AgriEngineering

Article

A Bibliometric Analysis and a Citation Mapping Process for the Role of Soil Recycled Organic Matter and Microbe Interaction due to Climate Change Using Scopus Database

Ioannis Vagelas [1,*] and Stefanos Leontopoulos [2]

[1] Department of Agriculture Crop Production and Rural Development, University of Thessaly, Fytokou Str., N. Ionia, 38446 Volos, Greece
[2] School of Applied Arts and Sustainable Design, Hellenic Open University, Parodos Aristotelous 18, 26335 Patras, Greece
* Correspondence: vagelas@uth.gr; Tel.: +30-6978299170

Abstract: Climate change has drawn the attention not only of scientists but of politicians and societies worldwide. The aim of this paper is to present a method for selecting research studies on climate change, waste management and the role of microbes in the recycling of organic matter in soil that analyze the role of organic agriculture as the main connection between agricultural losses and climate change. VOSviewer version 1.6.18 free software tool was used in this study in order to achieve the bibliometric and mapping approach for studies on the effects of climate change in terms of soil recycled organic matter and microbe interaction. Scopus database (accessed 29 September 2022) indexed a total of 1,245,809 bibliographic items classified into paradigms. The presented documents were downloaded from Scopus as graph-based maps and as distance-based maps in order to reflect the strength of the relation between the items. Climate change includes changes in soil and soil microorganisms as affected by natural climate variations and local weather, which have beneficial or negative effects on soil organic matter. From the examination of the selected papers, it was concluded that climate change and changing precipitation patterns are having an impact on microorganisms, particularly bacterial groups, and thus ecosystem function.

Keywords: climate change; agriculture; adaptation; selective review; bibliometric mapping

Citation: Vagelas, I.; Leontopoulos, S. A Bibliometric Analysis and a Citation Mapping Process for the Role of Soil Recycled Organic Matter and Microbe Interaction due to Climate Change Using Scopus Database. *AgriEngineering* **2023**, *5*, 581–610. https://doi.org/10.3390/agriengineering5010037

Academic Editor: Eugenio Cavallo

Received: 25 December 2022
Revised: 21 February 2023
Accepted: 23 February 2023
Published: 8 March 2023

1. Introduction

The latest literature reviews and meta-analyses on climate change, the use of organic wastes and soil microbe interactions have highlighted gaps relating to disputes while demonstrating the tremendous growth of global interest. Thus, despite the important role that entrepreneurship plays in climate change and the growing prominence of the use of organic wastes in many countries, overviews of this rapidly growing research area are still lacking.

1.1. Climate Change

The Earth is unique among known planets in being home to numerous living organisms, due to its atmospheric climate conditions. Nowadays, it is agreed that about 3.7 billion years ago, the Earth's living species began to diversify and adapt to nearly every conceivable environment. Thus, the Earth's climate is not stable and has been changeable over time. According to Ebi et al. [1], complex interactions between the Sun, seas, atmosphere, cryosphere, land surface, and biosphere influence the Earth's climate. The same authors also commented that "climate is the average state of the atmosphere, and the associated characteristics of the underlying land or water, in a particular region over a particular time-scale, usually considered over multiple years". Another definition has been given by NASA, where climate change was defined as "a broad range of global phenomena created predominantly by burning fossil fuels, which add heat-trapping gases to Earth's atmosphere. These phenomena include the increased temperature trends described by global warming, but also encompass changes such as sea-level rise; ice mass loss in Greenland, and mountain glaciers worldwide; shifts in flower/plant blooming; and extreme weather events". These physical changes in climate occurred due to changes such as the Sun's energy output, the Earth's orbit, volcanic activity, how the Earth's land masses are distributed geographically, and other internal and external processes [2].

According to the Royal Society, [3] the importance of CO_2 as one of the primary greenhouse gases affecting the energy balance of Earth has been known since the mid-1800s, with the CO_2 level in the atmosphere increasing by more than 40% since that time. However, only the last few decades have the majority of the world's leading climate experts agreed that climate change is as a result of human activities such as burning fossil fuels (oil, coal and gas) and deforestation worldwide; it is recognized as one of the most serious challenges of the 21st century [4]. Thus, since the 1980s, the scientific community has explored climate change through large-scale studies applying different methods and distinct models [5–10]. So far, numerous studies have calculated the effects of climate change in various parts of the world and concluded that the world average surface temperature has been increased by approximately 0.6 °C, while 12 of the 13 hottest years on record have occurred since 1995 [11]. Despite changes in climatological conditions and the presence of extreme weather events such as tropical cyclones, floods and heatwaves, a pattern of changes in ecosystems has become apparent across all continents. Furthermore, several effects, such as the retreat of glaciers, melting of sea ice, thawing of permafrost, extension of plant and insect species in northern habitats, and the early flowering of the plants, have influenced the functioning of ecosystems and have had biological health impacts on plants and other organisms, including the human population.

According to Inoue [12] and Friha et al. [13], agriculture, which provides the majority of the world's food, is confronted with significant challenges because of rising food product demand, worries about food safety and security, and demands for environmental protection, water conservation, and sustainability. Regarding crop production, the Food and Agriculture Organization (FAO) ref. [14] reported that climate change affects agricultural production systems both directly and indirectly. Changes in physical characteristics such as rainfall distribution and temperature levels on a regional scale or in specific agricultural production systems have direct impacts, while changes in pests, diseases, pollinators and other invasive species have had indirect effects. Furthermore, the National Research Council [15] reported that plants generally grow more quickly at warmer temperatures. In addition, the risk of higher temperature, water stress and the need for alternative energy production may affect crop production by damaging the plants, leading farmers to seek alternative cultivation methods [16,17]. Additionally, it was stated that the effects on agriculture will differ across locations and depending on the crop variety. A moderate warming associated with increased CO_2 levels and changes in precipitation is expected to benefit lands used for farming and pasture at medium to high latitudes, with the possible impacts expected to be mixed [18]. However, agricultural yield may be reduced in low-latitude and seasonally dry areas. For example, it is estimated that for each degree of warming, yields of corn in Africa and the United States, and wheat in India, will decrease by 5–15%, while weeds, crop pests and diseases will increase in geographic range and frequency. Uleberg et al. [19] and Svobodová et al. [20] mention that there are concerns that in high-latitude regions, climate change will favor proliferation of pests. Climate change may also have a greater influence on pests and nematodes, since higher temperatures will cause them to develop earlier in the season [21–28]. Climate change has also led to crop diseases in areas and during times that previously did not encounter such disease. For example, stem and stripe rusts in wheat crops have caused epidemic losses due to the favorable conditions in moisture, temperature and wind [29]. In order to better understand the effect of climate change on crop production, Pautasso et al. [30] studied the climate change impacts on plant health and categorized these impacts into three categories.

So far, the bulk of observations on how climate trends affect crop output show that climate change has already had a detrimental impact on wheat and maize yields globally as well as in many other regions [31,32]. Although results of the completed studies are still difficult to compare due to the different climate scenarios applied, it is agreed that they can provide insights into the signs and patterns of vulnerability. For example, Pearce et al. [33] and Fankhauser and Tol [34] commented on the effect of CO_2 on the population and the economy, estimating that developing countries would lose 2.0 to 9.05% of their GDP. In addition, Nordhaus and Boyer [35], using RICE-99 (Regional Dynamic Integrated model of Climate and the Economy) and DICE-99 (Dynamic Integrated Model of Climate and the Economy) models commented in their study that climate change effects may be more severe in some cases, while Zirnov et al. [36] mentioned that climate change poses an existential threat to many species in addition to being a prescription for disaster. Tol [37] in his review concluded that the best estimate of the additional impact caused by a delay of emission reduction is smaller than the cost savings, but uncertainties are too large to draw this conclusion with any certainty, as 7–24% of the damage is due to adaptation costs. Mendelsohn et al. [38] and Tol [39] provided an optimistic assumption about adaptive capacity using the Global Impact Model (GIM), combining empirically based response functions, careful climate forecasts and sectoral data by country. Similar conclusions were mentioned by Schneider [40], who commented that the real cost of climate change is underestimated due to the neglect of the cumulative effect of many stresses, the lack of climate details on a regional level and the lack of adaptability [41,42]. Thus, it is agreed that the real damage caused by global warming will occur in the future in a more severe way.

Regarding the effects of climate change on agriculture, Mendelsohn and Schlesinger [43] and Smith and Hitz [44] commented that the prospects for agriculture are more diverse. Their research indicates that some models can already predict overall losses under conditions of moderate warming, while other research indicates that, in some cases, the impact curve might be hump-shaped, with overall short-term gains under mild climate change turning into losses under more severe changes. Among the effects on crop production, soil impacts will increase steadily over time, more or less in proportion to the rise of differences in environmental conditions. Tol et al. [45] commented that the impacts of climate change differ depending on which activities are analyzed, as well as when and where, concluding that some will lose, while some others will benefit. Thus, future studies should focus on the adaptation capability and should draw from a wider range of socioeconomic scenarios that take vulnerability, economic growth and emissions into account. Nevertheless, according to the Royal Society report [3], in the future, it will be difficult to predict with any degree of certainty how global or regional temperature patterns would change decade by decade.

Climate change and land use change may negatively influence soil biodiversity [46]. According to the FAO [47], the soil is the largest C pool in the forest and potentially a large sink or source of greenhouse gas. Makiuppa et al. [48], in their study, found that climate change affects biomass due to decomposition rate. Cropland soil organic carbon plays an essential role in maintaining soil fertility for plant growth and mitigating climate change by storing a considerable amount of organic C [49,50]. Accurate mapping of soil organic carbon in cropland is essential for improving soil management in agriculture and assessing the potential of different strategies aiming at climate change mitigation. In their study, Wang et al. [51] concluded that the construction of a spatio-temporal database of agricultural management practices is a research priority to improve the reliability of soil organic carbon model prediction.

Soil microorganisms are generally believed to be limited by C [52,53]. Lu et al. [54], in their study, suggested that changes in soil microclimate and geochemistry caused by warming will lead to variations in soil microbial community composition, diversity and structure and that such changes in soil microbial communities could impact the functional processes of soil ecosystems underlying the carbon cycle [55,56]. Yang et al. [57] reported that interactions between soil organic matter composition and microbial communities determine soil basal respiration. Soil basal respiration is generally controlled by a range of biotic and abiotic factors, including climatic factors such as soil temperature and moisture, which directly and indirectly affect soil properties and microbial communities [58,59].

In addition to soil ecosystems in temperate and tropical climates, arctic ecosystems are being exposed to pronounced climate warming, resulting in increased plant-derived carbon (C) inputs to soils and faster rates of decomposition, releasing mineral nutrients and potentially shifting the limiting factor for microbial growth [60,61]. Neurauter et al. [62] concluded in their study that limitations for soil microorganisms will not change due to future warming but rather will affect degrees of fungal-to-bacterial dominance. In conclusion, climate change includes changes in soil and soil microorganisms affected by natural climate variations and local weather [3], all of which can have beneficial or negative effects on a variety of sectors. As a solution to combat climate change, international efforts, mainly led by the European Union, aim to ensure that countries take the appropriate actions in order to stop global warming from reaching dangerous levels. Thus, some nations have implemented policies including taxing carbon, tightening regulations on polluting enterprises and refineries, reducing the work week to four days, and setting a goal to become carbon neutral [36].

1.2. Bibliometric Mapping

Bibliometrics is an alternative term for the quantitative examination of bibliographic data. Despite Ziman's opinion arguing that science has reached a steady state, many scientists believe that science is more and more efficient, leading to new discoveries every day [63]. Due to this planned effectiveness of scientific research, despite the stable condition of science investments, science is nevertheless growing exponentially. According to van Raan [64], there are indications that the growth factor with a doubling time of 15 years [63–66] still applies. Scientific organizations undergo peer evaluations to determine the significance and impact of their work. As a result, a key concern for science policy now is the appraisal of scientific research. Noyons [66] commented that it is crucial to improve a tool presenting an overview in order to closely examine advancements in scientific and research disciplines.

The retrospective amount of research on climate change, organic waste and microbe interactions is overwhelming, which makes producing an overview difficult. Furthermore, as a field with continuous improvements, structured reviews need to be conducted to periodically summarize the extant literature and identify important research gaps. Thus, recent techniques, such as advanced bibliometric mapping, can help to visualize and structure the complex research in this matter [67]. According to Braun, [68] and van Leeuven [69], the term bibliometric refers to the use of quantitative measures and mathematical and statistical methods to analyze bibliographic data. In this situation, bibliometric mapping uses quantitative methods to analyze bibliographic data to create research clusters that visually represent scientific knowledge [70]. Numerous studies have concentrated on combining bibliographic metrics with analytical methods for mapping networks of connected contributions and contributors in order to illustrate the most potent links and uncover opportunities for future research proposals [71–80]. Despite the fact that these evaluations offer novel and significant insights, no comprehensive and up-to-date review based on bibliometrics can be found in the literature, which presents a clear knowledge gap [79]. In order to fill this knowledge gap and leverage quantitative methodology and rigorous bibliometric methods to examine the current state of research at the intersection of climate change, a review of soil organic matter and the role of microbe interaction is needed. It is believed that the current study makes several contributions to the existing literature by examining issues and technology important to agriculture, as it provides tremendous potential to alter several aspects in this sector. Similarly, it is necessary to systematically cluster the literature that relates to, and has an impact on, agriculture, taking into account the most important studies that form the basis of this research field.

In order to achieve the above-mentioned goal, during the past few decades, science maps have been created to monitor research field structures, and technological developments have provided excellent platforms to accomplish this task. Additionally, the digitalization of maps creates options for interaction, enabling the user to obtain information without being "bothered" by other informational data.

The aim of this paper is to present a method for selecting research studies regarding climate change, waste management and the role of microbes in the recycling of organic matter in soil, describing why organic farming might be seen as the primary relationship between agricultural losses and climate change. As mentioned above, in addition to the direct impacts of climate change in crop production, there are also indirect impacts through its effect on agricultural productivity, rural livelihoods and food insecurity. In this study, we mostly pay attention to articles published in leading journals mentioning climate change, crop yield, organic matter and microbe interaction in the agricultural sector. Additionally, given the emphasis on the significance of agriculture, we also focus on a selection of the research studies mentioning the quantifiable impact of climate change on agricultural outputs. The aim of this study is to determine which approach might be appropriate to empirically address the connection between climate change, the utilization of organic wastes, and microbial interaction.

2. Materials and Methods

2.1. Using Scopus to Thoroughly Search Scientific Literature

In this study, the Scopus database was used in order to access articles and book chapters provided by publishers regarding Soil, Soil and Food Web, Soil—Food Web and Organic Matter, Soil—Food Web and Organic Matter Recycling, Soil—Food Web—Organic Matter Recycling and Microbes, Soil—Food Web—Organic Matter Recycling and Microbes, Soil—Food Web—Organic Matter Recycling—Microbes and Bioremediation, Soil—Food Web—Organic Matter Recycling—Microbes—Bioremediation and Compost or Biochar or Plastics or Biofertilizer or Coal or Olive Mill Waste Water. In detail, the search query on Scopus was as follows:

Soil AND
Food Web AND
Organic Matter AND
Organic Matter Recycling AND
Microbes AND
Bioremediation AND
Compost or Biochar or Plastics or Biofertilizer or Coal or Olive Mill Waste Water
Biodegradation
Compost or Biochar or Plastics or Biofertilizer or Coal or Olive Mill Waste Water

The initial search used the keyword "Soil", filtering the search results to keywords up to "bioremediation" and "compost", as described above.

2.2. Data Analysis and Bibliometric Mapping

The VOSviewer version 1.6.18 free software tool (https://www.vosviewer.com, accessed on 29 September 2022) was used in order to distinguish the documents received from each query. In this study, the documents received from Scopus are presented as graph-based maps and as distance-based maps in order to reflect the strength of the relation between the items. All distance-based and graph-based maps were analyzed using the following methods of analysis (i) the type of analysis: Co-occurrence; (ii) the unit of analysis: Index keywords; and (iii) the counting method: Fractional counting.

Furthermore, VOSviewer's functionality was used for displaying bibliometric maps for each Scopus search query, e.g., "Soil". With the use of VOSviewer maps, the relations between the concepts were presented as circles, and circle size depended on the number of occurrences (in Figure 1, "soil" occurs more frequently than "soil pollution", which is represented by in a smaller circle). The connections between terms depend on the frequency of joint occurrence (in Figure 2a), "bioremediation" is associated with "soils", "soil pollution", "cadmium", "phytoremediation", "biodegradation environmental" and "metabolism"). In such a case, VOSviewer map defines the most appropriate arrangement (in Figure 2a, "biorementation" is associated more with "soils" and "soil pollution" than "metabolism"). This concept is presented by a cluster of specific color (Figure 2a, green vs. purple circles). Additionally, we wanted to demonstrate the passage of time; thus concept colors were chosen to reflect the typical publication year, i.e., the lighter the color, the more recent the concept. We also wanted to show time component, so the color of the concepts related to average publication year, i.e., the lighter the color (yellow vs. purple), the more recent the research (in Supplementary Figure S1, "metabolism" has a purple color related to 2017, whereas "microbiota" has yellow color related to 2021).

