobacter pylori and cholinesterase inhibitor research, respectively. Brazil, Russia, India, and China (BRICs) published 8.6% of the highly cited articles. China ranked 9th in total highly cited articles, Brazil ranked 15th, India ranked 15th, and Russia ranked 25th. Spain ranked 10th in total articles but 7th in first-author and corresponding-author articles. Highly cited papers are one indicator of a nation's relative competitiveness in a particular research area [44]. Our results showed that China had relatively low impact, although in total number of biomass-based bioenergy publications China ranked 2nd [45].

3.5. Journal and Web of Science category

Highly cited biomass articles were published in 448 journals and represent 91 Web of Science categories in the science edition. *Ecology* published the most highly cited articles with 159 articles (4.7%), followed by *Soil Biology* & *Biochemistry* with 144 articles and *Nature* with 111 articles, and their IF_{2013}s were 5.000, 4.410, and 42.351, respectively (Table 3). As expected, the top articles were published in journals with high impact factors, as in the subject area of anesthetics [15]. Classic articles are represented mainly in high-impact journals [46]. Highly cited biomass articles

Table 3
Characteristics of the top 15 journals with highly cited articles.

Journal	*TP* (%)	IF_{2013}	Web of Science category	Rank
Ecology	159 (4.7)	5.000	Ecology	17/141
Soil Biology & Biochemistry	144 (4.2)	4.410	Soil Science	1/34
Nature	111 (3.3)	42.351	Multidisciplinary Sciences	1/55
Journal of Geophysical Research-Atmospheres	108 (3.2)	N/A	Meteorology and Atmospheric Sciences	N/A
Bioresource Technology	107 (3.1)	5.039	Agricultural Engineering	1/12
			Biotechnology and Applied Microbiology	17/165
			Energy and Fuels	9/83
Applied and Environmental Microbiology	102 (3.0)	3.952	Biotechnology and Applied Microbiology	30/165
			Microbiology	24/119
Marine Ecology Progress Series	87 (2.6)	2.64	Ecology	48/141
			Marine and Freshwater Biology	15/103
			Oceanography	11/59
Limnology and Oceanography	84 (2.5)	3.615	Limnology	2/20
			Oceanography	5/59
Science	80 (2.3)	31.477	Multidisciplinary Sciences	2/55
Oecologia	67 (2.0)	3.248	Ecology	37/141
Proceedings of the National Academy of Sciences of the United States of America	65 (1.9)	9.809	Multidisciplinary Sciences	4/55
Biomass & Bioenergy	60 (1.8)	3.411	Agricultural Engineering	2/12
			Biotechnology and Applied Microbiology	41/165
			Energy and Fuels	20/83
Ecological Applications	58 (1.7)	4.126	Ecology	26/141
			Environmental Sciences	18/216
Biotechnology and Bioengineering	56 (1.6)	4.164	Biotechnology and Applied Microbiology	26/165
Environmental Science & Technology	56 (1.6)	5.481	Environmental Engineering	2/46
			Environmental Sciences	8/216

TP: total number of articles; IF_{2013}: impact factor in 2013.

with $TC_{2013} \geq 100$ were also found in journals with lower IF_{2013} scores, such as *Pulp & Paper–Canada* with $IF_{2013}=0.136$ and *Interciencia* with $IF_{2013}=0.248$. Forty-nine journals (10% of 448 journals) had no impact factor in JCR in 2013.

Eighteen percent of the top-cited articles (989 articles) were published in 72 journals with impact factors of at least five, for example, *Ecology* (5.000) with 159 articles (4.7%), *Nature* (42.351) with 111 articles (3.3%), *Bioresource Technology* (5.039) with 107 articles (3.1%), *Science* (31.477) with 80 articles (2.3%), and *Proceedings of the National Academy of Sciences of the United States of America* (9.809) with 65 articles (1.9%). Thirty-eight percent of the top-cited articles (1282 articles) were published in 122 journals with $3 \leq IF_{2013} < 5$. In total, 67% of the top-cited articles were published in 194 journals with impact factors higher than 3.

The top 11 categories accounted for more than 200 articles, including ecology with 700 (21%) articles, environmental sciences (505 articles; 15%), biotechnology and applied microbiology (470; 14%), energy and fuels (352; 10%), marine and freshwater biology (303; 8.9%), oceanography (301; 8.9%), soil science (275; 8.1%), multidisciplinary sciences (258; 7.6%), plant sciences (232; 6.8%), meteorology and atmospheric sciences (206; 6.0%), and chemical engineering (206; 6.0%),

