A bibliometric analysis of carbon exchange in global drylands (Postprint)

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Date: 2021-12-03T00:00:00+00:00

Abstract

Drylands refer to regions with an aridity index lower than 0.65, and billions of people depend on services provided by these critically important ecosystems. The mechanisms of ecosystem carbon exchange in global drylands (CED) and how climate change affects CED are critical to the global carbon cycle. In this study, we conducted a comprehensive bibliometric analysis examining annual publications, prominent journals, leading institutions, major countries, popular keywords, and their temporal evolution to understand the temporal trends of CED research over the past 30 years (1991-2020). We found that annual scientific publications on CED research exhibited a significant increase with an average annual growth rate of 7.93%. *Agricultural Water Management* ranked first among all journals and received the most citations. The ten most productive institutions were located in the dryland regions of America, China, and Australia, which together accounted for the largest number of publications and citations in CED research. "Climate change" and climate-related research (such as "drought", "precipitation", "temperature", and "rainfall") represented the most prominent research areas. Keywords were classified into five clusters, indicating five major research themes in CED studies: hydrological cycle, effects of climate change, carbon and water balance, productivity, and carbon-nitrogen-phosphorus coupling cycles. Temporal keyword analysis further revealed that the research focus of CED studies shifted from classical pedology and agricultural research to applied ecology, and subsequently to global change ecology over the past 30 years. Future CED research will likely concentrate on basic themes (such as "water", "yield", and "salinity") and motor themes (such as "climate change", "sustainability", and "remote sensing"). In particular, integrating multiple methods to understand climate change and ecosystem sustainability represents a potential new research frontier and hotspot.

Full Text

Preamble

A Bibliometric Analysis of Carbon Exchange in Global Drylands

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Abstract: Drylands refer to regions with an aridity index lower than 0.65, and billions of people depend on the critically important ecosystem services provided by these areas. Understanding how ecosystem carbon exchange occurs in global drylands (CED) and how climate change affects CED is critical to the global carbon cycle. Here, we performed a comprehensive bibliometric study examining annual publications, prominent journals, leading institutions, contributing countries, popular keywords, and their temporal evolution to understand research trends in CED over the past 30 years (1991–2020). We found that annual scientific publications on CED research increased significantly at an average growth rate of 7.93% per year.

Agricultural Water Management ranked first among all journals and received the most citations. The ten most productive institutions were centered in dryland regions of America, China, and Australia, which together had the largest number of publications and citations in CED research. “Climate change” and climate-related terms (such as “drought,” “precipitation,” “temperature,” and “rainfall”) were the most popular research areas. Keywords could be classified into five clusters, representing five main research foci in CED studies: hydrological cycle, effects of climate change, carbon and water balance, productivity, and carbon-nitrogen-phosphorus coupling cycles. The temporal evolution of keywords further revealed that CED research focus shifted from classical pedology and agricultural research to applied ecology and then to global change ecological research over the past three decades. In future CED studies, basic themes (such as “water,” “yield,” and “salinity”) and motor themes (such as “climate change,”“sustainability,”and “remote sensing”) will dominate the research agenda. In particular, multiple integrated methods to understand climate change and ecosystem sustainability represent potential new research trends and hotspots.

Keywords: bibliometric analysis; drylands; carbon exchange; climate change; arid areas; water resources; sustainability

1 Introduction

Drylands refer to regions with an aridity index (AI, i.e., the ratio of mean annual precipitation to mean annual potential evapotranspiration) lower than 0.65, encompassing dry subhumid (0.50<AI<0.65), semi-arid (0.20<AI$ 0.5), *arid*(0.05 < *AI* 0.20), *andhyperarid*(*AI* $0.05) areas (Barrow, 1992). They are critical terrestrial ecosystems located in regions subject to permanent or seasonal water shortages, covering approximately 41% of the Earth' s land area and supporting more than 38% of the global population. Drylands include shrublands, savannas, and grasslands and are considered the most widespread biome on Earth (Reynolds et al., 2007; Schimel, 2010; Prăvălie, 2016; Huang et al., 2017).

The unprecedented rise in atmospheric CO_2 concentrations causes global warming, glacier melting, sea level rise, and a series of global change problems. Drylands are highly sensitive to human activities and climate change (Berdugo et al., 2017), while climate warming and frequent severe droughts (Yi et al., 2015; Stoy, 2018) have seriously imperiled biological diversity and carbon sequestration capacity in these regions (Ma et al., 2016). Conversely, degradation of arid and semi-arid areas would have serious negative effects on economies and societies, particularly in developing countries (Huang et al., 2017).