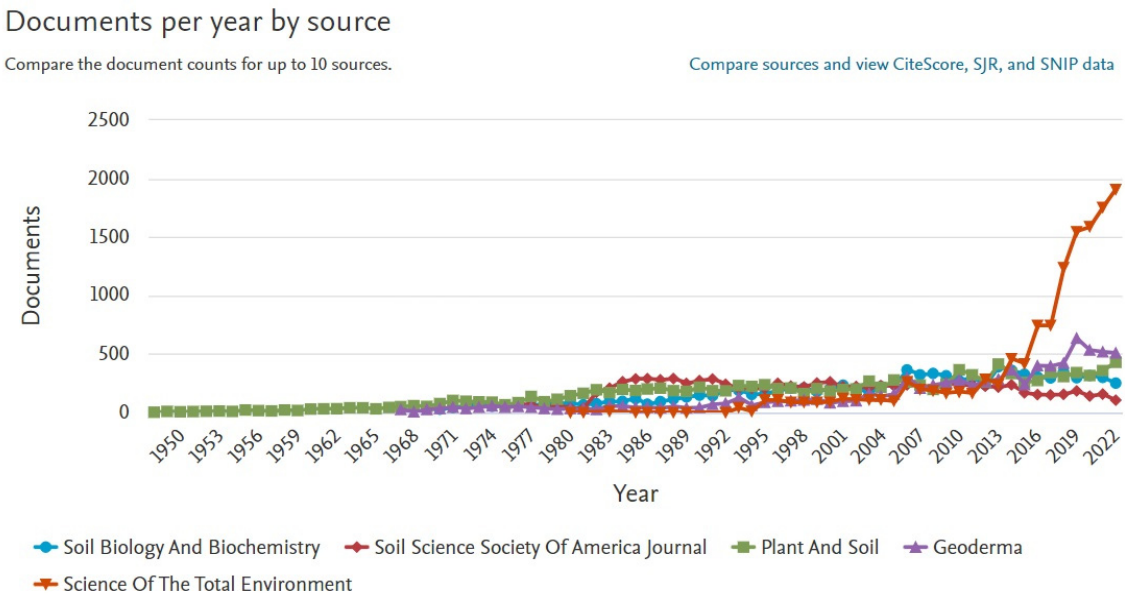
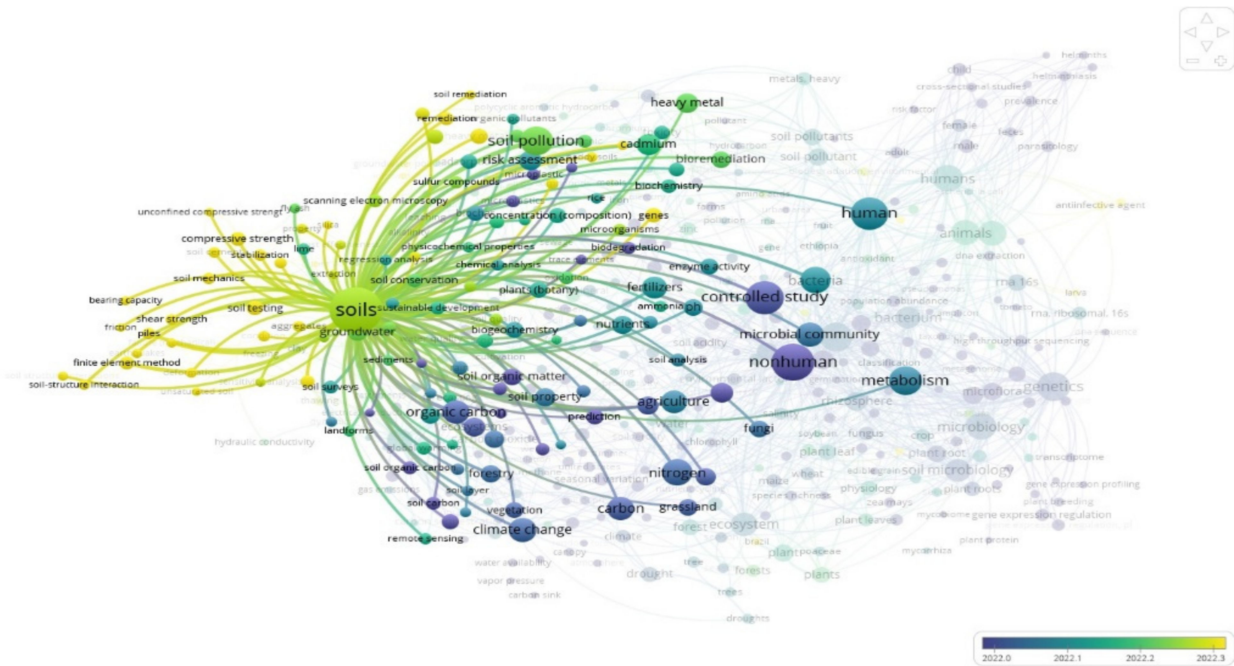
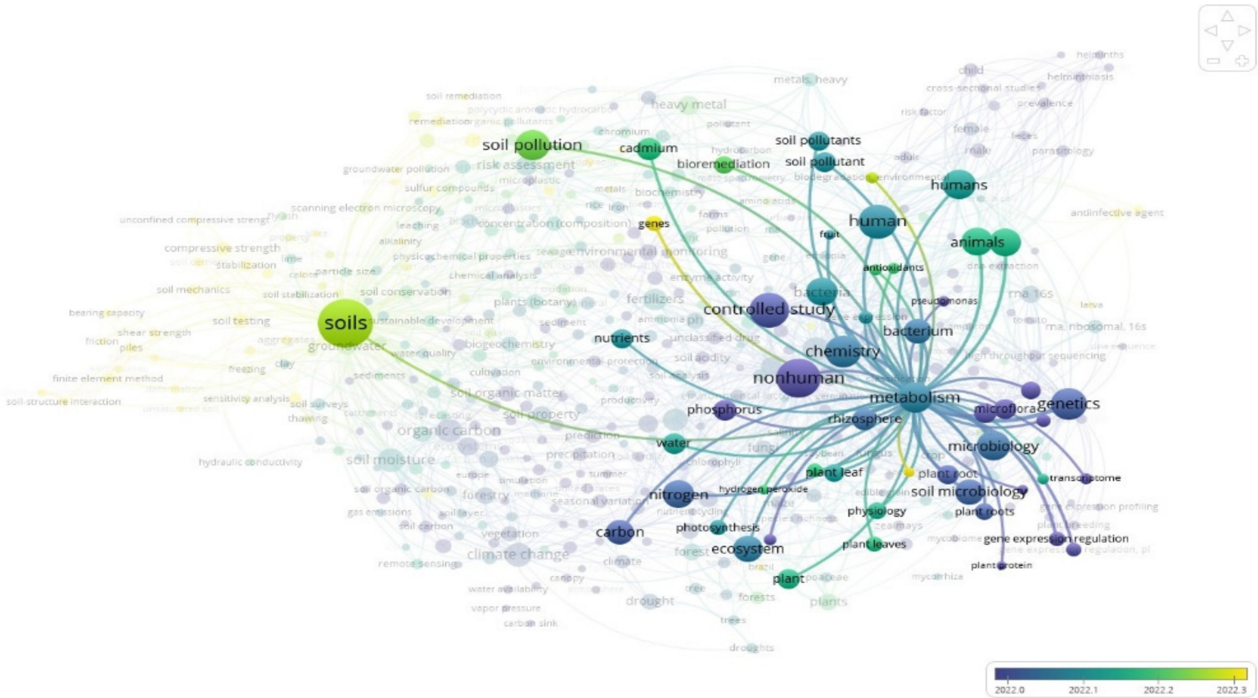


Figure 1. Search results for Soil with Scopus.



(**a**)

Figure 2. *Cont.*



(**b**)

Figure 2. Analyzing Scopus soil results with the VOSviewer. The soil (**a**) and the metabolism (**b**) paradigm. (**a**) Soils are associated with: Microbial community, Metabolism, Bacteria, Nitrogen, Carbon, Climate change and human (purple circles) Soil pollution, Cadmium, Heavy metal, Bioremention (green circles). (**b**) Metabolism is associated with: Chemistry, Metabolism, Microbiology, Bacteria, Human, Animals, Rhizosphere, Water, Nutrients, (green circles) Soil Microbiology, Nitrogen, Carbon, Plant roots (purple circles).

Overall, the VOSviewer tool was used for searching the Scopus database (29 September 2022) in order to develop and examine the research density and trends, with a focus on various target concepts, study areas and geographic coverage. Finally, it should be mentioned that when the number of documents matching the criteria exceeded the maximum number of 5000 documents, only the last 2000 documents were used for the analysis.

3. Results

3.1. Using Scopus to Thoroughly Search Scientific Literature

The Scopus database (29 September 2022) indexed a total of 1,199,680 bibliographic items for "Soil", 30,366 for "Soil and Food Web", 13,280 for "Soil—Food Web and Organic Matter", 1553 for "Soil—Food Web—Organic Matter Recycling", 526 for "Soil—Food Web—Organic Matter Recycling and Microbes", and 145 for "Soil—Food Web—Organic Matter Recycling—Microbes and Bioremediation", while results for the remaining searches were limited to less than 100 bibliographic items.

3.2. The "Soil" Paradigm

Figure 1 displays the publications' content analysis by year and source (e.g., Soil Biology and Biochemistry) retrieved from the Scopus database according to topic "Soil". Based to these Scopus results, the VOSviewer visualization data analysis (Supplementary Figures S1 and S2) indicated that (i) "Soils" (green circle, Figure 2a) are associated with: microbial community; metabolism; bacteria; nitrogen carbon; climate change; human (purple circles); soil pollution; cadmium; heavy metal; bioremediation (green circles); (ii) "Metabolism" (purple circle, Figure 2b) is associated with: chemistry; metabolism; microbiology; bacteria; human; animals; rhizosphere; water; nutrients (green circles) and soil microbiology; nitrogen; carbon and plant roots (purple circles); (iii) "Bioremediation"

(Figure 3(a1)) is associated with: soils; soil pollution and cadmium (green circles) and metabolism (purple circles); (iv) "Rhizosphere" (Figure 3(b1)) is associated with: chemistry; metabolism; bacteria; microbiology and soil microbiology (green circles) and microflora (purple circles); (v) "Climate change" (Figure 3(a2)) is associated with: soils (green circle) and ecosystem; organic carbon and human (purple circles); (vi) "Soil microbiology" (Figure 3(b2)) is associated with: chemistry; metabolism; agriculture human(s); ecosystem; nutrients; bacteria and fungi (green circles) and carbon and nitrogen (purple circles).

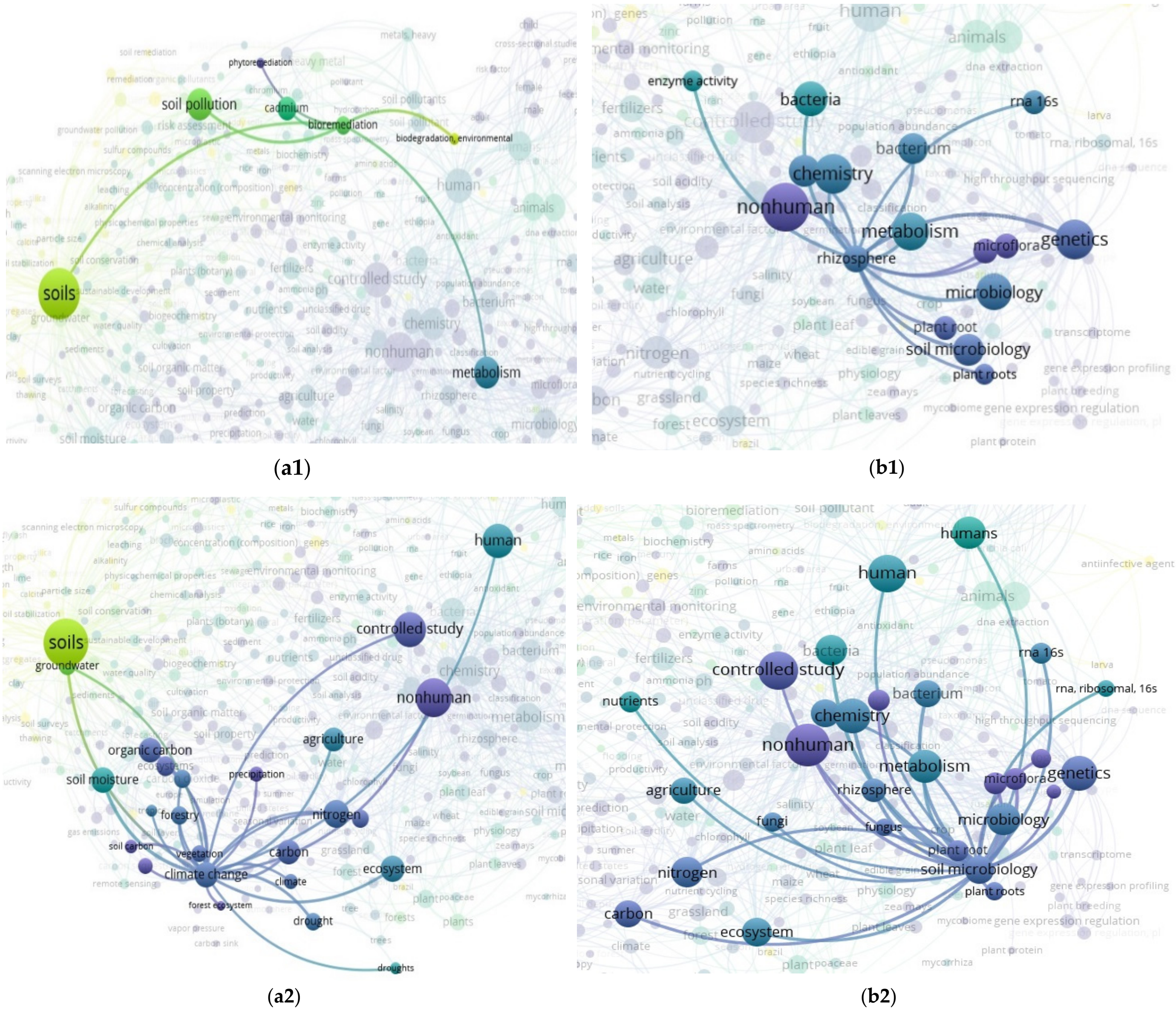
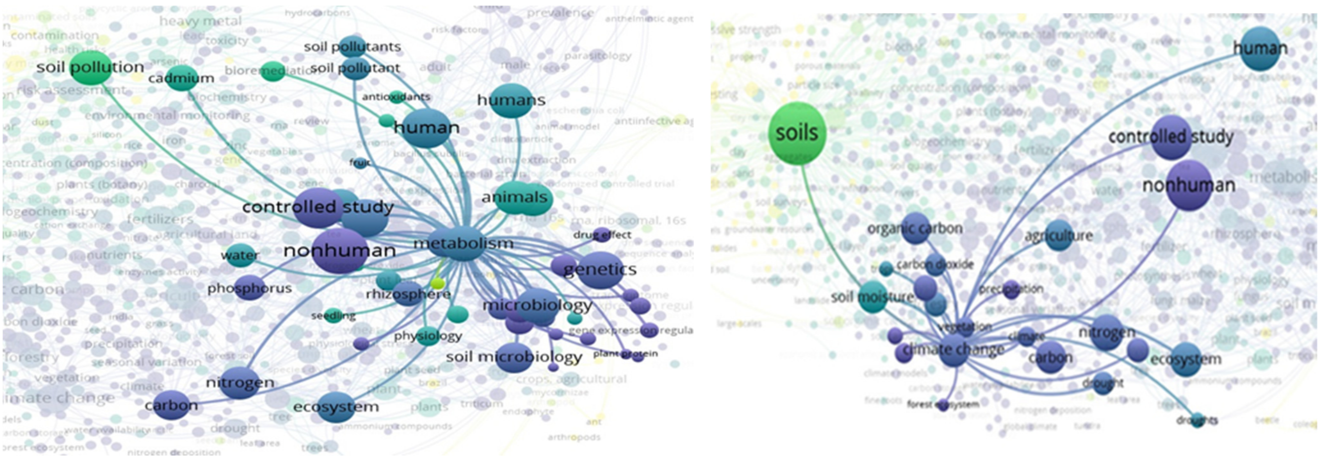


Figure 3. Analyzing Scopus soil results with the VOSviewer. The bioremediation, climate change, rhizosphere and the soil microbiology paradigm. (**a1**) Bioremediation is associated with soil pollution and metabolism. (**b1**) Rhizosphere is associated with chemistry, metabolism, microbiology. (**a2**) Climate change is associated with soils, ecosystem, organic carbon, human. (**b2**) Soil microbiology is associated with chemistry, metabolism, agriculture human(s), ecosystem, nutrients, bacteria, fungi, carbon and nitrogen.

Based on the above-mentioned results in Figure 3, we concluded that: (i) Bioremediation (Figure 3(a1)), "the branch of biotechnology that employs the use of living organisms like microbes and bacteria to decontaminate affected areas", is one of most important area of research currently; (ii) Plant roots (Figure 3(b1)), "the area of the soil right next to plant roots is a hotspot of microbial activity and diversity", is another important area of research strongly associated with soil; (iii) Climate change (Figure 3(a2)) is another important area of research, indicating that soil moisture and SOC (soil organic carbon) dynamics are likely affected by climate change; (iv) Soil microbial (Figure 3(b2)), "the metabolic activity of microorganisms in soil is a sensitive indicator that influence soil processes (carbon, nutrients) and ecological functions (ecosystem)", is another important research area.

3.3. "Soil" and "Food Web" Interactions Based on the Scientific Literature Search Query on SCOPUS

The VOSviewer visualization data indicated that (i) "Soils" are associated with: soil pollution; organic carbon and soil moisture (green circles) and soil microbiology; microbiology; carbon; nitrogen; ecosystem and climate change (purple circles); (ii) "Metabolism" (purple circle, Figure 4a) is associated with: animals; soil pollution; water; cadmium and bioremediation (green circles) and microbiology; soil microbiology; nitrogen; carbon; ecosystem; genetics and human(s) (purple circles); (iii) "Climate change" (purple circle, Figure 4b) is associated with: carbon; nitrogen; organic carbon; carbon dioxide; precipitation and drought (purple circles) and soils; soil moisture; agriculture; ecosystem and droughts (purple circles) and microbial community; metabolism; bacteria; nitrogen carbon; climate change; human (purple circles) and soil pollution; cadmium; heavy metal; bioremediation (green circles).