3.6. Citation life Cycles of highly cited articles

The relationship between citation frequency and time since publication has long been a topic of investigation [47]. Highly cited articles published in SCI-EXPENDED were clustered according to delayed rise, slow decline and early rise, and those with rapid decline patterns [17]. The life cycles of the most frequently cited articles in the subject category of water resources [8] in the Essential Science Indicators database, the citation life cycles of the top-cited adsorption-related articles [30], and the life cycles of the top-cited articles in chemical engineering in SCI-EXPANDED [9] have also been studied in recent years. Articles published earlier attract more citations compared to those published later [48]. A total of 1824 articles (54% of 3407 articles) had no citations in their publication year ($C_0=0$) and 29 articles (0.85%) had no citation in the most recent recorded year (2013) ($C_{2013}=0$). Articles with higher numbers of citations in their publication year (C_0) were likely to rise appreciably in later years. One reason for this rise might be that the number of journals in the SCI-EXPANDED database increased from 6536 journals in 2000 to 8539 journals in 2013. In SCI-EXPANDED, "Land clearing and the biofuel carbon debt" [49], published in *Science*, had the highest number of citations ($C_0=54$) in its publication year; it was written by five authors from the University of Minnesota and the Nature Conservancy (USA). This was followed by "Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change" [50], published in *Science*, with $C_0=53$; it was written by nine authors from six institutions in the USA. In 2013, only 29 articles (0.85% of 3407 articles) had no citations ($C_{2013}=0$), 1.6% had one citation, 2.6% had two citations, and 3.9% had three citations.

The citation life cycles of the top seven articles ($TC_{2013} > 1400$) are shown in Fig. 3. Four of these seven articles were published before 1990. The one with the highest number of citations (TC2013=3335) was "An extraction method for measuring soil microbial biomass-C" [51], published in *Soil Biology & Biochemistry*, by three authors from Rothamsted Experimental Station in UK. This was followed by "A global model of natural volatile organic compound emissions" [52], published in *Journal of Geophysical Research-Atmospheres* ($TC_{2013}=1910$) by Guenther and 15 other authors from 11 agencies in six countries, and "Biodiesel production: a review" [53], published in *Bioresource Technology* by Ma and Hanna from the USA. Four of the top seven articles were published in *Soil Biology & Biochemistry*, ranked 2nd of 448 journals, and others were in *Journal of Geophysical Research-Atmospheres*, *Bioresource Technology*, and *Ecological Applications*. Although one article for each C_0 of the top seven articles (1, 4, 0, 0, 1, 3, and 0) was not highly cited, as a whole their citations rose to reach C_{2013} values of 345, 143, 231, 157, 72, 50, and 126, respectively.

In terms of increasing speed of citations, these citation life cycles could be roughly classified into three patterns. One was an early delayed rise and a late rapid rise, such as Vance et al. [51]

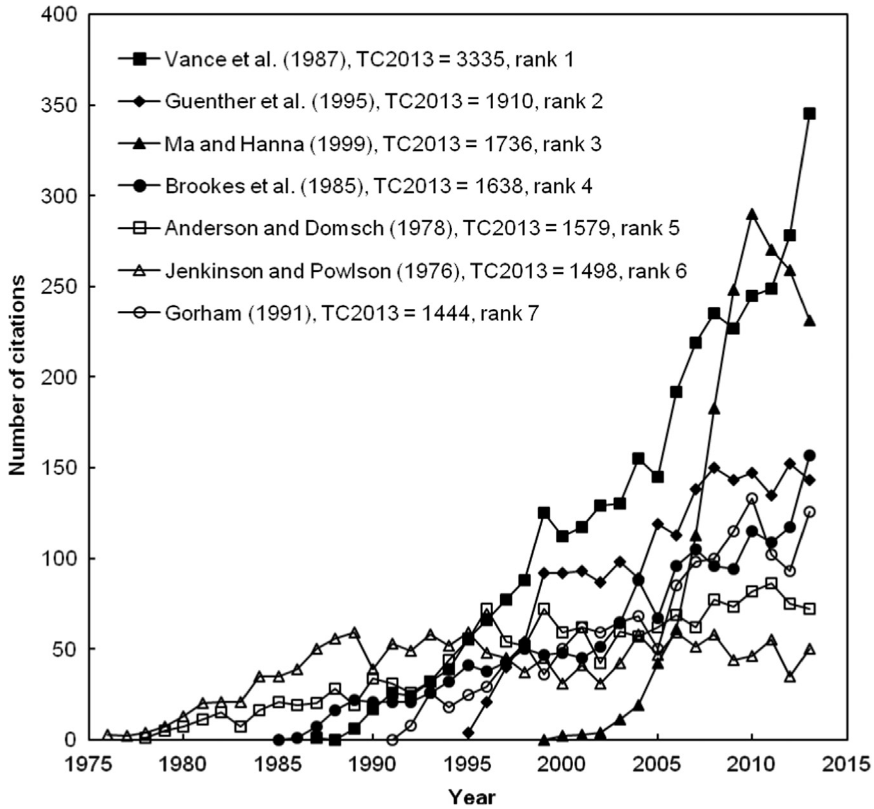

Fig. 3. Citation life cycles of the top seven articles ($TC_{2013} \geq 1400$).