Dryland ecosystems also play a key role in the global carbon cycle, dominating the trend and variability of the global terrestrial ecosystem carbon sink, and are highly vulnerable to interannual climatic variability (Poulter et al., 2014; Ahlstrom et al., 2015; Biederman et al., 2017). These characteristics make carbon exchange in global drylands (CED) a field of strong scientific significance, with numerous studies conducted in these areas (Krishnan et al., 2012; Poulter et al., 2014; Yao et al., 2020).

Bibliometric analysis is a statistical method for quantitative evaluation of articles, books, and other publications that has been applied across many research areas (Chen et al., 2016; Aria and Cuccurullo, 2017). Alan Pritchard proposed bibliometrics in 1969 as a way to review the progress of all subjects and provide comprehensive evaluation at different levels (Portner, 2008; Zyoud, 2016). As a statistical and visual method, the bibliometric review process is transparent, systematic, and reproducible, providing more objective and reliable analyses (Aria and Cuccurullo, 2017; Arfaoui et al., 2019). Specifically, bibliometrics can evaluate specific research fields and reveal temporal trends of disciplines and research hotspots, making studies more meaningful (Wang et al., 2016).

In the field of dryland research, Arfaoui et al. (2019) analyzed studies conducted from 2000–2017 to examine biochar application in soil under drought conditions. Zhang and Chen (2020) conducted a bibliometric study of published literature to understand research hotspots on the Chinese Loess Plateau, finding that greenhouse gas emissions, carbon sequestration, and climate are predominant topics in arid areas, especially the carbon cycle in the context of global change. However, explicit knowledge of CED across inclusive arid and semi-arid areas remains limited.

To review all publications on CED research, we performed a comprehensive bibliometric analysis using R software (Aria and Cuccurullo, 2017). Our study aims to: (1) evaluate temporal trends of publications and identify prominent countries, institutions, journals, and hot topics; (2) demonstrate the evolutionary dynamics of research topics and reveal underlying relationships between different research subjects; and (3) provide insights into potential new research trends and hotspots for future studies.

2.1 Data Collection and Preparation

This study focused on CED research, with data collection and preparation divided into two stages. The first stage involved data retrieval using search terms including "carbon flux & arid," "carbon exchange & arid," "gross primary production & arid," "net ecosystem exchange & arid," "production & arid," "carbon flux & dryland," "carbon exchange & dryland," "gross primary production & dryland," "net ecosystem exchange & dryland," and "production & dryland" as topics in all publications from 1991–2020. We selected this period because few studies before 1991 were found in the database. On January 8, 2021, we began our bibliometric collection in the Science Citation Index Expanded (SCI-E) database within the "Web of Science Core Collection" (http://www.webofknowledge.com). The SCI-E database comprehensively covers the most influential studies worldwide and includes explicit reference information that enables tracking of CED research trends (Zhang and Chen, 2020). We preliminarily screened publications, collecting information on 11 aspects: publication type, keywords, correspondence, title, abstract, citation count, year, month/day, volume, issue, and digital object identifier. Our dataset included 11,360 documents, primarily consisting of proceeding papers, articles, reviews, and letters (more details are shown in Table 1). The second stage involved downloading and converting data into BibTex format for comprehensive bibliometric analysis using the bibliometrix package in R software.

2.2 General Statistical Analysis

This section presents general statistical analyses, including the number of publications and books published and cited by each country, journal, and institution.

2.3 Most Used Keyword Analysis

Keywords can reflect study trends and frontiers (Chiu and Ho, 2007; Liu et al., 2012; Ji et al., 2014). Wordclouds enable quick perception of the most significant terms and allow determination of relative significance through alphabetical ordering and font size. We used wordcloud analysis to identify the 50 most popular keywords in CED research over the past 30 years. Labels included single words displayed in different font sizes and colors according to their frequency (Aria and Cuccurullo, 2017).