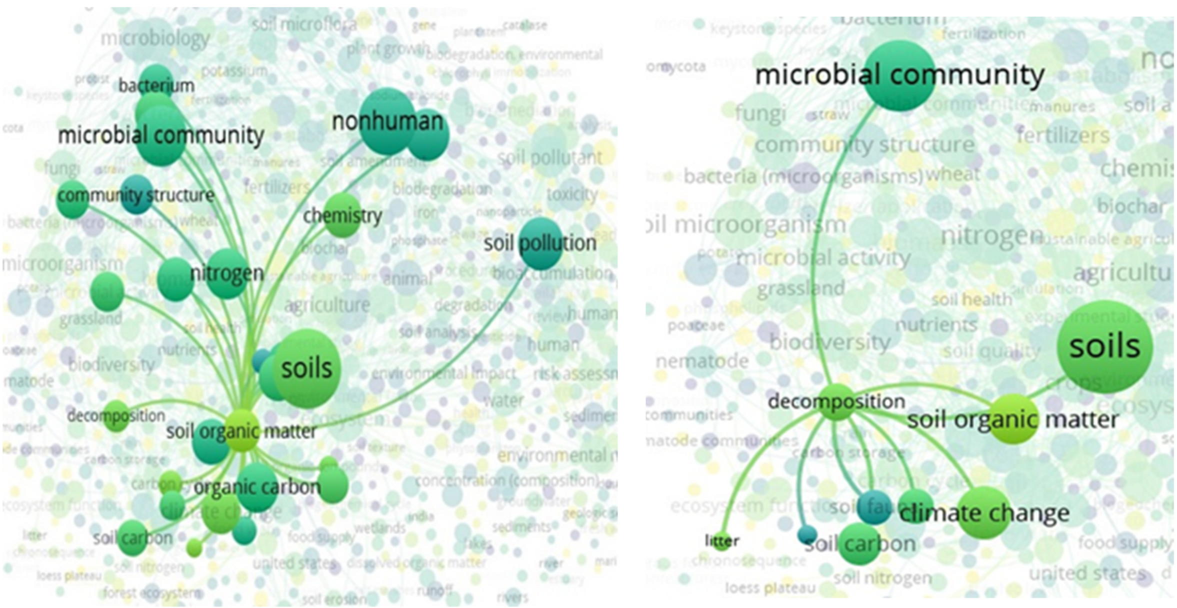
(**a**) (**b**)

Figure 4. Analyzing Scopus with the VOSviewer. The metabolism and climate change paradigm. (**a**) Metabolism is associated with: Animals; Soil pollution; Water; Cadmium and Bioremediation (green circles); Microbiology; Soil microbiology; Nitrogen; Carbon; Ecosystem; Genetics and Human(s) (purple circles). (**b**) Climate change is associated with: Carbon; Nitrogen; Organic carbon; Carbon dioxide; Precipitation and Drought (purple circles) and Soils; Soil Moisture; Agriculture; Ecosystem and Droughts (purple circles); Microbial community; Metabolism; Bacteria; Nitrogen Carbon; Climate change; Human (purple circles) and Soil pollution, Cadmium, Heavy metal, and Bioremediation (green circles).

Based on the above results in Figure 4, we concluded that soil metabolism is an important factor, embracing all the chemical consequences of microbial development in soil. As reported by Quastel [81], microbial communities are key players in regulating ecosystem processes affected by soil organic carbon stock. It is well known that the functional response of soil microbial communities determines how well crop residue amendment affects soil organic carbon stock and stability. Residue management is an essential agricultural practice for enhancing soil fertility [82]. For example, oat straw causes a rise in organic carbon, microbial biomass, and fungal abundances, which results in a microbial community structure more resembling that of soil found in wild forests [83].

Therefore, crop residue returning is not only beneficial to soil physicochemical properties but has also positive impacts on soil microbial communities and soil metabolism, which improve the residue composition, the nutrient content and the physical structure of the soil. Furthermore, according to Jansson and Hofmockel [84], climate change elements such as CO_2 and temperature impact the microbial composition, which in turn influences the activities of microbial communities in the ecosystem's setting. So, the macronutrients, micronutrients, and other components necessary for plant and animal growth are cycled biogeochemically under the control of the soil microbiome. Thus, understanding and anticipating how climate change will affect soil microbiomes and the ecosystem presents a significant opportunity to comprehend the issues facing our world [84]. Moreover, it is believed that understanding the relationship between climate change and microbiomes, including their adaptation, will be crucial for mitigating and combating climate change in a variety of ways, such as by encouraging carbon sequestration and playing a crucial role in maintaining soil nutrient balance [85].

The VOSviewer visualization data (Figure 5) indicated that (i) "Soils" (green circle, Figure 5) are associated with: soil pollution; organic carbon and soil moisture (green circles) and soil microbiology; microbiology; carbon; nitrogen; ecosystem and climate change (purple circles); (ii) "Metabolism" (purple circle, Figure 6a) is associated with: animals; soil pollution; water; cadmium and bioremediation (green circles) and microbiology; soil microbiology; nitrogen; carbon; ecosystem; genetics and human(s) (purple circles); (iii) "Climate change" (purple circle, Figure 6b) is associated with: carbon; nitrogen; organic carbon; carbon dioxide; precipitation and drought (purple circles) and soils; soil moisture; agriculture; ecosystem and droughts (purple circles) and microbial community; metabolism; bacteria; nitrogen carbon; climate change; human (purple circles) and soil pollution; cadmium; heavy metal; bioremediation (green circles).



(**a**) (**b**)

Figure 5. Analyzing Scopus results with the VOSviewer. The organic matter (**a**) and the decomposition (**b**) paradigm.

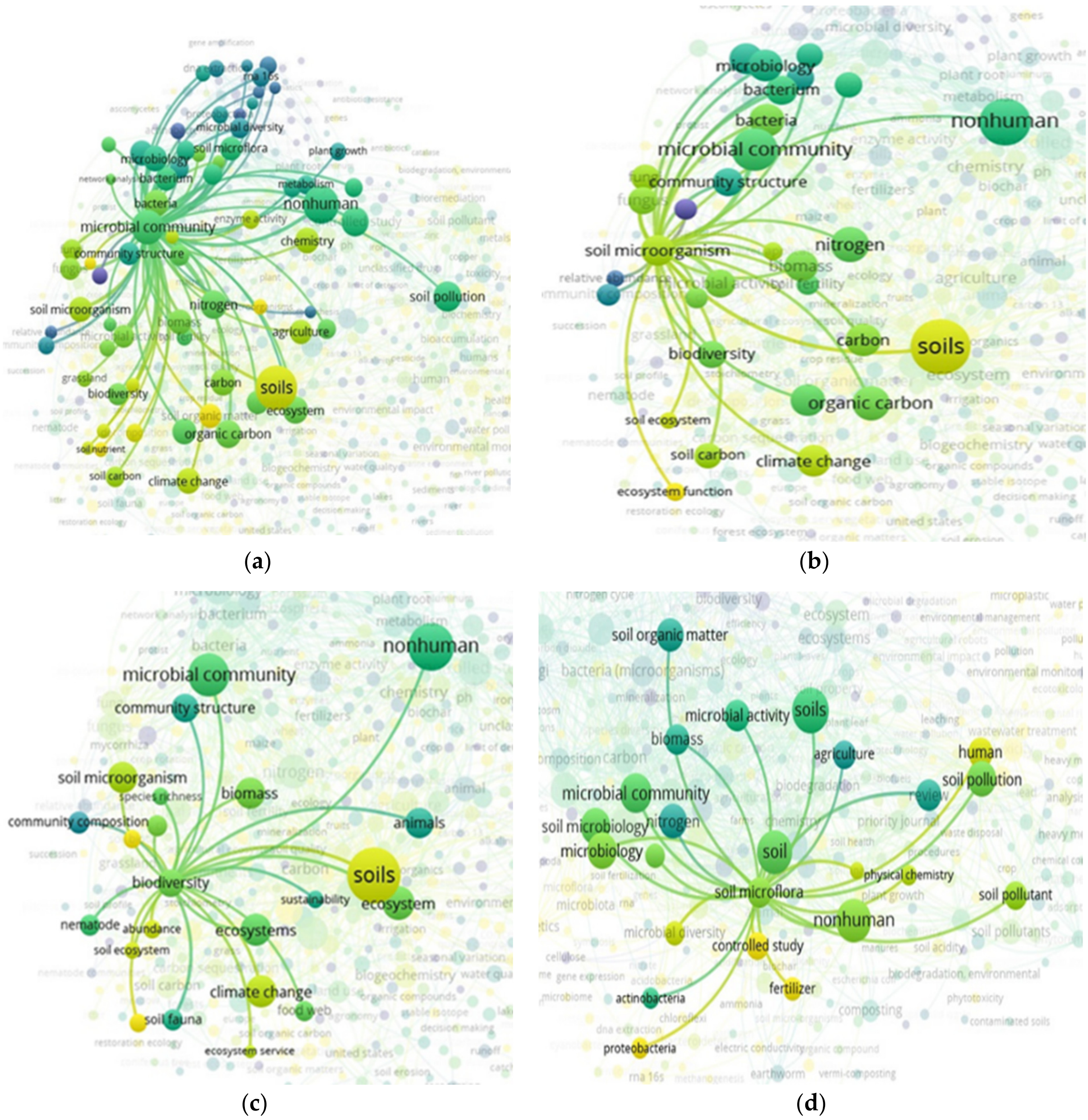


Figure 6. Analyzing Scopus results with the VOSviewer. The microbial community (**a**); soil microorganisms (**b**); the biodiversity (**c**); and (**d**) the soil microflora paradigm.

Based on the above results in Figure 6, we concluded that soil metabolism is an important factor, embracing all the chemical consequences of microbial development in soil. As reported by Quastel [81], microbial communities are important factors in regulating ecosystem processes affected by soil organic carbon stock. It is well known that the functional response of the soil microbial communities determines whether crop residue amendment has a positive impact on the stock and stability of soil organic carbon. Based on this, managing residues in agriculture is crucial for enhancing soil fertility [82]. For example, oat straw led to a microbial community structure closer to wild forest coverage soil, associated with increases in organic carbon, microbial biomass and fungal abundances [83]. Therefore, crop residue return is not only beneficial to soil physicochemical properties but also has positive impacts on soil microbial communities and soil metabolism, which improve the residue composition, the nutrient content and the physical structure of soil.

3.4. "Soil" and "Food Web" and "Organic Matter" Interactions Based on the Scientific Literature Search Query on Scopus

VOSviewer visualization data indicated that "Soils" are associated with: microbial community; microbiology; organic carbon; soil organic matter; decomposition; ecosystems; soil pollution, etc. Apart from the above-mentioned connections for "Soils", "Soil organic matter" (green circle, Figure 5a) is associated with: microbial community; bacterium; nitrogen; soil pollution; organic carbon and decomposition. Whereas "Decomposition" (green circle, Figure 5b) is associated strongly with soil and microbial community and less so but significantly with soil organic matter; climate change; litter (litter decomposition), etc. It is widely acknowledged that climate change can affect how litter decomposes, but little is known about how the bacteria engaged in the breakdown and climate change are related [86]. According to Cotrufo et al. [87], litter decomposition is the breakdown of dead organic matter into progressively smaller particles until the structure is unrecognizable and organic molecules are mineralized to their primary components: H_2O, CO_2, and mineral elements. Recalcitrant organic molecules are created throughout the process, and dissolved organic carbon may seep into the mineral soil. It is well recognized that the impact of climate change on decomposition can vary and depends greatly on detritus quality, species identification, species interactions and ecosystem type [88]. Based on this, Stuble et al. [89] showed that long-term warming effects accelerate decomposition and change how soils operate in ecosystems, both directly by influencing microbial physiology and indirectly by changing the makeup of the microbial population. So, the afterlife of soil and plant matter plays a significant role in ecosystems, as a crucial nutrient processor and supplier. The rate of decomposition has a significant impact on both animal and plant health and likely has a biodiversity-related impact on assessments of future changes in the biogeochemical cycles and climatic feedback, all of which are crucial in this era of rapid environmental change.

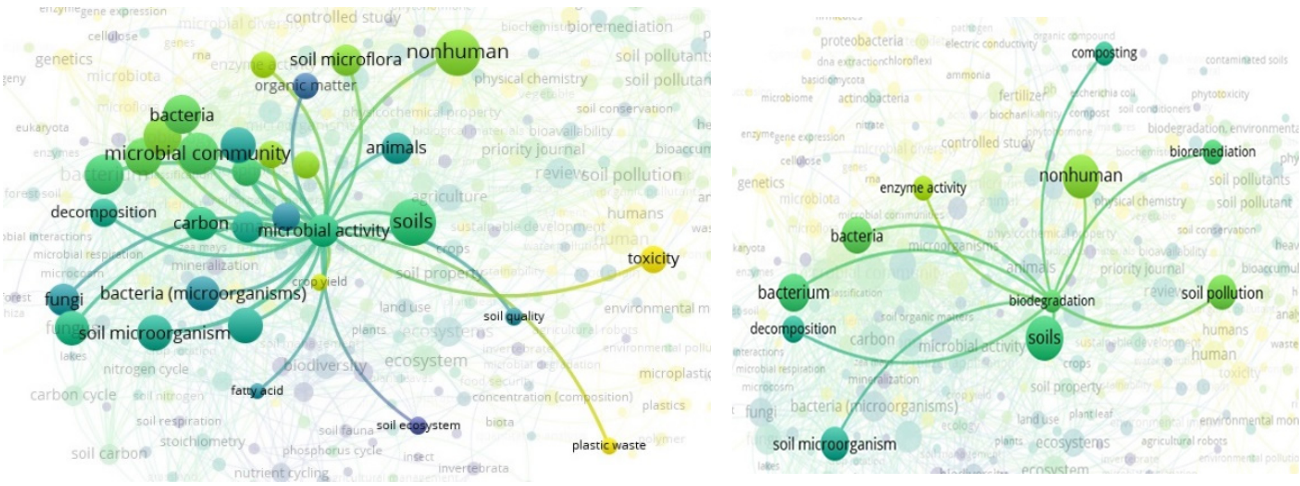
3.5. "Soil" and "Food Web" and "Organic Matter Recycling" Interactions Based on the Scientific Literature Search Query in Scopus

VOSviewer visualization data indicated that "Soils" are associated with: soil pollution; soil pollutant; human; bioaccumulation; microbial community; microbiology, soil microflora; soil microorganism; metabolism; microbial activity; organic carbon; carbon; environmental monitoring; biodiversity; biogeochemistry; climate change, etc. In detail, "Microbial community" (Figure 6a) is associated with: metabolism and plant growth; microbial diversity; microbiology, mainly with bacteria (Figure 6a, green circles on the top); soil microorganisms; nitrogen; agriculture; biodiversity; organic carbon; soil carbon (Figure 6a, green circles on the bottom) and climate change (Figure 6a, yellow cycle). "Soil microorganisms" (Figure 6b) is associated with: microbial community; community structure; microbiology and (mainly) bacteria nitrogen; carbon; organic carbon; biodiversity; soil carbon and climate change. "Biodiversity" (Figure 6c) is associated with: microbial community; community structure; soil microorganism; biomass and community composition, ecosystems; food web; soil fauna; nematode and climate change. Based on "Soil microflora", the most important microorganisms are actinobacteria (Figure 6d, green cycle) and proteobacteria (Figure 6d, green cycle). It is well known that bacteria play an essential role in agricultural production, are effective participants in the carbon and nutrient cycling process, and serve as a vital mediator for plant health. Furthermore, microbes such as bacteria, fungus, and actinomycetes are effective in decomposing organic matter, which accelerates environmental warming and the atmospheric CO_2 flux [90]. The region surrounding the aerial portion of the plant termed the phyllosphere contains an abundant microscopic non-pathogenic bacterial population, including α- and γ-proteobacteria belong to proteobacterial phyla Bacteriodetes and Actinobacteria. The phyllosphere region is dynamic and influenced by a variety of elements, including temperature, precipitation, light, etc. As a result, phyllosphere microbiomes are under increased stress from climate change, especially from warming and drought [90]. Moreover, microbial communities are effective biogeochemical cycle regulators, making them a better option for mitigating the effects of shifting climate trends [90]. Based on this and concerning climate change, it is necessary to understand not only how microorganisms affect climate change but also how they will be affected by climate change and other human activities [91]. Climate change and changing precipitation patterns are having an impact on macro-organisms, particularly bacterial groupings, and ecosystem functioning. Research by Zhang et al. [92] showed that 16 phyla/classes respond differentially to climate change, with Acidobacteria, Bacteroidetes, Proteobacteria, Acidimicrobidae, δ-proteobacteria and γ-proteobacteria being the most sensitive. In more detail, Acidobacteria, Rubrobacteridae, δ-proteobacteria and γ-proteobacteria were correlated with soil water content, and the relative abundance of Proteobacteria was correlated with soil pH. Zhang et al. [92] concluded that by increasing soil water content, for example, climate change affects bacterial group abundance and richness directly. It also affects community composition both directly and indirectly (e.g., reducing soil total nitrogen content and increasing soil pH).