with $TC_{2013}=3335$ ranked 1st and $C_{2013}=345$ ranked 1st, and Ma and Hanna [53] with $TC_{2013}=1736$ ranked 3rd and $C_{2013}=231$ ranked 3rd. The second was an early rapid rise and a late delayed rise, such as Guenther et al. [52]. Others were generally delayed rise pattern. “An extraction method for measuring soil microbial biomass-C” [51], by Vance, is such a methodology paper. Its number of citations rose over 26 years and accelerated significantly in recent years ($C_{2013}=345$). This indicates that a classic article has attracted recent interest. We expect that this article will continue to have increasing numbers of citations. The article “Biodiesel production: a review” [53], by Ma and Hanna, had few citations before 2002, but its citations rose rapidly, reached a peak in 2010 (290), and declined after 2010. This may be explained by both the timeliness of reviews and the introduction of new classic reviews in 2010. A highly cited review entitled “Microalgae for biodiesel production and other applications: a review” [54], by Mata et al. was published in *Renewable & Sustainable Energy Reviews* in 2010 and had a TC_{2013} of 501 with a topic similar to that of the article by Ma and Hanna [53]. “A global model of natural volatile organic compound emissions” [52], by Guenther, was cited with almost exponential speed between 1995 and 1999, when its citations climbed from 4 to 92, and subsequently leveled off. This indicates that there were no good models on the emissions of natural volatile organic compound in that publishing year (1995). This model [53] was the best 3-D global computer model for estimates at that time and had been used successfully since 1990.

The number of citations of papers by Vance et al. [51] were 1, 0, and 6 in 1987, 1988, and 1989, respectively, similar to the numbers for Anderson and Domsch [32], Brookes et al. [57] and Jenkinson and Powlson [33] with citations (1, 5, 7; 0, 1, 7; and 3, 2, 4, respectively) in three early publication years. Vance et al. [51], Anderson and Domsch [32], and Brookes et al. [57] published a series of articles related to those by Jenkinson and Powlson [33]. For example, the studies by Vance et al. [51] were a continuation of work by Jenkinson and Powlson [33] based on earlier work on fumigation, and all were performed at the Rothamsted Experimental Station in UK except those of Anderson and Domsch, which were performed at the Institut für Bodenbiologie in Germany. Their total citations were expected to be high, but there were few early citations of continuity studies.

Jenkinson, from Rothamsted Research, was the first author to publish soil and biomass related research in 1966 [34], based on data from SCI-EXPANDED. In 1976, Jenkinson and Powlson [33] put forth a new method for the determination of biomass in soil based on Jenkinson's work [34]. Soil was fumigated with $CHCl_3$, and then incubated. The actual weight of biomass was calculated from the difference between the amounts of CO_2 in fumigated and unfumigated soil. The previous method, involving direct counting, extraction methods, and respiratory methods, often presented difficulties. Each of these biomass methods has its limitations. Jenkinson is not only a pioneer in soil biomass research, he also proposed an innovative method of measuring soil biomass by fumigation. In 1978, the biomass method was improved by Anderson and Domsch [32] from Germany using the initial respiratory response of microbial populations based on Jenkinson's technique [33]. This offered a direct means for converting respiratory values into actual biomass weights. In 1985, a new direct extraction method for measuring soil microbial biomass nitrogen was established by Brookes et al. [57], also from Rothamsted Research, based on Jenkinson's technique [33]. The new fumigation-extraction method was described by Vance et al. [51] from Rothamsted Research based on fumigation with $CHCl_3$ followed by immediate extraction with 0.5 M K_2SO_4 and measurement of total C released by $CHCl_3$ in the soil extracts. Vance et al. attempted to make these measurements quickly. They found that the fumigation-extraction method provides a rapid method for measuring biomass. Rothamsted Research, established in 1843, is