2.4 Keyword Co-Occurrence Analysis

Keywords appearing in publications form an association network known as a co-word network, which helps understand topics covered in a research area and defines the most important and latest issues (the so-called research front). It also aids in studying the evolution of research topics over time (Choi et al., 2011; Aria and Cuccurullo, 2017). In this study, we constructed a co-occurrence network of the top 50 keywords to identify current research hotspots in the CED field. Different colors represent different clusters, suggesting that these keywords are more likely to appear together in the same publication. Circle size represents keyword frequency, while lines between circles represent relationships between keywords, with thicker lines indicating closer relationships (Lu et al., 2020).

2.5 Temporal Trend Analysis of Keywords

To better understand the temporal evolution of research topics, we conducted temporal trend analysis of keywords by dividing the 30-year publication period into six intervals: 1991–1995, 1996–2000, 2001–2005, 2006–2010, 2011–2015, and 2016–2020. By dividing the timespan into slices, topic evolution in a specific research field can be represented through an alluvial graph (Aria and Cuccurullo, 2017). Additionally, applying a clustering algorithm to keyword networks highlights different topics within a given field. We analyzed two theme types: motor themes and basic themes. Motor themes are topics that are both important and well-developed, while basic themes refer to fundamental concepts that are very important in the field but have not been well developed (Cobo et al., 2011).

All bibliometric and text analyses (e.g., annual number of publications, prominent journals, institutions, countries, and popular keywords), data analysis, and figure plotting were conducted using R 4.0.3 software and SigmaPlot 12.5 software.

3.1 Trends of Publications and Citations

The number of CED research publications and their growth rate during 1991–2020 were closely related to the development of this scientific field (Fig. 1 [Figure 1: see original paper]). We found that the annual number of CED publications increased significantly at an average growth rate of 7.93% per year. Publications increased moderately during 1991–2005, then rose remarkably after 2005, with nearly 80% of all CED publications appearing between 2005–2020 (Fig. 1a). This increasing trend in CED research publications was consistent with trends in global scientific publications in other reported areas (Zhang and Chen, 2020).

Over the past three decades, the mean number of citations per publication showed an opposite trend to the number of publications (Fig. 1b). The mean citations per publication increased in a wave-like pattern during 1991–2005 but decreased significantly after 2005. A similar pattern was observed when calculating mean citations per publication five years after publication. One explanation is that recent publications require more time to reach high citation levels, while older publications are gradually replaced by newer ones. Another reason is that the number of annual publications is rapidly increasing (Arfaoui et al., 2019). The results showed that publications increased remarkably after 2005 (Fig. 1a), which may have led to the decreasing trend in mean citations per publication during this period.

3.2 Marked Journals

CED studies have been published in 1,516 journals with considerable variation. *Agricultural Water Management*, *Journal of Arid Environments*, *Field Crops Research*, *Agronomy Journal*, and *Agricultural and Forest Meteorology* were the five most productive journals (Table 2). *Agricultural Water Management* ranked first among the top journals and received more citations than other journals (Table 2). In semi-arid areas, agriculture has high potential yield due to high energy availability, while actual yield is seriously constrained by water resource shortages. Drought frequently occurs in these areas, resulting in more frequent crop failures. Improved understanding of the hydrological cycle in semi-arid regions could contribute to better water resources management and adaptation policies (Yang et al., 2019). The aims and scopes of these journals are mainly related to water and agriculture, explaining why they are the most productive. Furthermore, scientists more frequently cite high-impact-factor journals, although these journals publish fewer articles in the CED field (Xiang et al., 2015; Zhang and Chen, 2020).

The top five journals in CED research showed various temporal trends (Fig. 2 [Figure 2: see original paper]). *Agricultural Water Management*, *Journal of Arid Environments*, and *Agricultural and Forest Meteorology* have maintained increasing trends in publishing CED research in recent years, with *Agricultural Water Management* showing the most remarkable increase, indicating high-quality publications in CED research. This aligns with the period when "water" and "water use efficiency" became popular keywords (Zhang and Chen, 2020). Additionally, the number of publications in each journal generally showed an increasing trend annually.

3.3 Marked Institutions

Our results showed that 7,692 institutions worldwide have participated in CED research, with the ten most prominent institutions contributing 29.06% (3,301 publications) of the total output. During the study period, Northwest A&F University ranked first with the most publications (596), followed by China Agricultural University and Colorado State University (Table 3). The ten marked institutions were almost all located in dryland regions of America, China, and Australia. Many studies have shown that drylands have strong carbon sequestration potential (Tagesson et al., 2016; Kou et al., 2018; Abdi et al., 2019).