3.6. "Soil" and "Food Web" and "Organic Matter Recycling" and "Microbes" Interactions Based on the Scientific Literature Search Query on Scopus

VOSviewer visualization data indicated that "Soils"are associated with: microbial community; microbial activity; soil microorganism; bacteria (microorganisms); bacteria; fungi, etc. In more detail, "Microbial activity" (Figure 7a) is associated with: microbial community; bacteria; soil microflora; carbon, soil microorganism, bacteria (microorganism); fungi, etc., and "Biodegradation" (Figure 7b) is associated with: composting; soil microorganisms; bacteria; decomposition; bioremediation, etc. Microbes play an important role in net carbon exchange through various ways, such as respiration and decomposition of organic matter, due to the pathogenic or symbiotic association with plants and by altering the nutrient status of the soil [90]. However, climate change may have an impact on the soil's microbial biomass, the breakdown of organic matter, and the nutrient cycle, which are all directly tied to changes in the function of the microbiota communities in the soil. Climate and other stressors, such as extreme heat and drought, are anticipated to have a negative impact on agricultural productivity, ecosystem health, and the ability of plants to withstand stress [93,94]. Moreover, decomposition of organic matter is the principal process in soils that recycles plant nutrients and produces humus, and during the decomposition process, microorganisms convert the carbon structures of fresh residues into transformed carbon products in the soil. In contrast to fungi, bacteria have proven to have a greater influence on the rate of decomposition of grassland litter, and bacteria have also responded to climatic change more quickly [95]. Glassman et al. [95] concluded that this information is critical to improving global terrestrial carbon models and predicting ecosystem responses to climate change. While the impact of changes in abiotic circumstances and substrate quality on decomposition rates is well recognized, the function of microbial community makeup is still poorly understood. This knowledge gap may be the solution for predicting how ecosystems will respond to climate change [95].

Moreover, bioremediation is a process where biological organisms such as fungi, algae and bacteria are used to break down, remove or neutralize organic pollutants by metabolic processes. Microorganisms play a major role in bioremediation; thus, many organic and inorganic pollutants can be metabolized by microorganisms to produce products such as carbon dioxide, water, chloride, and biomass as well as carbon and/or energy for growth [96,97]. Bioremediation requires the use of microbial enzymes such as cytochrome P450s, laccases, hydrolases, etc., to break down organic chemical compounds composed only of the elements carbon and hydrogen (hydrocarbons) into less harmful compounds [98]. Since microbes are considered the most important elements in the bioremediation process, research studies have shown that climate change has a strong impact on soil microbes and, hence, bioremediation performance [99].



(**a**) (**b**)

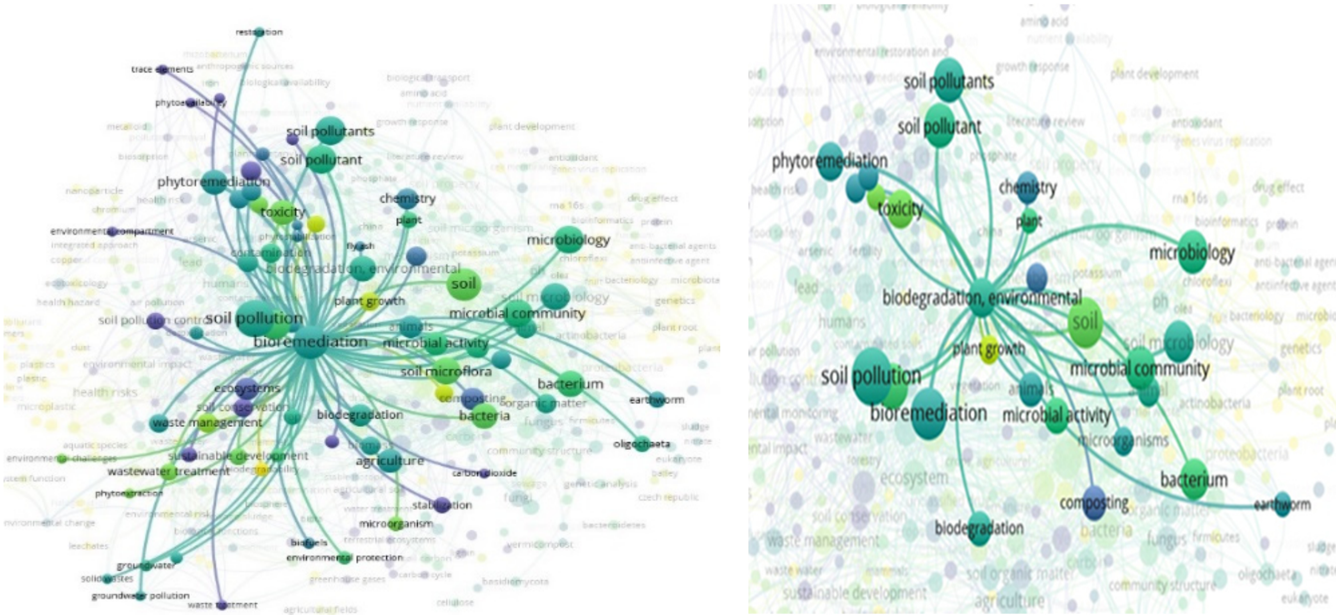
Figure 7. Analyzing Scopus results with the VOSviewer. The microbial activity (**a**) and the biodegradation (**b**).

3.7. "Soil" and "Food Web" and "Organic Matter Recycling" and "Microbes" and "Bioremediation" Interactions Based on the Scientific Literature Search Query on Scopus

VOSviewer visualization data indicated that "Bioremediation" is associated with: soil pollution; soil pollutant; phytoremediation; chemistry; microbial community; soil microflora; microbial activity; bacterium; bacteria; fungus; actinobacteria; agriculture; carbon, etc. The same key words are presented in Figure 8a. Besides the above keywords, "Bioremediation" (green circle, Figure 8b) is associated with: biodegradation (environmental); microbiology; microbial activity; bacterium and earthworm. The key word difference between biodegradation and bioremediation is that the former is an environmental process that happens naturally. On the other hand, bioremediation is a human-made method used to purify the environment. Both processes are governed mainly by microorganisms. In general, through the use of bacteria, fungi and plants, bioremediation involves removing, modifying, immobilizing or detoxifying different chemicals and physical pollutants from the environment. Bioremediation is a natural process with a short timeframe and is seen as an acceptable waste treatment process for contaminated material such as soil [100]. Microbes such as *Penicillium chrysogenum*, *Pseudomonas cepacia* and *Bacillus cereus* are able to degrade the contaminant, e.g., in oil bioremediation, and increase in numbers when the contaminant is present [100]. Moreover, research studies have shown that earthworms can modify the heavy metal dynamic and speciation. In more detail, earthworms decrease the amount of metal associated with the most available fraction, such as the exchangeable one, and increase the amount of metal bound to the more stable fraction, such as Mn and Fe oxide [101]. Apart from the above-mentioned factors, climate change increases precipitation variability and the probability of extreme dry and wet events; thus, climate change is expected to disrupt the Earth's ecosystem as a whole, including soil microbes.

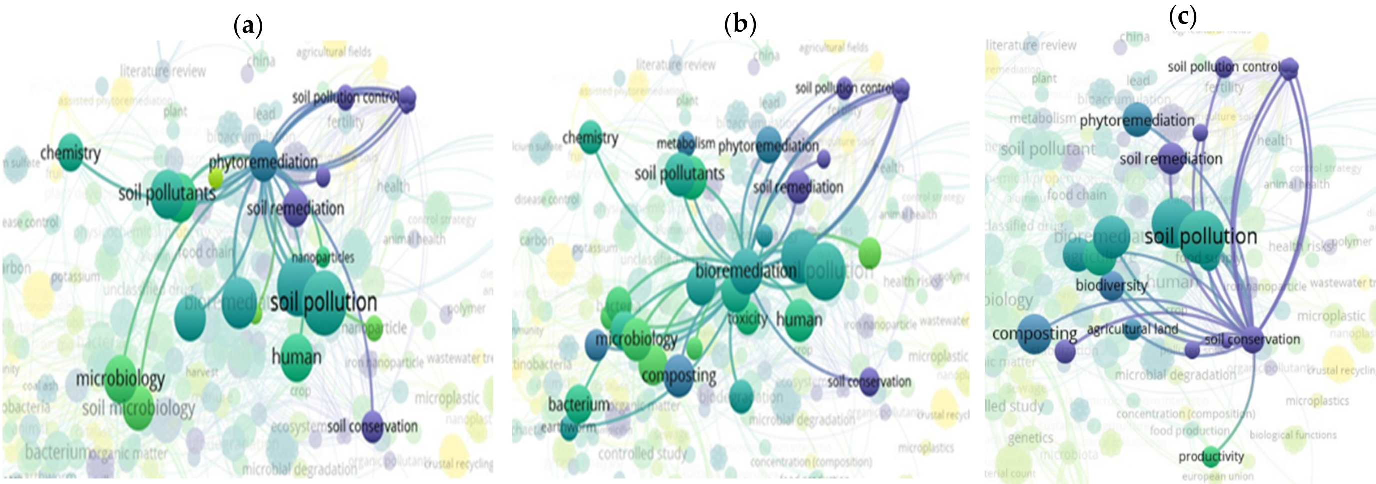
3.8. "Soil" and "Food Web" and "Organic Matter Recycling" and "Microbes" and "Bioremediation" and "Compost" Interactions Based on the Scientific Literature Search Query on Scopus

VOSviewer visualization data indicated that "Compost" is associated with: soil pollution; agriculture; composting; microbiology; bacteria; phytoremediation; bioremediation; soil conservation; soil remediation, etc. Furthermore, from Figure 9, it is observed that "Phytoremediation" (green circle, Figure 9a) is associated with: soil pollution; human; soil pollutants, chemistry; microbiology; soil microbiology; and soil conservation. "Bioremediation" (green circle, Figure 9b) is associated with: soil pollutants; human; chemistry; microbiology; composting; bacterium; and soil conservation. "Soil conservation" (green circle, Figure 9c) is associated with: soil pollution; composting; biodiversity; soil remediation; and phytoremediation. Based on the above-mentioned factors, it could be concluded that phytoremediation uses plants to clean up contaminated environments. Numerous toxins, such as metals, pesticides, explosives and oil, can be cleaned up by plants. Biological organisms are used in bioremediation methods to eliminate or neutralize environmental pollution through a metabolic reaction. Soil conservation is the prevention of the loss of the top-most layer of the soil from erosion or prevention of reduced fertility caused by over-usage, acidification, salinization or other chemical soil contamination.



(**a**) (**b**)

Figure 8. Analyzing Scopus results with the VOSviewer. The bioremediation (**a**) and biodegradation environmental (**b**) paradigms.



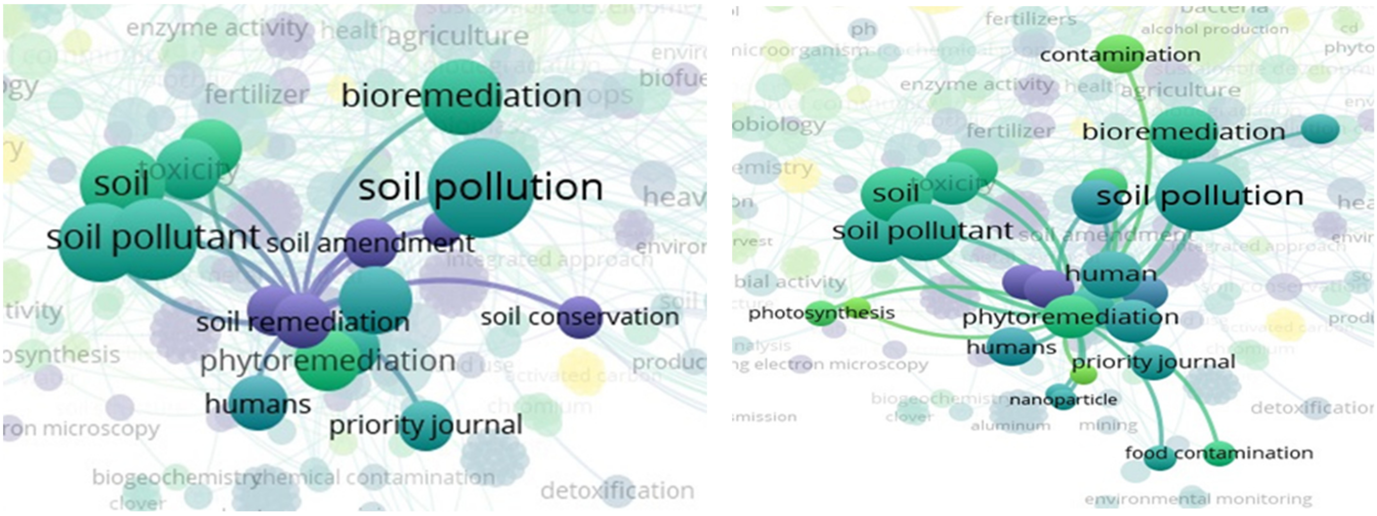
Phytoremediation is associated with: soil pollution; human; soil pollutants, chemistry, microbiology; soil microbiology; soil conservation	Bioremediation is associated with: soil pollutants; human; chemistry; microbiology; composting; bacterium; soil conservation	Soil conservation is associated with: soil pollution; composting; biodiversity; soil remediation; phytoremediation

Figure 9. Analyzing Scopus results with the VOSviewer. Phytoremediation (**a**), bioremediation (**b**) and soil conservation (**c**) paradigm.

When compost is incorporated into soil as an amendment, it immediately affects a number of physicochemical characteristics, including pH, OC, metal (loid) solubility, etc. In addition to improving the fertility of heavy metal–contaminated soils, organic waste additions also encourage certain processes such as complexation and sorption, which reduce the bioavailability and mobility of potentially harmful elements. The application of these amendments ameliorates the phytoremediation process in contaminated sites [102]. Compost bioremediation refers to the use of a biological system of micro-organisms in a mature, cured compost to sequester or break down contaminants in water or soil. The pollutants are broken down into humus and benign byproducts such as carbon dioxide, water, and salts through digestion, metabolism, and transformation. Many different types of contaminants, including solvents, heavy metals, pesticides, and chlorinated and hydrocarbons, have been shown to be degraded or altered. More broadly, composting also helps to reduce greenhouse gas emissions that affect climate change. Thus, it is believed that compost applications can be used to combat climate change by capturing and storing more carbon dioxide in soil. Phytoremediation is a plant-based approach that involves the use of plants to extract and remove elemental pollutants or lower their bioavailability in soil [103]. Even at low quantities, ionic substances in the soil can be absorbed by plants through their root systems. In order to absorb heavy metals and control their bioavailability, plants stretch their root systems into the soil matrix and create rhizosphere ecosystems, reclaiming the polluted soil and stabilizing soil fertility [104]. A question here is why phytoremediation linked to adaptation and climate resilience is so important? Possible answers to that question include (i) phytoremediation is an eco-friendly approach that could be a successful mitigation measure to revegetate heavy metal–polluted soil in a cost-effective way and (ii) phytoremediation is increasingly relevant due to plants' high effectiveness and sustainability during remediation and the ability of potential phytoremediation plants to adapt to changes in climate.

3.9. "Soil" and "Food Web" and "Organic Matter Recycling" and "Microbes" and "Bioremediation" and "Biochar" Interactions Based on the Scientific Literature Search Query on Scopus

"Soil remediation" is strongly associated with: soil pollution; soil pollutant; bioremediation; and phytoremediation (Figure 10a, green circles) and less so with soil amendment and soil conservation (Figure 10a, purple circles). "Phytoremediation" is strongly associated with soil pollution; soil pollutant, bioremediation; human (Figure 10b, dark-green circles) and less so with contamination and photosynthesis (Figure 10b, light-green circles). The term "soil remediation" means returning the soil to a form of ecological stability, together with the establishment of the plant communities it supported prior to disturbance [105]. The term "phytoremediation" (as mentioned above) uses plants to clean up contaminated environments. According to recent studies, adding biochar to soil is a promising way to reduce soil contamination by immobilizing organic and heavy metal contaminants. The decontamination effectiveness varies with the biochar source, amendment rate, soil type and pollutant species. According to existing literature reviews, biochar amendment immobilizes heavy metals and organic pollutants in contaminated soils and reduces their bioavailability primarily through precipitation, electrostatic interaction, surface adsorption, structural sequestration and facilitated decomposition [106]. Additionally, these heavy metals and organic contaminants have a negative impact on physiological processes, including photosynthesis, transpiration and energy metabolism, which inhibits plant growth and development in general [107]. Biochar is used in order to increase crop yields in challenging soil conditions and combat climate change. Studies completed by Joseph et al. [108] show that biochar boosts climate change mitigation by up to 20% and can lower nitrous oxide emissions from soil. It also restores carbon from the atmosphere into the soil, where it is stored for hundreds to thousands of years.



(**a**) (**b**)

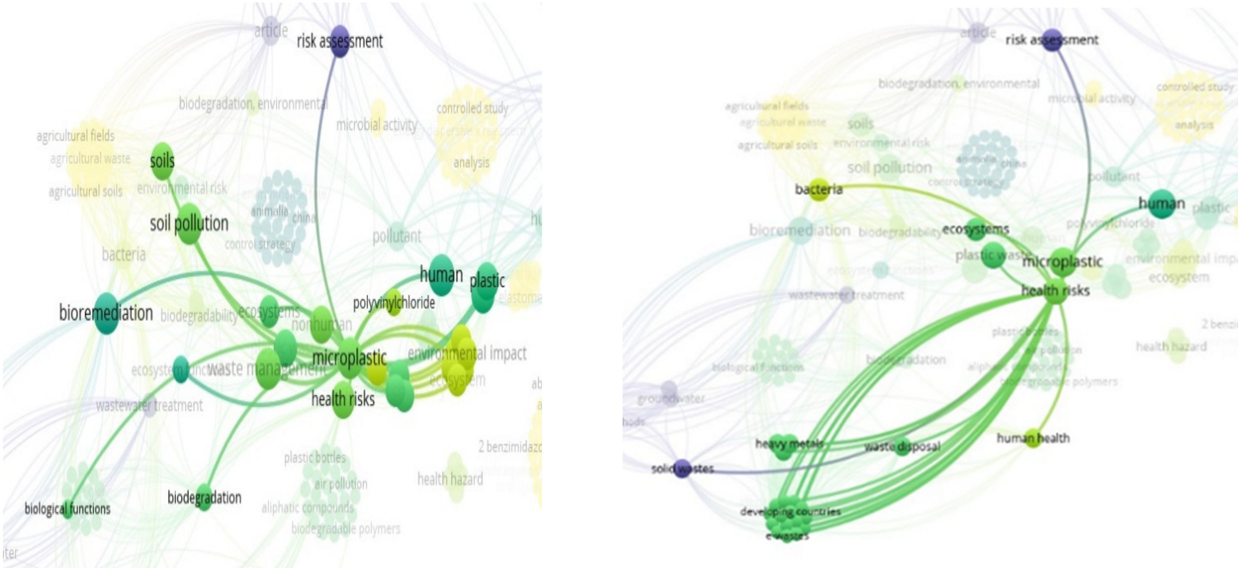
Figure 10. Analyzing Scopus results with the VOSviewer. The soil remediation (**a**) and phytoremediation (**b**) paradigms.