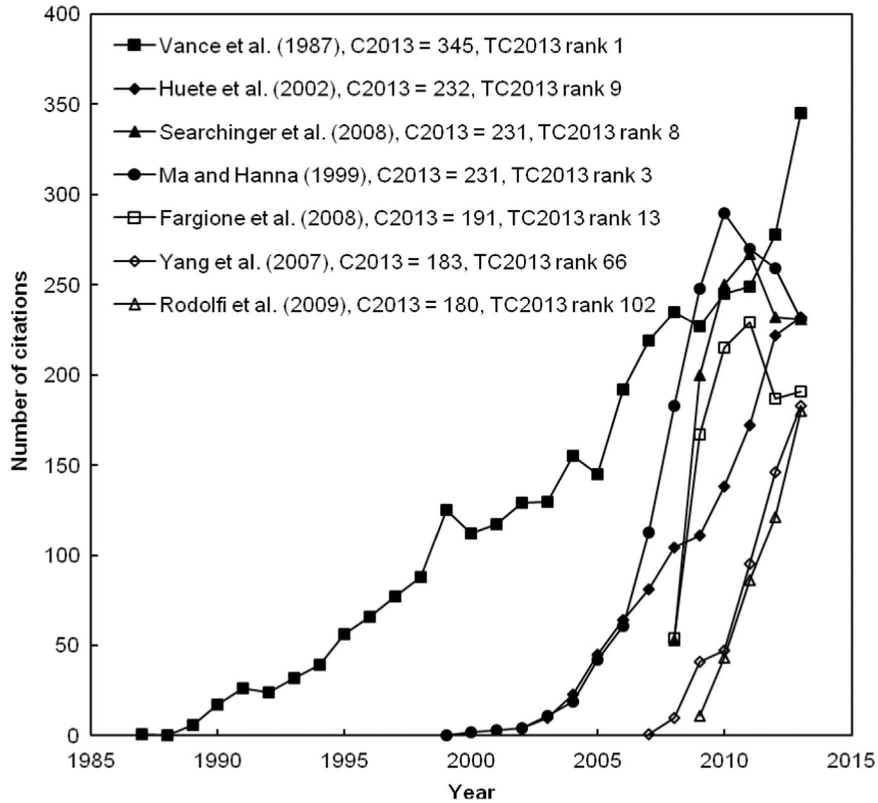

Fig. 4. Citation life cycles of the top seven articles ($C_{2013} \geq 180$).

one of the oldest agricultural research institutes in the world, and it is famous for its continuous long-term experiments.

In SCI-EXPANDED, the article entitled “An extraction method for measuring soil microbial biomass-C” [51], by Vance et al. was not only the most frequently cited article with $TC_{2013}=3335$ citations, but also the most-cited article in 2013, with $C_{2013}=345$. In 2013, 31 articles (0.91% of 3407 articles) were cited at least 100 times ($C_{2013} \geq 100$), including two articles published in the 1980s, six in the 1990s, 19 in the 2000s, and four in 2010. The citation life cycles of the top seven articles ($C_{2013} \geq 180$) are shown in Fig. 4. The delayed rise pattern of the article by Vance et al. [51] was similar to that of articles by Huete et al. [55], with $C_{2013}=232$, ranked 2nd, and $TC_{2013}=1206$, ranked 9th. Others were early rapid rise pattern. However, Ma and Hanna [53], Searchinger et al. [50], and Fargione et al. [49] had declining numbers of citations in recent years. Interestingly, the curves of the citation life cycles of two articles by Searchinger et al. [50] and Fargione et al. [49] were identical. They all proposed that the use of croplands or the conversion of rainforests to produce food crops for biofuels could increase greenhouse gas production. They published in the same journal, *Science*, in the same year (2008), with the highest number of citations in their publication year ($C_0=53$ and 54), and their numbers of citations (200 and 167) rose sharply in the second year of publication. Their citations both reached peaks (267, 229) in 2011 and declined to 231 and 191, respectively, in 2013. Their opinions were completely opposite to those of most studies before 2008 based on references and introductions [49,50]. The article “Studies on the environmental effects of biomass burning have been much neglected until rather recently but are now attracting increased attention” was published in 1990 [56]. This indicated that an original, creative idea was put forward in the articles and quickly became a hot topic. Some hot topics have arisen in other publication years; an example of such an article is “Biodiesel has become more attractive recently” [53]. Such an idea may have defects or may not conform to real-world situations after validation, leading to decreasing researcher interest.

4. Conclusion

A total of 3407 highly cited biomass related articles were published in SCI-EXPANDED from 1966 to 2011. Interestingly, the 1990s and 2000s saw the publication of the overwhelming majority of highly cited articles. Figure with Y-index values presented a clear view of authors' publication intensities and characteristics. The National Aeronautics and Space Administration (NASA) was the most productive institution in terms of the total number of highly cited articles and inter-institutionally collaborative articles, and Oregon State University produced the most single-institution articles, first-author articles, and corresponding-author articles. The United States Department of Agriculture's Agricultural Research Service (USDA ARS) published the most single-author articles. The USA took the lead in six indicators, followed by the UK. *Ecology*, *Soil Biology & Biochemistry*, and *Nature* were the top three journals, and ecology, environmental sciences, and biotechnology and applied microbiology were the three most productive categories. Citations in an article's publication year, in the most recent recorded year, and total citations from publication to the end of 2013 produced different rankings of highly cited articles. The citation life cycle provides a clear overview of an article's impact history.

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