America, China, and Australia cover tremendous typical semi-arid and arid areas at the global scale (Yang et al., 2019) and attach great importance to trends and variability in the land carbon balance (Ahlstrom et al., 2015). Compared with America and Australia, Chinese institutions had more publications (Table 3), suggesting that Chinese institutions have invested more heavily in CED research.

3.4 Marked Countries

The number of publications can reflect a country' s development level in a research field. To obtain comprehensive information, we analyzed both publication counts and citation numbers. The results indicated that 117 countries worldwide have engaged in CED research. America, China, Australia, India, Brazil, Spain, Iran, Germany, South Africa, and Canada were the ten most relevant countries by corresponding authors, contributing 68.04% (7,729 publications) of the total output. Furthermore, America, China, Australia, Spain, Germany, the UK, India, Israel, Argentina, and Canada were the ten most cited countries, contributing 72.42% (184,547 citations) of total citations (Fig. 3 [Figure 3: see original paper]).

Our results showed that countries with large dryland areas typically have high participation in CED research publications. The most cited countries have been closely related to their publication numbers and scientific research strengths (Oliveira and Pereira, 2021). As mentioned above, institutions with the most CED research were mainly from America, China, and Australia (Table 3). Evidently, CED research has been greatly highlighted and developed in America, China, and Australia; however, few CED studies have emerged from countries in Africa and Central Asia. This suggests a research gap across countries, fostering collaboration between researchers from developed and developing countries, particularly in drylands.

3.5.1 Most Popular Keywords

"Climate change" (total frequency of 395) was the most popular keyword, suggesting that climate change is one of the most attention-attracting areas in CED research (Fig. 4 [Figure 4: see original paper]). This is likely because dryland ecosystems greatly impact global carbon cycle variability while being highly sensitive to climate change events such as drought, heat waves, and extreme rainfall (Zscheischler et al., 2014; Huang et al., 2016). Furthermore, model simulations have indicated large uncertainties in dryland ecosystem responses to climate change (Ahlstrom et al., 2015). Consequently, many studies have examined climate change effects on carbon exchange in arid and semi-arid areas, with climate-related research (such as "drought," "precipitation," "temperature," and "rainfall") becoming a focal area of CED research over the past three decades (Fig. 4).

"Soil," "irrigation," "water use efficiency," "yield," and "wheat" were frequently used keywords beyond climate-related terms, reflecting main CED research contents (Fig. 4). As one of the most active components of the carbon pool, agroecosystems are strongly affected by human activities (Soegaard et al., 2003). Achieving high crop yields has become a major goal in drylands (Ahakpaz et al., 2021). Measuring carbon fluxes from croplands can provide references for management practices affecting crop growth, carbon absorption, and carbon release (Menefee et al., 2020). For this purpose, scientists are expending considerable effort on understanding relationships between crop yield and CED research.

Advanced methods were also among the most popular keywords, including "model," "remote sensing," and "eddy covariance" (Fig. 4). These represent the three main approaches for observing and assessing ecosystem carbon exchange and balance from local to global scales (Piao et al., 2013; Chen et al., 2015, 2018; Li et al., 2021). An increasing number of studies have combined various observation methods; for example, eddy covariance tower observation data and MODIS data-driven models have been used to test different ecosystem sites in drylands (Li et al., 2021).

3.5.2 Co-Occurrence Network of Popular Keywords

The keyword co-occurrence network indicated that CED research hotspots focused on five clusters: "evapotranspiration," "climate change," "water use efficiency," "photosynthesis," and "nitrogen" (Fig. 5 [Figure 5: see original paper]). "Evapotranspiration" was the most popular keyword in the dark blue cluster (Fig. 5). This cluster mainly described sources, formation mechanisms, and regional evaluation of evapotranspiration, and was associated with "soil," "soil organic carbon," "soil moisture," "carbon sequestration," and "remote sensing." Evapotranspiration is one of the most important fluxes in ecosystems and has been reported to be greatly enhanced by climate warming both regionally (Liu et al., 2010) and globally (Zhang et al., 2015). Precipitation, temperature, radiation, and wind speed can influence evapotranspiration processes (Yang et al., 2019). As an important component of the water cycle, quantifying spatiotemporal patterns of evapotranspiration across major drylands along climatic gradients is crucial for water resources management in water-limited areas (Wang et al., 2021). Therefore, systematic and comprehensive studies are needed to better understand evapotranspiration, which may explain why these keywords appeared in a cluster.