3.10. "Soil" and "Food Web" and "Organic Matter Recycling" and "Microbes" and "Bioremediation" and "Plastics" Interactions Based on the Scientific Literature Search Query on Scopus

VOSviewer visualization data indicated that "Plastics" are associated with soil pollution; bioremediation; biodegradability; biodegradation (environmental), etc. Furthermore, from Figure 11 it is observed that "Microplastics" (Figure 11a) are associated with: bioremediation; human; plastic; soil pollution; health risk (green circles) and risk assessment (purple circles). "Microplastics" (Figure 11b) are associated with: human; health risk; ecosystems; bacteria (green circles) and risk assessment; soil wastes (purple circles). According to He et al. [109], microplastics may possibly pose a concern to human health due to their ecological effects on soil biota. However, based on the effects of nature and biology on (micro)plastics, soil breakdown of plastic may be exceedingly slow. Some review publications highlighted the negative effects on biota like earthworms and noted the potential consequences of ubiquitous microplastics. It has been shown that earthworms have some advantages, such as being able to consume microplastics directly, produce secondary plastics, and introduce microplastics into the soil through their burrowing activities [109].

3.11. "Soil" and "Food Web" and "Organic Matter Recycling" and "Microbes" and "Bioremediation" and "Biofertilizer" Interactions Based on the Scientific Literature Search Query on Scopus

VOSviewer visualization data indicated that "Biofertilizer" is associated with: soil; microbiology; fungi; chemistry; plants; nitrogen soil microflora; acidobacteria; fertilizer; metabolism; composting; contamination; biodegradation, etc. Furthermore, from Figure 12 it is observed that "Assisted phytoremediation" (Figure 12) is associated with: soil; bacteria; microbiology; microbial activity; chemistry; physicochemical property (yellow circles), contamination and bioremediation (green circles). Assisted phytoremediation covers a wide range of uses of plants for remediation of environmental pollutants and includes microbe-assisted phytoremediation [110] and mycorrhizal-assisted phytoremediation [111]. Biochar assists phytoremediation [112] and chelate assists phytoremediation [113], while streptomyces pactum assists phytoremediation in Zn/Pb [114]. Phytoremediation is associated with changes in the form of contaminant, seasonal changes in the physical or chemical properties of soil, and changes in plant physiological response to abiotic stress and climate conditions; these all contribute to the efficiency of such process [115]. Phytoremediation offers a nature-based solution for contaminated soil remediation. Although, there has been little research on the possible effects on cleanup, climate change could have a significant impact on a number of contaminated sites [116].



(**a**) (**b**)

Figure 11. Analyzing Scopus results with the VOSviewer. The microplastics (**a**) and health risks (**b**) paradigms.

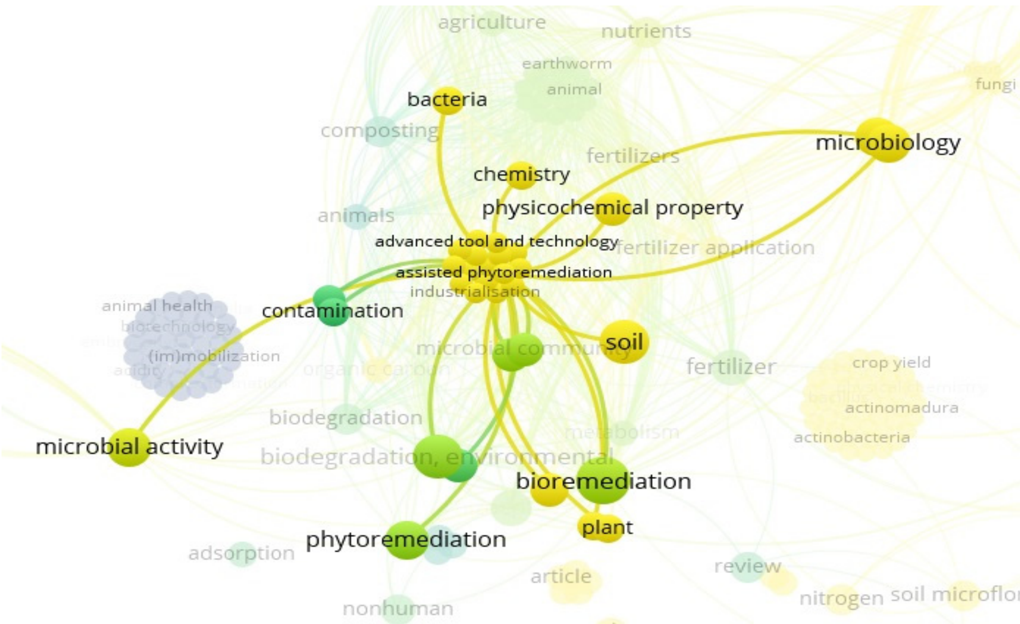
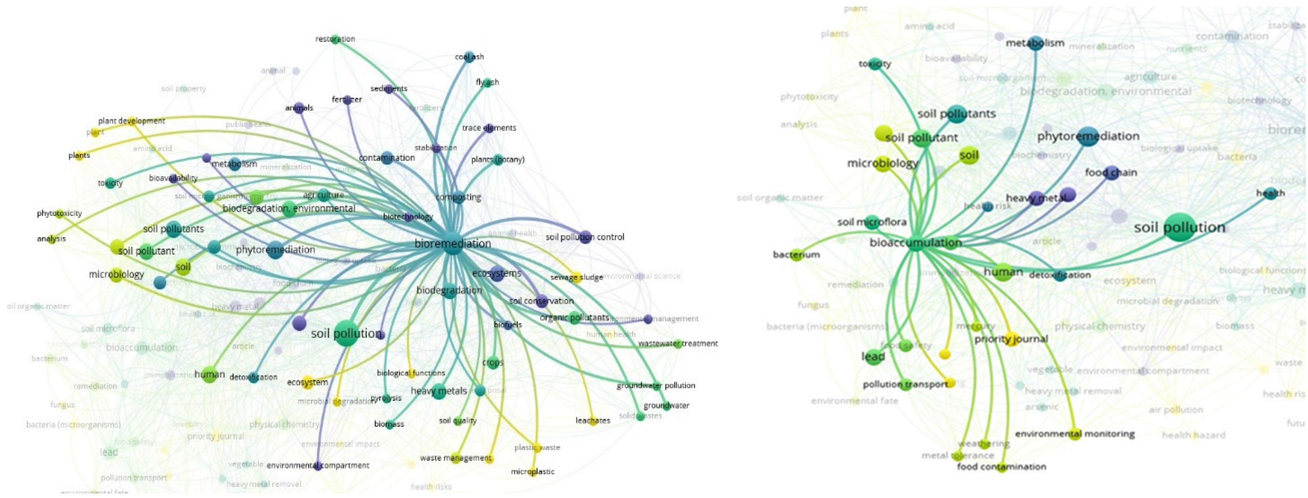


Figure 12. Analyzing Scopus results with the VOSviewer. The assisted phytoremediation paradigm.

3.12. "Soil" and "Food Web" and "Organic Matter Recycling" and "Microbes" and "Bioremediation" and "Coal" Interactions Based on the Scientific Literature Search Query on Scopus

VOSviewer visualization data indicated that "Coal" is associated with: soil pollution; bioremediation; heavy metals; organic pollutants, microbiology; bacteria; ecosystem; microbial degradation, etc. Furthermore, from Figure 3 it is observed that "Bioremediation" (Figure 13a) is associated with: soil pollution; soil pollutants; composting; plants, (green circles), microbiology; waste management; microplastic; leachates, etc. (yellow circles). "Bioaccumulation" (Figure 13b) is associated with soil pollution; soil pollutants; soil microflora; metabolism; lead (green circles), soil and soil microbiology (yellow–green circles). According to Sharma, [117], bioaccumulation is the process of chemicals building up in an organism when the rate of intake exceeds the rate of excretion, whereas bioremediation uses biological organisms to remove or neutralize environmental pollution through metabolic activity. Using plants to work 'soaking up' heavy metals (bioremediation) and microbes (bioaccumulation), predominantly to clean contaminated soil and ground water, is a relatively new technology for mining the amount of pollution. Environmental bioremediation by bio-sorption and bioaccumulation is considered as a low-cost alternative to bioremediation-based processes. Methods such as bioaccumulation have gained increasing interest from scientists and stakeholders for ensuring sustainable environmental remediation. The use of phytoremediation includes the usage of plants with respect to ecological and environmental science. A potential solution could be achieved used microbe- assisted phytoremediation in order to remove pollutants from watercourses and sediments in order to improve ecosystem services.

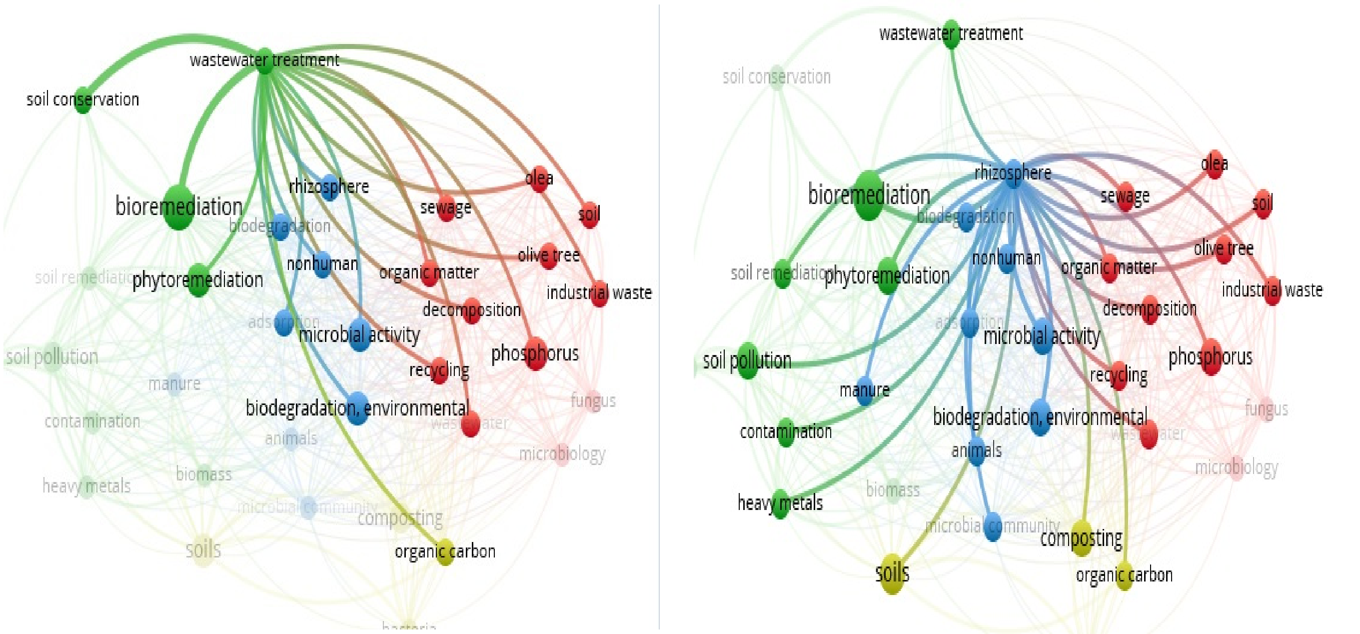


(**a**) (**b**)

Figure 13. Analyzing Scopus results with the VOSviewer. The bioremediation (**a**) the bioaccumulation (**b**) paradigms.

3.13. "Soil" and "Food Web" and "Organic Matter Recycling" and "Microbes" and "Bioremediation" and "Olive Mill Waste Water" Interactions Based on the Scientific Literature Search Query on Scopus

VOSviewer visualization data indicated that "olive mill waste water" is associated with: bioremediation; phytoremediation; soil pollution; contamination; heavy metals, biodegradation, environmental; microbial activity; rhizosphere, organic matter; decomposision; microbiology; fungus; phosphorus. Furthermore, from Figure 14 it is observed that "wastewater treatment" (Figure 14a) is associated with: bioremediation; phytoremediation; soil conservation (green circles), rhizosphere; microbial activity; biodegradation, environmental (blue circles), sewage; organic matter, decomposition; phosphorus, etc. (red circles). "Rhizosphere" (Figure 14b) is associated with: bioremediation; phytoremediation; soil pollution; contamination; heavy metals (green circles), microbial activity; biodegradation; environmental; animals (blue circles); sewage; organic matter; decomposition; phosphorus, etc. (red circles).



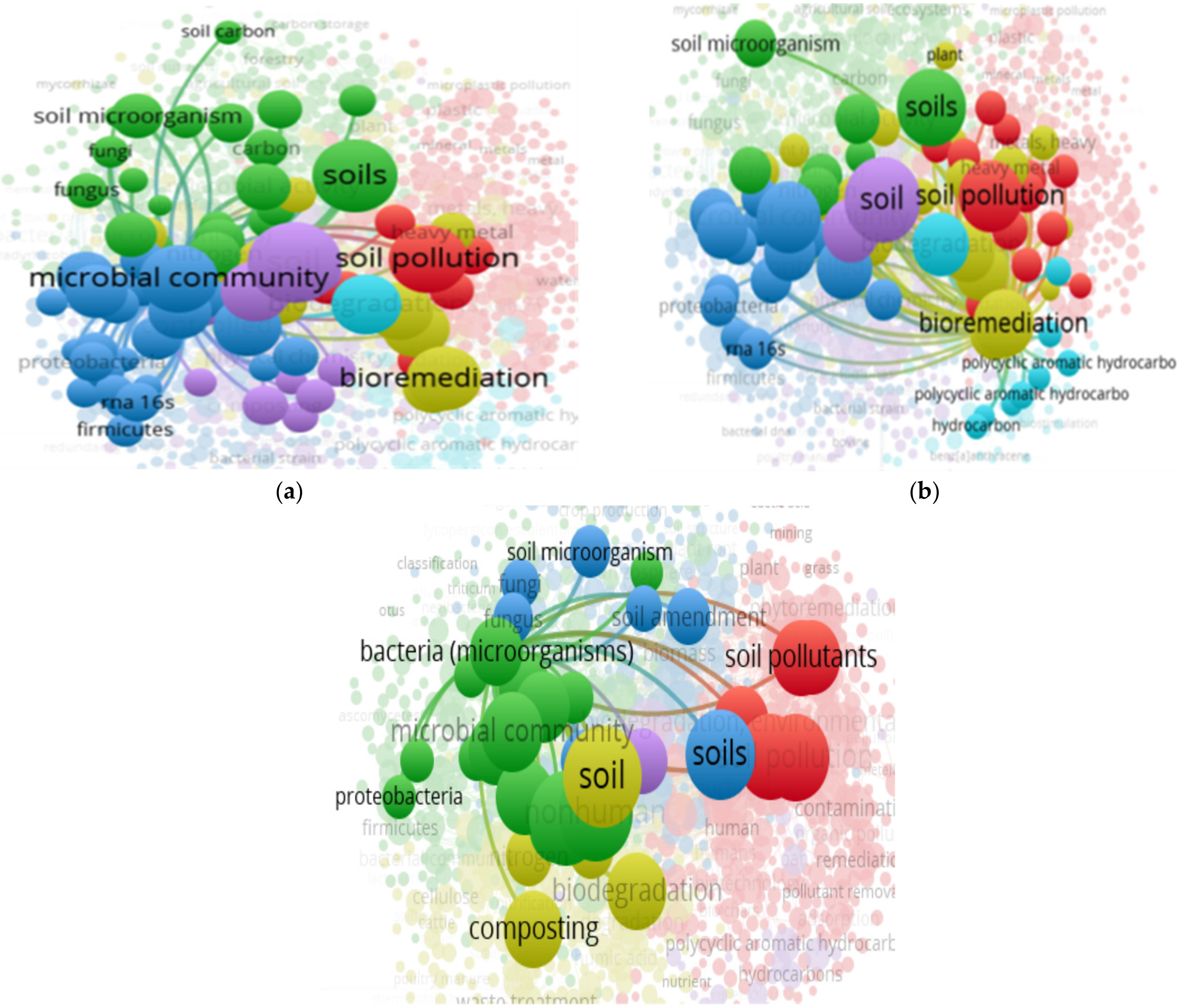
(**a**) (**b**)

Figure 14. Analyzing Scopus results with the VOSviewer. The wastewater treatment (**a**) and rhizosphere (**b**) paradigms.

Olive oil manufacturing is characterized by the creation of wastewater from olive mills, which is harmful to the environment due to its highly polluting organic load [118]. Every day, trillions of cubic meters of wastewater are produced around the world, the vast majority of which is left untreated. These compounds range from new pollutants and heavy metals to simple chemical molecules and nutrients like sugars, ammonium and phosphate [119]. However, due to their antioxidant qualities, these effluents also include phenolic chemicals that have a considerable positive impact on health [118,120–123]. Olive oil production benefits from irrigation, but with a changing climate and uncertainty in precipitation patterns, wastewaters will likely play a larger role supplementing irrigation water requirements. Furthermore, in many Mediterranean countries, olive farming is regarded as one of the most important agricultural pursuits from a financial, social and ecological standpoint [124]. Due to the fact that even today there remain many farmers who do not use environmentally friendly cultivation methods [125,126], the impact of crop cultivation and their wastes on climate change is dramatic, especially in regions where intense competition for natural resources between agriculture and ecosystems occurs. Relevant research was completed by Meftah et al. [127], who studied the impacts of olive mill wastewaters applied over a lengthy period of time on the main properties of Mediterranean soil in a dry climate. The results of their study showed that the irrigation of sandy soils by different doses of olive mill wastewaters has influenced the soil physicochemical and microbiological characteristics, providing a favorable environment for the development of soil microflora by recycling organic matter and enriching mineral elements that increase soil fertility [128]. Furthermore, olive mill wastewaters, alone or combined with pomegranate and orange waste extracts, provided satisfactory control of plant soil-borne pathogens, concludeing that polyphenolic extracts could protect plants' rhizosphere from fungal infection [129–135].

3.14. "Soil" and "Food Web" and "Organic Matter Recycling" and "Microbes" and "Biodegradation" Interactions Based on the Scientific Literature Search Query on Scopus

VOSviewer visualization data indicated that "Biodegradation" is associated with: soils; carbon; soil microorganisms; biogeochemistry; soil microorganisms; fungus, soil microbiology; bacterium; proteobacteria; firmicutes, soil pollution; organic pollutants; water pollutants, etc. Furthermore, from Figure 15 it is observed that "microbial community" (Figure 15a) is associated with: proteobacteria; rna 16s; firmicutes (blue circles), soil pollution and heavy metals (red circles); soils; soil microorganisms; carbon and fungi (green circles). "Bioremediation" (Figure 15b) is associated with: soil pollution and heavy metals (red circles); soil microorganisms and fungi (green circles); proteobacteria; rna 16s; firmicutes and hydrocarbon (blue circles). To understand humans and other life forms on Earth, such as microbes, it is vital to learn not just how microorganisms affect climate change but also how they will be affected by climate change and other human activities. It is well known that the abundance of bacteria/archaea and diversity of microorganisms underlies their role in maintaining a healthy global ecosystem. Research has reported a strong difference in microbiota diversity and Proteobacteria and Bacteroidetes influenced by temperature changes in different climates [136].



(**a**) (**b**)

(**c**)

Figure 15. Analyzing Scopus results with the VOSviewer. Microbial community association with Proteobacteria; rna 16s (**a**) and soil pollution (**b**,**c**) soil association: bacteria; microbial community; proteobacteria (green circles).

3.15. "Soil" and "Food Web" and "Organic Matter Recycling" and "Microbes" and "Biodegradation" and "Compost" Interactions Based on the Scientific Literature Search Query on Scopus

VOSviewer visualization data indicated that "olive mill waste water" is associated with: soils; agriculture; biomass; soil organic matter; soil microorganism maize; charcoal; contamination; heavy metals; soil pollution control; plytoremediation; bacteria; microbiology; proteobacteria; firmucutes, composting; waste treatment; composting process; total organic carbon, etc. Furthermore, from Figure 15 it is observed that "Soil" is associated with: bacteria; microbial community; proteobacteria (green circles); soil pollutants (red circles); fungus; soil amendments and soil microorganism (blue circles); composting and biodegradation (brown circles).

3.16. "Soil" and "Food Web" and "Organic Matter Recycling" and "Microbes" and "Biodegradiation" and "Olive Mill Waste Water" Interactions Based on the Scientific Literature Search Query on Scopus

VOSviewer visualization data indicated that "olive mill waste water" is associated with: soil; biodegradation; composting; waste treatment; bacterium; microbial diversity; actinobacteria; rna 16s; fimicutes Fusarium; Alternaria; bioremediation; soil remediation; water pollution; ground water, etc. Furthermore, from Figure 16 it is observed that "composting" is associated with: bioremediation; chemistry and biodiversity (yellow circles); bacterium; rna 16s and firmicutes (red circles); biodegradation; waste treatment; quality control, etc. (blue circles). According to Chen et al. [137], compost is a stabilized and sanitized product that plays an important role in the soil enrichment process by replenishing vital nutrients taken in during cultivation and, through its absorbent function, minimizing the migration of pollutants into the soil environment. It is well known that OMW are mainly disposed of in the environment without treatment, leading to water, air and land pollution. According to Ahmed et al. [138], OMW's discharge into soils has direct detrimental effects not only on plant growth and soil microorganism metabolism but also on the physicochemical properties of soil. Kefalogiani et al. [139] indicated that co-composting is an interesting approach for the exploitation of large quantities of agro-industrial residues, with a final product suitable for improving soil fertility and health. Thus, co-composting of OMW is highly advised for the efficient treatment of wastes and the creation of a premium product appropriate for biofertilizer. Moreover, according to Elmansour et al. [140], there are several studies that have reported the impact of phenol solution on how biological processes behave generally while treating wastewater [141,142].

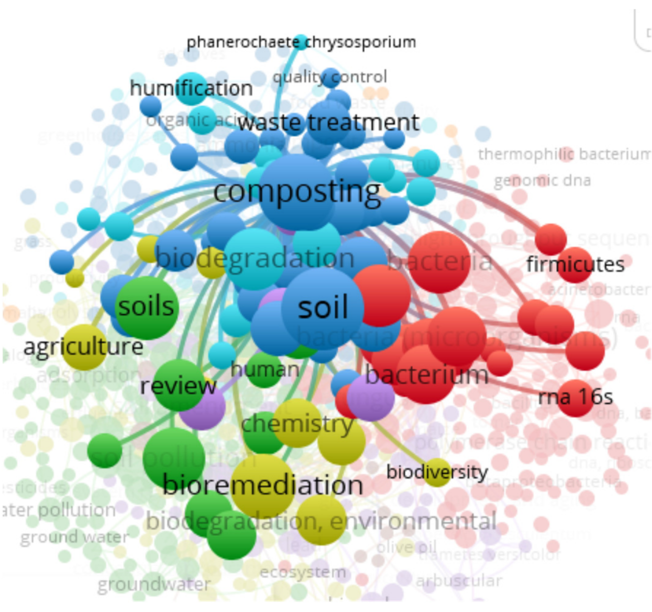


Figure 16. Composting association: bioremediation, chemistry and biodiversity (yellow circles).

4. Discussion

The soil is the world's richest microbial ecosystem, comprising bacteria, fungi, viruses and other microorganisms such as archaea and protists. These microbial communities play a crucial role in plant health through their resistance to drought, pollution and parasites [143]. Up to 98.8% of the food consumed comes from soils, and the Food and Agriculture Organization predicts that soil erosion will reduce agricultural yields by 20–80%, depending on the soil type [144].

Mapping studies in this research show some trends that may indicate how microbes will respond to ongoing climate change. Climate change has a potential effect on organic matter decomposition, soil microbial biomass, bioremediation and soil metabolism and is directly related to changes in the role of microbiota communities in soil.

Based on the results presented above, microbes are unlikely to become extinct as they are adaptable, but climate change is likely gradually reducing the diversity of many plant ecosystems and changing the composition of microbes.

Rapid temperature change may cause many species to become extinct while also allowing other species to colonize from neighboring warmer habitats. In light of this information, it is predicted that as the climate warms, plant community variety will decrease rather than rise [145].

The uneven effects of climate change, like changing precipitation, will be seen on the Earth's surface. Warming will effectively make the environment drier over a huge portion of the terrestrial Earth, which will reduce plant productivity and exacerbate the importance of water as the primary limiting factor for plants and soil microbes [145].

Terrestrial ecosystems will be impacted by climate change both directly and indirectly, both above- and belowground [146]. The effects of climate change will be most pronounced aboveground, where changes in temperature, precipitation and nitrogen availability will all have an impact on the quantity of plant species and the composition of the land surface in unmanaged ecosystems. Changes in the underground microbial population indirectly affect land use, plant species composition and plant production, all of which have an impact on plant communities [146].

The reaction to climate change is more complicated belowground. The type and quantity of carbon that enters the soil system as well as the physical structure of the plant root zone are influenced by the responses of the plants. The biomass and makeup of the microbial population are indirectly affected by this. The microbial community is directly impacted by water, temperature and nitrogen as the organisms adapt to changes in resource availability as well as temperature or drought stress. Whether direct or indirect, microbial reactions to climatic changes will have an impact on plants by affecting the availability of nutrients or pathogen production. Therefore, improving our understanding of the reaction of the microbial population must be a crucial step in our understanding of ecosystem response to climate change [146].

Numerous studies [147–150] have shown the direct impacts of specific climatic change factors on soil communities. These changes lead to increased fungal/bacterial ratios under dry conditions, as measured by increased microbial C/N ratios and increased fungal/bacterial ratios, contributing to nutrient cycling and nutrient degradation processes and resulting in significant changes in community composition.

According to ref. [151], perturbations caused by climate change will have an impact on soil microbial communities either directly (such as seasonality and temperature) or indirectly (for example, soil organic matter and water content, pools of C, N and P, plant litter and root biomass). The cycling of both carbon and nutrients in soils is influenced by biogeochemical processes, which are fundamentally influenced by microbial populations. The types of organic and inorganic materials that can be used as substrates, as well as the response rate of substrate consumption, depend on the makeup and abundance of the soil microbial population [151].

Regional and global climate and weather phenomena are influenced by microbes. Different groups of microorganisms respond differently to elevated temperatures; for instance, Firmicutes and Actinobacteria have been observed to respond positively to elevated temperature, whereas Gram-negative bacteria have been observed to respond negatively. Variable changes occur in the total microbial biomass as a result of increased temperature [151]. By changing the activity of temperature-sensitive microbial enzymes, increased temperature can directly change how the soil microbial community functions [148].

By changing net primary output and, in turn, the pool of accessible substrates used for microbial development, increased temperature can also have an impact on the diversity and composition of soil microbes [149,151]. Additionally, higher temperatures cause more water to evaporate from the soil, which indirectly affects microorganisms by causing the soil to dry up [150,151].

Different taxonomic and functional groupings of microorganisms have varying levels of drought resistance, which can have an impact on the composition and operation of the soil microbial community. In contrast, the quantity of Gram-negative bacteria typically decreases when soil dries out [147,151–153], whereas more drought-tolerant microorganisms like fungi, Firmicutes, and Actinobacteria typically benefit from dry circumstances.

According to Balser et al. [146], soil microorganisms are an essential component of agroecosystems' response to climate change through their ability to cycle nutrients and process soil carbon. To fully understand and manage the impacts of climate change on soil communities, studies should include assessments of their composition and biomass, longer-term studies should be carried out. Short-term studies are inadequate to understand the effects of climate change on soil microbial dynamics [146].

There are a number of reasons why soil microbes will be impacted; here, we offer some ideas about how climate change elements such as CO_2 and temperature alter the microbial composition. The assessment of potential future changes in the biogeochemical cycles and climatic feedbacks must take into account the potential detrimental impact of climate change on decomposition as well as biodiversity. However, the largest area of interest is soil microbiome's amazing complexity and the web of relationships that exists there [154].

Further, research has shown that actinomycetes are efficient at breaking down organic matter, which accelerates environmental warming and CO_2 flux in the atmosphere [117]. Climate warming can reduce the diversity of microbes, increase the complexity of their relationships, and speed up the decomposition of soil organic matter, with new pathogens likely to emerge.

5. Conclusions

In this study, it was concluded that climate warming and shifting precipitation regimes are affecting biodiversity and ecosystem functioning and are altering microorganisms, especially the bacterial groups. In more detail, soil metabolism is an important factor, involving all the chemical consequences of microbial development. The presented research study shows that long-term warming effects accelerate decomposition and change how soils operate in ecosystems, both directly by influencing microbial physiology and indirectly by changing the makeup of the microbial population. Furthermore, the phyllosphere region is dynamic and is influenced by a variety of factors. Thus, phyllosphere microbiomes are under increased stress from climate change, especially from warming and drought. Thus, it is necessary to determine not only how microorganisms affect climate change but also how they will be affected by climate conditions and other human activities.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agriengineering5010037/s1, Figure S1: Visualizing Scopus soil results with the VOSviewer, and Figure S2: Analyzing Scopus soil results with the VOSviewer. The soil (a) and the metabolism (b) paradigms.

Author Contributions: Conceptualization, S.L. and I.V.; investigation, I.V.; writing—original draft preparation, S.L. and I.V.; writing—review and editing, S.L. and I.V.; visualization, S.L. and I.V.; supervision, I.V. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Ebi, K.L.; Mearns, L.O.; Nyenzi, B. Weather and climate: Changing human exposures. In *Climate Change and Human Health. Risks and Responses*; McMichael, A.J., Campbell-Lendrum, D.H., Corvalán, C.F., Ebi, K.L., Githeko, A.K., Scheraga, J.D., Woodward, A., Eds.; World Health Organization: Geneva, Switzerland, 2003.
2. Riedy, C. Climate change. In *Blackwell Encyclopedia of Sociology*; Ritzer, G., Ed.; Blackwell: Hoboken, NJ, USA, 2016.
3. Royal Society. *Climate Change. Evidence and Causes. An Overview from the Royal Society and the US National Academy of Sciences*; National Academy of Sciences and Royal Society: Washington, DC, USA, 2020.
4. Ghosh, P. Climate change education. *Curr. Sci.* **2016**, *110*, 1887.
5. Thuiller, W. Climate change and the ecologist. *Nature* **2007**, *448*, 550–552. [CrossRef] [PubMed]
6. Vermeulen, S.; Zougmoré, R.; Wollenberg, E.; Thornton, P.; Nelson, G.; Kristjanson, P.; Kinyangi, J.; Jarvis, A.; Hansen, J.; Challinor, A.; et al. Climate change, agriculture and food security: A global partnership to link research and action for low-income agricultural producers and consumers. *Curr. Opin. Environ. Sustain.* **2012**, *4*, 128–133. [CrossRef]
7. Frieler, K.; Levermann, A.; Elliott, J.; Heinke, J.; Arneth, A.; Bierkens, M.F.P.; Ciais, P.; Clark, D.B.; Deryng, D.; Döll, P.; et al. A framework for the cross-sectoral integration of multi-model impact projections: Land use decisions under climate impacts uncertainties. *Earth Syst. Dyn.* **2015**, *6*, 447–460. [CrossRef]
8. Rosenzweig, C.; Elliott, J.; Deryng, D.; Ruane, A.C.; Müller, C.; Arneth, A.; Boote, K.J.; Folberth, C.; Glotter, M.; Khabarov, N.; et al. Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison. *Proc. Natl. Acad. Sci. USA* **2014**, *111*, 3268–3273. [CrossRef]
9. Falco, C.; Donzelli, F.; Olper, A. Climate change, agriculture and migration: A Survey. *Sustainability* **2018**, *10*, 1405. [CrossRef]
10. Gowdy, J. Our hunter-gatherer future: Climate change, agriculture and uncivilization. *Futures* **2020**, *15*, 102488. [CrossRef]
11. McMichael, A.J.; Campbell-Lendrum, D.H.; Corvalán, C.F.; Ebi, K.L.; Githeko, A.K.; Scheraga, J.D.; Woodward, A. *Climate Change and Human Health. Risks and Responses*; World Health Organization: Geneva, Switzerland, 2003.
12. Inoue, Y. Satellite and drone-based remote sensing of crops and soils for smart farming—A review. *Soil Sci. Plant Nutr.* **2020**, *66*, 798–810. [CrossRef]
13. Friha, O.; Ferrag, M.A.; Shu, L.; Maglaras, L.A.; Wang, X. Internet of things for the future of smart agriculture: A comprehensive survey of emerging technologies. *IEEE CAA J. Autom. Sin.* **2021**, *8*, 718–752. [CrossRef]
14. FAO. *Climate Change and Food Security: Risks and Responses*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2015. Available online: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwif5tS48sn9AhVVRPEDHa1gBGYQFnoECAsQAQ&url=https%3A%2F%2Fwww.fao.org%2F3%2Fi5188e%2FI5188E.pdf&usg=AOvVaw1_SU62-xkdqLasBc8LmOGx (accessed on 15 December 2022).
15. National Research Council. *Climate Change, Evidence, Impacts and Choices*; National Academy of Sciences: Washington, DC, USA, 2012.
16. Anatolioti, V.; Leontopoulos, S.; Skoufogianni, G.; Skenderidis, P. A study on the potential use of energy crops as alternative cultivation in Greece. Issues of farmer's attitudes. In Proceedings of the 4th International Conference on Food and Biosystems Engineering, Crete Island, Greece, 30 May–19 June 2019; pp. 410–445.
17. Leontopoulos, S.; Arabatzis, G. The contribution of energy crops to biomass production. In *Low Carbon Energy Technologies in Sustainable Energy Systems*; Kyriakopoulos, D., Ed.; Elsevier: London, UK, 2020; pp. 47–94.
18. IPCC. Climate change 2014: Synthesis Report. In *Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Core Writing Team, Pachauri, R.K., Meyer, L.A., Eds.; IPCC: Geneva, Switzerland, 2014; p. 151.
19. Uleberg, E.; Hanssen-Bauer, I.; van Oort, B.; Dalmannsdottir, S. Impact of climate change on agriculture in Northern Norway and potential strategies for adaptation. *Clim. Chang.* **2014**, *122*, 27–39. [CrossRef]
20. Svobodová, E.; Trnka, M.; Dubrovský, M.; Semerádová, D.; Eitzinger, J.; Štěpánek, P.; Zalud, Z. Determination of areas with the most significant shift in persistence of pests in Europe under climate change. *Pest Manag. Sci.* **2014**, *70*, 708–715. [CrossRef] [PubMed]
21. Cressman, K. Climate change and locusts in the WANA Region. In *Climate Change and Food Security in West Asia and North Africa*; Sivakumar, M.V.K., Lal, R., Selvaraju, M.R., Hamdan, I., Eds.; Springer: Berlin/Heidelberg, Germany, 2013; pp. 131–143.
22. Hannukkala, A.O.; Kaukoranta, T.; Lehtinen, A.; Rahkonen, A. Late-blight epidemics on potato in Finland, 1933-2002; increased and earlier occurrence of epidemics associated with climate change and lack of rotation. *Plant Pathol.* **2007**, *56*, 167–176. [CrossRef]
23. Leontopoulos, S.V.; Vagelas, I.K.; Gravanis, F.T. Estimate the emergence of *Pectinophora gossypiella* Saunders. (Lepidoptera: Gelechiidae) with degree days in the region of Thessaly, Greece. *J. Agric. Sci. Technol.* **2011**, *1*, 182–186.
24. Baker, M.B.; Venugopal, P.D.; Lamp, W.O. Climate change and phenology: *Empoasca fabae* (Hemiptera: Cicadellidae) migration and severity of impact. *PLoS ONE* **2015**, *10*, e0124915. [CrossRef]
25. Luedeling, E.; Steinmann, K.P.; Zhang, M.; Brown, P.H.; Grant, J.; Girvetz, E.H. Climate change effects on walnut pests in California. *Glob. Change Biol.* **2011**, *17*, 228–238. [CrossRef]