The green cluster focused on "climate change" (Fig. 5). In this cluster, the keyword "drought" occupied a large portion and most frequently appeared with climate change. Drylands are the most sensitive areas to climate change, and extreme drought is the main factor threatening sustainable development of arid regions (Huang et al., 2016; Miao et al., 2020). These results indicated that climate change effects were extensively highlighted in dryland studies under drought conditions, especially in arid and semi-arid areas where ecosystems are very fragile and sensitive to drought. In semi-arid areas, droughts are frequent and negatively affect crops (Yang et al., 2019).

The purple cluster was associated with "water use efficiency" (Fig. 5). This cluster mainly described "water use efficiency" and "yield," along with related topics such as "irrigation," "salinity," "wheat," and others. Water use efficiency is a key parameter linking global carbon and water cycles (Tarin et al., 2020) and is an important index in agriculture. In semi-arid areas, actual agricultural yield is seriously constrained by water shortage (Seneviratne et al., 2010; Yang et al., 2019). Therefore, improving water use efficiency is an essential issue for agricultural management in dryland ecosystems.

The red cluster included "photosynthesis" as the most popular keyword and was related to "biomass" and "productivity" (Fig. 5). The final orange cluster consisted of keywords for "carbon," "nitrogen," and "phosphorus" (Fig. 5). These two clusters reflected research on carbon and nutrient cycles. In dryland ecosystems, carbon exchange and storage are strongly controlled by the supply of other key nutrient elements such as nitrogen and phosphorus (Hessen et al., 2004). For example, nitrogen deposition promotes net carbon absorption in ecosystems by increasing nitrogen availability for photosynthesis and growth, which can unbalance the relationship between supply and demand (Magnani et al., 2007). Therefore, studying the balance of carbon, nitrogen, and phosphorus is important for understanding ecosystem carbon sink potential and predicting how ecosystems will respond to future climate warming (Grace and Rayment, 2000; Hobbie et al., 2002).

3.5.3 Temporal Evolution of Keywords

During 1991–2000, classical pedology and agricultural science research dominated, with keywords such as "water use efficiency/water use," "semi-arid," "salinity," "soil," "irrigation," "wheat," "sorghum," "nitrogen," "grazing," "growth," "agroforestry," "production," and "yield" (Fig. 6 [Figure 6: see original paper]). With the development of applied ecological research related to CED, keywords such as "drought," "sheep," "cropping system," "desertification," and "agriculture" increased from 2001 to 2005. During 2006–2010, the study region expanded from "semi-arid region" to "arid region," and studies further developed into "climate change." In the 2010s, global change ecological research became dominant. For example, during 2011–2015, "biofuel," "nitrous oxide," and "vegetation" emerged as new popular research fields (Fig. 6). After 2016, "remote sensing" and "sustainability" emerged as new popular keywords.

Popular keywords transformed over the past three decades, shifting from classical pedology and agricultural science research in the 1990s to applied ecological research in the 2000s and then to global change ecological research in the 2010s. In the early stage, with the implementation of policies promoting scientific development, many scientists devoted themselves to basic research (Zhu, 1999). In the new millennium, global drylands face numerous problems posing severe challenges to research, management, and policy, with scientists concerned about land degradation, poverty, biodiversity safeguarding, and other issues (Reynolds et al., 2007).

Some topics, such as "nitrogen," "irrigation," "agroforestry," "grazing," and "water use efficiency," have gradually cooled down, while other hot topics such as "climate change,""sustainability,"and "remote sensing"have recently emerged (Fig. 6). Therefore, we further conducted thematic analysis to understand keyword temporal evolution. "Grazing," "agriculture," "climate change," "sustainability," and "remote sensing"were motor themes over the past 30 years, while "irrigation" and "water use efficiency"were basic themes (Table 4). This is a very interesting phenomenon. Generally, motor themes are both important and well-developed, while basic themes are important for a research field but not well developed (Cobo et al., 2011). Therefore, it is not difficult to understand why "climate change," "sustainability," and "remote sensing" have been hot topics in recent years while "irrigation" and "water use efficiency" have gradually become less popular. Although "grazing"and "agriculture"were motor themes and important, they were studied intensively in the early stage (Fig. 6) and may have reached a bottleneck through long-term development. The thematic analysis also showed that each keyword evolves into different themes over time (Cobo et al., 2011).