26. Ghini, R.; Hamada, E.; Pedro, M.L.; Marengo, J.A.; Gonçalves, R.R.V. Risk analysis of climate change on coffee nematodes and leaf miner in Brazil. *Pesqui. Agropecuária Bras.* **2008**, *43*, 187–195. [CrossRef]
27. Leontopoulos, S.V.; Petrotos, K.; Anatolioti, V.; Skenderidis, P.; Tsilfoglou, S.; Vagelas, I. Chemotactic responses of *Pseudomonas oryzihabitans* and second stage juveniles of *Meloidogyne javanica* on tomato root tip exudates. *Int. J. Food Biosyst. Eng.* **2017**, *5*, 75–100.
28. Leontopoulos, S.; Petrotos, K.; Anatolioti, V.; Skenderidis, P.; Tsilfoglou, S.; Papaioannou, C.; Kokkora, M.; Vagelas, I. Preliminary studies on mobility and root colonization ability of *Pseudomonas oryzihabitans*. *Int. J. Food Biosyst. Eng.* **2017**, *3*, 73–89.
29. Luck, J.; Spackman, M.; Freeman, A.; Trebicki, P.; Griffiths, W.; Finlay, K.; Chakraborty, S. Climate change and diseases of food crops. *Plant Pathol.* **2011**, *60*, 113–121. [CrossRef]
30. Pautasso, M.; Döring, T.F.; Garbelotto, M.; Pellis, L.; Jeger, M.J. Impacts of climate change on plant diseases-opinions and trends. *Eur. J. Plant Pathol.* **2012**, *133*, 295–313. [CrossRef]
31. Porter, J.R.; Xie, L.; Challinor, A.J.; Cochrane, K.; Howden, S.M.; Iqbal, M.M.; Lobell, D.B.; Travasso, M.I. Food security and food production systems. In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects*; Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., et al., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2014; pp. 485–533.
32. Lobell, D.B.; Schlenker, W.; Costa-Roberts, J. Climate trends and global crop production since 1980. *Science* **2011**, *333*, 616–620. [PubMed]
33. Pearce, D.W.; Cline, W.R.; Achanta, A.N.; Fankhauser, S.; Pachauri, R.K.; Tol, R.S.J.; Vellinga, P. The Social costs of climate change: Greenhouse damage and the benefits of control. In *Climate Change 1995: Economic and Social Dimension*; Bruce, J.P., Lee, H., Haites, E.F., Eds.; Cambridge University Press: Cambridge, UK, 1996; pp. 179–224.
34. Fankhauser, S.; Tol, R.S.J. Climate change costs—Recent advancements in the economic assessment. *Energy Policy* **1996**, *24*, 665–673. [CrossRef]
35. Nordhaus, W.D.; Boyer, J.G. *Warming the World: Economic Models of Global Warming*; MIT Press: Cambridge, UK, 1999.
36. Zirnov, S.; Mardon, A.; Johnson, P. Climate Change. 2021. Available online: https://www.academia.edu/81278489/Climate_Change (accessed on 10 October 2022).
37. Tol, R.S.J. On the difference in impact of two almost identical climate change scenarios. *Energy Policy* **1998**, *26*, 13–20. [CrossRef]
38. Mendelsohn, R.O.; Morrison, W.N.; Schlesinger, M.E.; Andronova, N.G. Country-specific market impacts of climate change. *Clim. Change* **1998**, *45*, 553–569. [CrossRef]
39. Tol, R.S.J. Estimates of the damage costs of climate change—Part 1: Benchmark Estimates. *Environ. Resour. Econ.* **2002**, *21*, 47–73. [CrossRef]
40. Schneider, S.H. *Abrupt Non-Linear Climate Change, Irreversibility and Surprise*; (ENV/EPOC/GSP(2003)13/FINAL); OECD: Paris, France, 2003.
41. Mahlman, J.D. Uncertainties in projections of human-caused climate warming. *Science* **1997**, *278*, 1416–1417. [CrossRef]
42. Wigley, T. *Modelling Climate Change under No-Policy and Policy Emissions Pathways*; (ENV/EPOC/GSP(2003)7/FINAL); OECD: Paris, France, 2003.
43. Mendelsohn, R.O.; Schlesinger, M.E. Climate-response functions. *Ambio* **1999**, *28*, 362–366.
44. Smith, J.; Hitz, S. *Background Paper: Estimating Global Impacts from Climate Change*; (ENV/EPOC/GSP (2002)12/FINAL); OECD: Paris, France, 2003.
45. Tol, R.S.J.; Downing, T.E.; Kuik, O.J.; Smith, J.B. Improving Information for Policy Makers Distributional Aspects of Climate Change Impacts. Climate Change. Working Party on Global and Structural Policies OECD. Workshop on the Benefits of Climate Policy. 2003. Available online: https://www.oecd.org/env/cc/2483223.pdf (accessed on 22 February 2023).
46. Filho, W.L.; Nagy, G.J.; Setti, A.F.F.; Sharifi, A.; Donkor, F.K.; Batista, K.; Djekic, I. Handling the impacts of climate change on soil biodiversity. *Sci. Total Environ.* **2023**, *869*, 161671. [CrossRef]
47. FAO. *Global Forest Resources Assessment 2020: Main Report*; Food and Agriculture Organization of the United Nations: Rome, Italy. [CrossRef]
48. Makipaa, R.; Abramoff, R.; Adamczyk, B.; Baldy, V.; Biryol, C.; Bosela, M.; Casals, P.; Yuste, J.C.; Dondini, M.; Filipek, S.; et al. How does management affect soil C sequestration and greenhouse gas fluxes in boreal and temperate forests?—A review. *For. Ecol. Manag.* **2023**, *529*, 120637.
49. Lal, R. Soil carbon sequestration impacts on global climate change and food security. *Science* **2004**, *304*, 1623–1627. [CrossRef]
50. Rovai, A.S.; Twilley, R.R.; Castaneda-Moya, E.; Riul, P.; Cifuentes-Jara, M.; Manrow-Villalobos, M.; Horta, P.A.; Simonassi, J.C.; Fonseca, A.; Pagliosa, P.R. Global controls on carbon storage in mangrove soils. *Nat. Clim. Chang.* **2018**, *8*, 534–538. [CrossRef]
51. Wang, Q.; Le Noe, J.; Li, Q.; Lan, T.; Gao, X.; Deng, O.; Li, Y. Incorporating agricultural practices in digital mapping improves prediction of cropland soil organic carbon content: The case of the Tuojiang River Basin. *J. Environ. Manag.* **2023**, *330*, 117203. [CrossRef] [PubMed]
52. Soong, J.L.; Fuchslueger, L.; Marañon-Jimenez, S.; Torn, M.S.; Janssens, I.A.; Penuelas, J.; Richter, A. Microbial carbon limitation: The need for integrating microorganisms into our understanding of ecosystem carbon cycling. *Glob. Change Biol.* **2020**, *26*, 1953–1961. [CrossRef]
53. Rosinger, C.; Rousk, J.; Sanden, H. Can enzymatic stoichiometry be used to determine growth-limiting nutrients for microorganisms?—A critical assessment in two subtropical soils. *Soil Biol. Biochem.* **2019**, *128*, 115–126. [CrossRef]

54. Lu, W.; Ren, H.; Ding, W.; Li, H.; Yao, X.; Jiang, X. The effects of climate warming on microbe-mediated mechanisms of sediment carbon emission. *J. Environ. Sci.* **2023**, *129*, 16–29. [CrossRef] [PubMed]
55. Ding, J.; Chen, L.; Zhang, B.; Liu, L. Linking temperature sensitivity of soil CO_2 release to substrate, environmental, and microbial properties across alpine ecosystems. *Glob. Biogeochem. Cycles* **2016**, *30*, 1310–1323. [CrossRef]
56. Wu, L.; Zhang, Y.; Guo, X.; Ning, D.; Zhou, X.; Feng, J. Reduction of microbial diversity in grassland soil is driven by long-term climate warming. *Nat. Microbiol.* **2022**, *7*, 1054–1062.
57. Yang, Y.; Cheng, S.; Fang, H.; Guo, Y.; Li, Y.; Zhou, Y. Interactions between soil organic matter chemical structure and microbial communities determine the spatial variation of soil basal respiration in boreal forests. *Appl. Soil Ecol.* **2023**, *183*, 10474.
58. Bond-Lamberty, B.; Bailey, V.L.; Chen, M.; Gough, C.M.; Vargas, R. Globally rising soil heterotrophic respiration over recent decades. *Nature* **2018**, *560*, 80–83. [CrossRef]
59. Wang, Q.; Liu, S.; Tian, P. Carbon quality and soil microbial property control the latitudinal pattern in temperature sensitivity of soil microbial respiration across Chinese forest ecosystems. *Glob. Chang. Biol.* **2018**, *24*, 2841–2849. [CrossRef]
60. Delgado-Baquerizo, M.; Giaramida, L.; Reich, P.B.; Khachane, A.N.; Hamonts, K.; Edwards, C.; Lawton, L.A.; Singh, B.K. Lack of functional redundancy in the relationship between microbial diversity and ecosystem functioning. *J. Ecol.* **2016**, *104*, 936–946. [CrossRef]
61. Liu, Y.R.; Delgado-Baquerizo, M.; Wang, J.T.; Hu, H.W.; Yang, Z.; He, J.Z. New insights into the role of microbial community composition in driving soil respiration rates. *Soil Biol. Biochem.* **2018**, *118*, 35–45. [CrossRef]
62. Neurauter, M.; Yuan, M.; Hicks, L.C.; Rousk, J. Soil microbial resource limitation along a subarctic ecotone from birch forest to tundra heath. *Soil Biol. Biochem.* **2023**, *177*, 108919. [CrossRef]
63. Ziman, J.M. *An Introduction to Science Studies: The Philosophical and Social Aspects of Science and Technology*; Cambridge University Press: Cambridge, UK, 1984; ISBN 0-521-34680-0.
64. van Raan, A.F.J. On the growth, aging and fractal differentiation of science. *Scientometrics* **2000**, *47*, 347–362. [CrossRef]
65. Price, D.J.D. *Little Science, Big Science*; Columbia University Press: New York, NY, USA, 1963.
66. Noyons, E.C.M. *Bibliometric Mapping as a Science Policy and Research Management Tool*; DSWO Press: Leiden, The Netherlands, 1999; Available online: https://hdl.handle.net/1887/38308 (accessed on 10 December 2022).
67. Fellnhofer, K. Toward a taxonomy of entrepreneurship education research literature: A bibliometric mapping and visualization. *Educ. Res. Rev.* **2019**, *27*, 28–55. [CrossRef]
68. Braun, T. *Handbook of Quantitative Science and Technology Research. The Use of Publication and Patent Statistics in Studies of S & T Systems*; Springer: Dordrecht, The Netherlands, 2005.
69. van Leeuwen, T. *Descriptive Versus Evaluative Bibliometrics, Handbook of Quantitative Science and Technology Research*; Springer: Dordrecht, The Netherlands, 2004.
70. Börner, K.; Chen, C.; Boyack, K.W. Visualizing knowledge domains. *Annu. Rev. Inf. Sci. Technol.* **2003**, *37*, 179–255. [CrossRef]
71. Cronin, B. Bibliometrics and beyond: Some thoughts on web-based citation analysis. *J. Inf. Sci.* **2001**, *27*, 1–7. [CrossRef]
72. Ding, Y. Scientific collaboration and endorsement: Network analysis of co-authorship and citation networks. *J. Informetr.* **2011**, *5*, 187–203. [CrossRef]
73. Moya-Anegón, F.; Vargas-Quesada, B.; Herrero-Solana, V.; Chinchilla-Rodríguez, Z.; Corera-Álvarez, E.; Munoz-Fernández, F.J. A new technique for building maps of large scientific domains based on the cocitation of classes and categories. *Scientometrics* **2004**, *61*, 129–145. [CrossRef]
74. Velasco-Muñoz, J.F.; Aznar-Sánchez, J.A.; Belmonte-Ureña, L.J.; López-Serrano, M.J. Advances in water use efficiency in agriculture: A bibliometric analysis. *Water* **2018**, *10*, 377. [CrossRef]
75. Sweileh, W.M. Bibliometric analysis of peer-reviewed literature on food security in the context of climate change from 1980 to 2019. *Agric. Food Secur.* **2020**, *9*, 11. [CrossRef]
76. Fusco, G. Twenty years of common agricultural policy in Europe: A bibliometric analysis. *Sustainability* **2021**, *13*, 10650.
77. Pan, X.; Lv, J.; Dyck, M.; He, H. Bibliometric analysis of soil nutrient research between 1992 and 2020. *Agriculture* **2021**, *11*, 223. [CrossRef]
78. Papadopoulou, C.I.; Loizou, E.; Melfou, K.; Chatzitheodoridis, F. The knowledge based agricultural bioeconomy: A bibliometric network analysis. *Energies* **2021**, *14*, 6823. [CrossRef]
79. Rejeb, A.; Abdollahi, A.; Rejeb, K.; Treiblmaier, H. Drones in agriculture: A review and bibliometric analysis. *Comput. Electron. Agric.* **2022**, *198*, 107017. [CrossRef]
80. Mühl, D.D.; de Oliveira, L. A bibliometric and thematic approach to agriculture 4.0. *Heliyon* **2022**, *8*, 09369. [CrossRef] [PubMed]
81. Quastel, J.H. Soil metabolism. *Proc. Royal Soc. Lond. Ser. B Biol. Sci.* **1955**, *911*, 159–178. [CrossRef]
82. Xie, Z.; Yu, Z.; Li, Y.; Wang, G.; Liu, X.; Tang, C.; Lian, T.; Adams, J.; Liu, J.; Liu, J.; et al. Soil microbial metabolism on carbon and nitrogen transformation links the crop-residue contribution to soil organic carbon. *NPJ Biofilms Microbiomes* **2022**, *8*, 14. [CrossRef]
83. García-Orenes, F.; Morugán-Coronado, A.; Zornoza, R.; Scow, K.M. Changes in soil microbial community structure influenced by agricultural management practices in a Mediterranean agro-ecosystem. *PLoS ONE* **2013**, *8*, e80522. [CrossRef]
84. Jansson, J.K.; Hofmockel, K.S. Soil microbiomes and climate change. *Nat. Rev. Microbiol.* **2019**, *18*, 35–46. [CrossRef]
85. Ibrahim, A.D.; Uhuami, A.O.; Abdulkadir, N.; Uzoh, I.M. Climate change alters microbial communities. In *Soil Biology, Climate Change and the Microbiome*; Choudhary, D.K., Mishra, A., Varma, A., Eds.; Springer: Cham, Switzerland, 2021; p. 63.

86. Wahdan, S.F.; Hossen, S.; Tanunchai, B.; Sansupa, C.; Schädler, M.; Noll, M.; Dawoud, T.M.; Wu, Y.; Buscot, F.; Purahong, W. Life in the wheat litter: Effects of future climate on microbiome and function during the early phase of decomposition. *Microb. Ecol.* **2021**, *84*, 90–105. [CrossRef] [PubMed]
87. Cotrufo, M.; Galdo, I.; Piermatteo, D. Litter decomposition: Concepts, methods and future perspectives. In *Soil Carbon Dynamics: An Integrated Methodology*; Kutsch, W., Bahn, M., Heinemeyer, A., Eds.; Cambridge University Press: Cambridge, UK, 2010; pp. 76–90.
88. Wu, X.; Niklas, K.; Sun, S. Climate change affects detritus decomposition rates by modifying arthropod performance and species interactions. *Curr. Opin. Insect Sci.* **2021**, *47*, 62–66. [CrossRef] [PubMed]
89. Stuble, K.L.; Ma, S.; Liang, J.; Luo, Y.; Classen, A.T.; Souza, L. Long-term impacts of warming drive decomposition and accelerate the turnover of labile, not recalcitrant, carbon. *Ecosphere* **2019**, *10*, 2715. [CrossRef]
90. Sharma, B.; Singh, B.N.; Dwivedi, P.; Rajawat, M.V. Interference of climate change on plant-microbe interaction: Present and future prospects. *Front. Agron.* **2022**, *3*, 725804. [CrossRef]
91. Cavicchioli, R.; Ripple, W.J.; Timmis, K.N.; Azam, F.; Bakken, L.R.; Baylis, M.; Behrenfeld, M.J.; Boetius, A.; Boyd, P.W.; Classen, A.T.; et al. Scientists' warning to humanity: Microorganisms and climate change. *Nat. Rev. Microbiol.* **2019**, *17*, 569–586. [CrossRef]
92. Zhang, X.; Zhang, G.; Chen, Q.S.; Han, X. Soil bacterial communities respond to climate changes in a temperate steppe. *PLoS ONE* **2013**, *8*, 78616. [CrossRef]
93. Trumbore, S.; Brando, P.; Hartmann, H. Forest health and global change. *Science* **2015**, *349*, 814–818. [CrossRef]
94. Lesk, C.; Rowhani, P.; Ramankutty, N. Influence of extreme weather disasters on global crop production. *Nature* **2016**, *529*, 84. [CrossRef]
95. Glassman, S.I.; Weihe, C.; Li, J.; Albright, M.B.; Looby, C.I.; Martiny, A.C.; Treseder, K.K.; Allison, S.D.; Martiny, J.B. Decomposition responses to climate depend on microbial community composition. *Proc. Natl. Acad. Sci. USA* **2018**, *115*, 11994–11999. [CrossRef]
96. Bouwer, E.J.; Zehnder, A.J. Bioremediation of organic compounds–putting microbial metabolism to work. *Trends Biotechnol.* **1993**, *11*, 360–367. [CrossRef]
97. Bala, S.; Garg, D.; Thirumalesh, B.V.; Sharma, M.; Sridhar, K.; Inbaraj, B.S.; Tripathi, M. Recent strategies for bioremediation of emerging pollutants: A review for a green and sustainable environment. *Toxics* **2022**, *10*, 484. [CrossRef] [PubMed]
98. Bhandari, S.; Poudel, D.K.; Marahatha, R.; Dawadi, S.; Khadayat, K.; Phuyal, S.R.; Shrestha, S.; Gaire, S.; Basnet, K.; Khadka, U.; et al. Microbial enzymes used in bioremediation. *J. Chem.* **2021**, *2021*, 8849512. [CrossRef]
99. Alkorta, I.; Epelde, L.; Garbisu, C. Environmental parameters altered by climate change affect the activity of soil microorganisms involved in bioremediation. *FEMS Microbiol. Lett.* **2017**, *364*, 19. [CrossRef] [PubMed]
100. Abatenh, E.; Gizaw, B.; Tsegaye, Z.; Wassie, M. The role of microorganisms in bioremediation. A review. *Open J. Environ. Biol.* **2017**, *2*, 38–46. [CrossRef]
101. Boughattas, I.; Hattab, S.; Alphonse, V.; Livet, A.; Giusti-Miller, S.; Boussetta, H.; Banni, M.; Bousserrhine, N. Use of earthworms *Eisenia andrei* on the bioremediation of contaminated area in north of Tunisia and microbial soil enzymes as bioindicator of change on heavy metals speciation. *J. Soils Sediments* **2018**, *19*, 296–309. [CrossRef]
102. Pandey, J.; Sarkar, S.; Pandey, V.C. Compost-assisted phytoremediation. In *Assisted Phytoremediation*; Elsevier: Amsterdam, The Netherlands, 2022; pp. 243–264.
103. Berti, W.R.; Cunningham, S.D. Phytostabilization of metals. In *Phytoremediation of Toxic Metals: Using Plants to Clean-Up the Environment*; Raskin, I., Ensley, B.D., Eds.; John Wiley & Sons, Inc.: New York, NY, USA, 2010; pp. 71–88.
104. Yan, A.; Wang, Y.; Tan, S.N.; Mohd Yusof, M.L.; Ghosh, S.; Chen, Z. Phytoremediation: A promising approach for revegetation of heavy metal-polluted land. *Front. Plant Sci.* **2020**, *11*, 359. [CrossRef] [PubMed]
105. Poonam, A.; Bhardwaj, R.; Sharma, R.C.; Handa, N.; Kaur, H.; Kaur, R.; Sirhindi, G.; Thukral, A.K. Prospects of field crops for phytoremediation of contaminants. *Emerg. Technol. Manag. Crop Stress Toler.* **2014**, *2*, 449–470.
106. Guo, M.; Song, W.; Tian, J. Biochar-facilitated soil remediation: Mechanisms and efficacy variations. *Front. Environ. Sci.* **2020**, *8*, 521512. [CrossRef]
107. Alsafran, M.; Usman, K.; Ahmed, B.; Rizwan, M.; Saleem, M.H.; Al jabri, H. Understanding the phytoremediation mechanisms of potentially toxic elements: A proteomic overview of recent advances. *Front. Plant Sci.* **2022**, *13*, 881242. [CrossRef]
108. Joseph, S.; Cowie, A.L.; van Zwieten, L.; Bolan, N.S.; Budai, A.; Buss, W.; Cayuela, M.; Graber, E.R.; Ippolito, J.A.; Kuzyakov, Y.; et al. How biochar works, and when it doesn't: A review of mechanisms controlling soil and plant responses to biochar. *GCB Bioenergy* **2021**, *13*, 1731–1764. [CrossRef]
109. He, D.; Luo, Y.; Lu, S.; Liu, M.; Song, Y.; Lei, L. Microplastics in soils: Analytical methods, pollution characteristics and ecological risks. *TrAC Trends Anal. Chem.* **2018**, *109*, 163–172. [CrossRef]
110. Rabani, M.S.; Hameed, I.; Mir, T.A.; Gupta, M.K.; Habib, A.; Jan, M.; Hussain, H.; Tripathi, S.; Pathak, A.; Ahad, M.B.; et al. Microbial-assisted phytoremediation. In *Phytoremediation*; Elsevier: Amsterdam, The Netherlands, 2022; pp. 91–114.
111. Coninx, L.; Martinová, V.; Rineau, F. Mycorrhiza-assisted phytoremediation. *Adv. Bot. Res.* **2017**, *83*, 127–188.
112. Lebrun, M.; Nandillon, R.; Miard, F.; Bourgerie, S.; Morabito, D. Biochar assisted phytoremediation for metal(loid) contaminated soils. In *Assisted Phytoremediation*; Elsevier: Amsterdam, The Netherlands, 2022; pp. 101–130.
113. Ranđelović, D.; Jakovljević, K.; Zeremski, T. Chelate-assisted phytoremediation. In *Assisted Phytoremediation*; Elsevier: Amsterdam, The Netherlands, 2022; pp. 131–154.
114. Ali, A.; Guo, D.; Mahar, A.; Ma, F.; Li, R.; Shen, F.; Wang, P.; Zhang, Z. Streptomyces pactum assisted phytoremediation in Zn/Pb smelter contaminated soil of Feng County and its impact on enzymatic activities. *Sci. Rep.* **2017**, *7*, 46087. [CrossRef] [PubMed]

115. Shahid, M.; Dumat, C.; Khalid, S.; Niazi, N.K.; Antunes, P.M. Cadmium bioavailability, uptake, toxicity and detoxification in soil-plant system. *Rev. Environ. Contam. Toxicol.* **2017**, *241*, 73–137. [PubMed]
116. O'Connor, D.; Zheng, X.; Hou, D.; Shen, Z.; Li, G.; Miao, G.; O'Connell, S.; Guo, M. Phytoremediation: Climate change resilience and sustainability assessment at a coastal brownfield redevelopment. *Environ. Int.* **2019**, *130*, 104945. [CrossRef] [PubMed]
117. Sharma, I. Bioremediation Techniques for Polluted Environment: Concept, Advantages, Limitations, and Prospects. In *Trace Metals in the Environment—New Approaches and Recent Advances*; IntechOpen: London, UK, 2021.
118. Cassano, A.; Conidi, C.; Galanakis, C.M.; Castro-Muñoz, R. Recovery of polyphenols from olive mill wastewaters by membrane operations. In *Membrane Technologies for Biorefining*; Elsevier: Amsterdam, The Netherlands, 2016; pp. 163–187.
119. Sakarika, M.; Koutra, E.; Tsafrakidou, P.; Terpou, A.; Kornaros, M.E. Microalgae-based remediation of wastewaters. In *Microalgae Cultivation for Biofuels Production*; Elsevier: Amsterdam, The Netherlands, 2020; pp. 317–335.
120. Leontopoulos, S.; Skenderidis, P.; Vagelas, I.K. Potential use of polyphenolic compounds obtained from Olive Mill Waste Waters on plant pathogens and plant parasitic nematodes. In *Plant Defence: Biological Control*; Ramawat, K.G., Ed.; Springer: Berlin/Heidelberg, Germany, 2020; pp. 137–177.
121. Skenderidis, P.; Leontopoulos, S.; Petrotos, K.; Mitsagga, C.; Giavasis, I. The in vitro and in vivo synergistic antimicrobial activity assessment of Vacuum Microwave Assisted aqueous extracts from pomegranate and avocado fruit peels and avocado seeds based on a mixtures design model. *Plants* **2021**, *10*, 1757. [CrossRef] [PubMed]
122. Skenderidis, P.; Leontopoulos, S.; Petrotos, K.; Giavasis, I. Vacuum Microwave-Assisted aqueous extraction of polyphenolic compounds from avocado (*Persea americana*) solid waste. *Sustainability* **2021**, *13*, 2166. [CrossRef]
123. Skenderidis, P.; Leontopoulos, S. Goji berry: Important bioactive ingredients: A mini review. *Biomed. J. Sci. Tech. Res.* **2022**, *41*, 34125–34128.
124. Michalopoulos, G.K.; Kasapi, A.; Koubouris, G.; Psarras, G.; Arampatzis, G.; Hatzigiannakis, E.; Kavvadias, V.; Xiloyannis, C.; Montanaro, G.; Malliaraki, S.; et al. Adaptation of Mediterranean olive groves to climate change through sustainable cultivation practices. *Climate* **2020**, *8*, 54. [CrossRef]
125. Kavvadias, V.; Papadopoulou, M.; Vavoulidou, E.; Theocharopoulos, S.; Koubouris, G.; Psarras, G.; Manolaraki, C.; Giakoumaki, G.; Vasiliadis, A. Effect of sustainable management of olive tree residues on soil fertility in irrigated and rain-fed olive orchards. *J. Water Clim. Chang.* **2018**, *9*, 764–774. [CrossRef]
126. Morianou, G.; Kourgialas, N.; Psarras, G.; Koubouris, G. Mapping sensitivity to desertification in Crete (Greece), the risk for agricultural areas. *J. Water Clim. Change* **2018**, *9*, 691–702. [CrossRef]
127. Meftah, O.; Guergue, Z.; Braham, M.; Sayadi, S.; Mekki, A. Long term effects of olive mill wastewaters application on soil properties and phenolic compounds migration under arid climate. *Agric. Water Manag.* **2019**, *212*, 119–125. [CrossRef]
128. Sierra, J.; Marti, E.; Garau, M.A.; Cruanas, R. Effects of the agronomic use of olive oil mill wastewater: Field experiment. *Sci. Total Environ.* **2007**, *378*, 90–94. [CrossRef]
129. Leontopoulos, S.V.; Giavasis, I.; Petrotos, K.; Kokkora, M.; Makridis, C. Effect of different formulations of polyphenolic compounds obtained from OMWW on the growth of several fungal plant and food borne pathogens. Studies in vitro and in vivo. *Agric. Agric. Sci. Procedia* **2015**, *4*, 327–337. [CrossRef]
130. Leontopoulos, S.V.; Kokkora, M.I.; Petrotos, K.B. In vivo evaluation of liquid polyphenols obtained from OMWW as natural bio-chemicals against several fungal pathogens on tomato plants. *Desalination Water Treat.* **2016**, *57*, 20646–20660.
131. Leontopoulos, S.; Mitsagga, C.; Giavasis, I.; Papaioannou, C.; Vasilakoglou, I.; Petrotos, K. Potential synergistic action of liquid olive Fruit polyphenol extract with aqueous extracts of solid wastes of pomegranate or/and orange juice industry as organic phyto-protective agents against important plant pathogens—Part 1 (*in vitro* Studies). *Univ. J. Agric. Res.* **2020**, *8*, 202–222. [CrossRef]
132. Leontopoulos, S.; Petrotos, K.; Papaioannou, C.; Vasilakoglou, I. Effectiveness of olive fruit polyphenol extract combined with aqueous extracts of solid wastes of pomegranate or/and orange juice against important plant pathogens—Part 2 (in vivo studies). *Univ. J. Agric. Res.* **2020**, *9*, 23–38. [CrossRef]
133. Leontopoulos, S.; Skenderidis, P.; Skoufogianni, G. Potential use of medicinal plants as biological crop protection agents. *Biomed. J. Sci. Tech. Res.* **2020**, *25*, 19320–19324. [CrossRef]
134. Lambakis, D.; Skenderidis, P.; Leontopoulos, S. Technologies and extraction methods of polyphenolic compounds derived from pomegranate (Punica granatum) peels. A mini review. *Processes* **2021**, *9*, 236. [CrossRef]
135. Leontopoulos, S.; Skenderidis, P.; Petrotos, K.; Mitsagga, C.; Giavasis, I. Preliminary studies on suppression of important plant pathogens by using pomegranate and avocado residual peel and seed extracts. *Horticulturae* **2022**, *8*, 283. [CrossRef]
136. Sbaoui, Y.; Ezaouine, A.; Toumi, M.; Farkas, R.; Kbaich, M.A.; Habbane, M.; El Mouttaqui, S.; Kadiri, F.Z.; El Messal, M.; Tóth, E.; et al. Effect of climate on bacterial and archaeal diversity of Moroccan marine microbiota. *Microorganisms* **2022**, *10*, 1622. [CrossRef] [PubMed]
137. Chen, M.; Xu, P.; Zeng, G.; Yang, C.; Huang, D.; Zhang, J. Bioremediation of soils contaminated with polycyclic aromatic hydrocarbons, petroleum, pesticides, chlorophenols and heavy metals by composting: Applications, microbes and future research needs. *Biotechnol. Adv.* **2015**, *33*, 745–755. [CrossRef]
138. Ahmed, P.M.; Fernandez, P.M.; de Figuero, L.I.C.; Pajot, H.F. Exploitation alternatives of olive mill wastewater: Production of value-added compounds useful for industry and agriculture. *Biofuel Res. J.* **2019**, *22*, 980–994. [CrossRef]
139. Kefalogianni, I.; Skiada, V.; Tsagou, V.; Efthymiou, A.; Xexakis, K.; Chatzipavlidis, I. Co-composting of cotton residues with olive mill wastewater: Process monitoring and evaluation of the diversity of culturable microbial populations. *Environ. Monit. Assess.* **2021**, *193*, 641. [CrossRef]

140. Elmansour, T.E.; Mandi, L.; Hejjaj, A.; Ouazzani, N. Nutrients' behavior and removal in an activated sludge system receiving Olive Mill Wastewater. *J. Environ. Manag.* **2022**, *305*, 114254. [CrossRef]
141. Papadimitriou, C.A.; Rouse, J.D.; Karapanagioti, H.K. Treatment efficiency and sludge characteristics in conventional and suspended PVA gel beads activated sludge treating phenol containing wastewater. *Glob. NEST J.* **2018**, *20*, 42–48.
142. Uygur, A.; Kargi, F. Phenol inhibition of biological nutrient removal in a four-step sequencing batch reactor. *Process Biochem.* **2004**, *39*, 2123–2128. [CrossRef]
143. Munir, N.; Hanif, M.; Abideen, Z.; Sohail, M.; El-Keblawy, A.A.; Radicetti, E.; Mancinelli, R.; Haider, G. Mechanisms and strategies of plant microbiome interactions to mitigate abiotic stresses. *Agronomy* **2022**, *12*, 2069. [CrossRef]
144. Kopittke, P.M.; Menzies, N.W.; Wang, P.; McKenna, B.A.; Lombi, E. Soil and the intensification of agriculture for global food security. *Environ. Int.* **2019**, *132*, 105078. [CrossRef]
145. Harrison, S.P. Plant community diversity will decline more than increase under climatic warming. *Philos. Trans. R. Soc. B* **2020**, *375*, 20190106. [CrossRef] [PubMed]
146. Balser, T.C.; Gutknecht, J.L.M.; Liang, C. How will climate change impact soil microbial communities? In *Soil Microbiology and Sustainable Crop Production*; Dixon, G., Tilston, E., Eds.; Springer: Dordrecht, The Netherlands, 2010.
147. Montealegre, C.M.; van Kessel, C.; Russelle, M.P.; Sadowsky, M.J. Changes in microbial activity and composition in a pasture ecosystem exposed to elevated atmospheric carbon dioxide. *Plant Soil* **2004**, *243*, 197–207. [CrossRef]
148. Lützow, M.V.; Kögel-Knabner, I. Temperature sensitivity of soil organic matter decomposition-what do we know? *Biol. Fertil. Soils* **2009**, *46*, 1–15. [CrossRef]
149. Pendall, E.; Bridgham, S.D.; Hanson, P.J.; Hungate, B.A.; Kicklighter, D.W.; Johnson, D.W.; Law, B.E.; Luo, Y.; Megonigal, J.P.; Olsrud, M.; et al. Below-ground process responses to elevated CO_2 and temperature: A discussion of observations, measurement methods, and models. *New Phytol.* **2004**, *162*, 311–322. [CrossRef]
150. Zogg, G.P.; Zak, D.R.; Ringelberg, D.B.; White, D.C.; MacDonald, N.W.; Pregitzer, K.S. Compositional and functional shifts in microbial communities due to soil warming. *Soil Sci. Soc. Am. J.* **1997**, *61*, 475–481. [CrossRef]
151. Gray, S.B.; Classen, A.T.; Kardol, P.; Yermakov, Z.; Mille, R.M. Multiple climate change factors interact to alter soil microbial community structure in an old-field ecosystem. *Soil Sci. Soc. Am. J.* **2011**, *75*, 2217–2226. [CrossRef]
152. Jensen, K.D.; Beier, C.; Michelsen, A.; Emmett, B.A. Effects of experimental drought on microbial processes in two temperate heathlands at contrasting water conditions. *Appl. Soil Ecol.* **2003**, *24*, 165–176. [CrossRef]
153. Drenovsky, R.E.; Vo, D.H.; Graham, K.J.; Scow, K.M. Soil water content and organic carbon availability are major determinants of soil microbial community composition. *Microb. Ecol.* **2003**, *48*, 424–430. [CrossRef]
154. Bastida, F.; Eldridge, D.J.; García, C.; Kenny Png, G.; Bardgett, R.D.; Delgado-Baquerizo, M. Soil microbial diversity–biomass relationships are driven by soil carbon content across global biomes. *ISME J.* **2021**, *15*, 2081–2091. [CrossRef]