In drylands, agriculture represents a major economic activity, with approximately one-third of the population in these zones depending on it. However, studies have pointed out that water irrigation technology has not improved in recent years (Echchelh et al., 2018). As the thematic analysis showed, although "irrigation" and "water use efficiency" were very important, they did not develop well (Table 4). This may explain why these keywords did not appear recently (Fig. 6). Additionally, we identified strategies to take advantage of emerging opportunities in remote sensing to overcome previous challenges (such as low vegetation signal-to-noise ratios, high soil background reflectance, and presence of photosynthetic soils) in drylands and to analyze drylands more accurately within the broader Earth system (Smith et al., 2019). Therefore, remote sensing technology has become a research hotspot in arid areas.

Many studies have found that soil carbon storage and plant and microbial biomasses are limited by nitrogen availability in drylands (Maestre et al., 2016). In the early stage, scientists studied nitrogen intensively and thoroughly due to its importance for CED research. At present, "nitrogen" has gradually cooled through long-term development and evolved into "climate change" (Fig. 6). Climate change is one of the major global change drivers affecting dryland functioning (Maestre et al., 2016). Due to their vast area, sensitivity to global change, and intensive spatial variability in productivity, dryland ecosystem responses to climate change have important scientific implications for regional and global carbon cycle studies (Schimel, 2010). Under the context of global change, understanding climate change impacts on CED in future scenarios is urgently needed (Yao et al., 2020). These results help explain why "climate change" has appeared frequently in recent years.

Understanding how drylands respond to ongoing environmental change is also extremely important for maintaining ecosystem service sustainability and global sustainable development (Maestre et al., 2016), since 90% of the dryland population lives in developing countries (Lu et al., 2018). Therefore, we discovered that the keyword "sustainability" entered the hot keyword list. The sustainability of drylands is a challenging issue due to their relatively low natural and socioeconomic carrying capacities. However, without the contribution of drylands and people living there, achieving the world' s 2030 sustainable development goals is impossible (Lü et al., 2021). Therefore, studying and accomplishing ecological and socioeconomic sustainability in drylands is a critical goal (Wang et al., 2021).

In short, basic themes (such as "water," "yield," and "salinity") and motor themes (such as "climate change," "sustainability," and "remote sensing") will be the focus of CED research. These results also indicated that multiple integrated methods (remote sensing technology and various models) to understand climate change and ecosystem sustainability represent potential new research trends and hotspots in future CED studies.

4 Conclusions

Based on bibliometric analysis, we examined annual publications, prominent journals, leading institutions, contributing countries, popular keywords, and their temporal evolution in CED research from 1991 to 2020. Over the past 30 years, CED research publications have increased significantly. *Agricultural Water Management* ranked first among all journals and received the most citations. The ten marked institutions were centered in drylands of America, China, and Australia, which had the largest number and most citations of CED publications. The most frequently used keyword was "climate change," with other keywords including climate-related terms (such as "drought," "precipitation," "temperature," and "rainfall"), main research contents (such as "soil," "irrigation," "water use efficiency," "yield," and "wheat"), and applied methods (such as "model," "remote sensing," and "eddy covariance"). Keywords could be classified into five clusters, indicating five main research foci in CED studies: hydrological cycle, effects of climate change, carbon and water balance, productivity, and carbon-nitrogen-phosphorus coupling cycles. We found that classical pedology and agricultural science research dominated in the 1990s, applied ecological research in the 2000s, and global change ecology research in recent years.

Our findings indicated that CED research has been greatly highlighted and developed in America, China, and Australia; however, few CED studies have emerged from countries in Africa and Central Asia. Therefore, developing countries need to further promote cooperation and communication with developed countries, especially in arid and semi-arid areas. Additionally, our results may change over time because bibliometric data are constantly updated. Although the scope of search results is limited, our findings provide a good example for clarifying temporal trends in CED research. Basic themes (such as "water," "yield," and "salinity") and motor themes (such as "climate change," "sustainability," and "remote sensing") will be the focus of CED research. In particular, multiple integrated methods to understand climate change and ecosystem sustainability represent potential new research trends and hotspots in future CED studies.

Acknowledgements: This study was supported by the National Key Research and Development Program of China (2016YFA0600104), the National Natural Science Foundation of China (41991234, 31800406), and the International Partnership Program of Chinese Academy of Sciences (121311KYSB20170004).

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Note: Figure translations are in progress. See original paper for figures.