Progress of Study on Interception of Soil Mulching with an Insight into Karst Soil Leakage Control: A Review

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Abstract: Soil erosion is a global issue of great concern, especially in karst areas with special environments, where subsurface soil leakage is closely related to soil erosion, which has become a key factor limiting agricultural development. To explore how to improve soil erosion in karst areas to enhance soil quality and maintain the sustainable use of the land in the long term, a total of 176 studies on the interception characteristics of soil mulching and erosion management were reviewed using a systematic review approach, through the WoS and CNKI databases. Firstly, quantitative analysis was conducted in terms of the annual volume, content and countries of the published literature. Secondly, from four aspects (theoretical research, mechanism research, technology research and technical demonstration), the main progress and landmark achievements of soil mulching interception and erosion management were classified. It is shown that the interception characteristics of soil mulching can produce an effective blockage for soil leakage in karst areas. Based on the global classification, compared to synthetic materials, natural materials have received more attention. We propose five key scientific questions that still need to be addressed. This review explores the insightful role of soil mulching for karst soil leakage management and aims to provide theoretical support for future research on sustainable land development in karst areas.

Keywords: soil leakage control; soil mulching; soil erosion; karst; soil quality; interceptions; soil engineering; global review

1. Introduction

“Karst” originally referred to a place in the limestone plateau of the Republic of Slovenia [1]. Since the end of the 19th century, people have been calling the natural landscape of limestone areas with surface peaks, depressions, waterfall caves, underground rivers and a large number of karst springs exposed as karst [2]. The global karst landscape covers 22 million km², accounting for 15% of the total land area of Earth [3]. It is mainly concentrated in southwest China, south-central Europe and eastern North America [4–6].

Karst soil erosion affects regional ecological and environmental security, and it also restricts regional economic and social development, which is manifested in the barrenness and fragility of soil systems in karst mountains, the poverty of surface water, the fragility of vegetation, water pollution problems, etc. Karst lands have a two-layer erosion structure and a “binary three-dimensional” hydrological system on the spatial scale [7,8]. The most visual manifestation is the large amount of bedrock that is exposed, and the soil cover is discontinuous. Due to the single vegetation on the ground and surface layer, much surface water infiltrates into the soil directly from the ground. Although the water infiltration reduces the aboveground runoff during the rainfall process, the rainwater scours and destroys the internal structure of the soil, leading to the underground soil erosion intensity increasing significantly. The special geological structure makes the process...
of water transformation in the sub-bedding surface of karst areas complicated and difficult to recover after being damaged. Therefore, once karst soil is subjected to long-term erosion during the process of succession, it will intensify the local water-fertilizer loss, and the cash crop yield will gradually experience a lower trend. However, karst soil erosion can be prevented. For a while now, researchers in this field have conducted a large number of studies with fruitful results, and karst erosion has been effectively alleviated at the temporal and spatial scales [9]. However, that is not enough. It is worth mentioning that revealing the occurrence and transport mechanisms of soil erosion in karst areas is the key to controlling karst water and soil loss [10]; controlling soil erosion starts with reducing the karst leakage of soil and water [11,12]. Different experts have different understanding of “soil leakage”, and there is no clear definition at present. Combining the study topic and previous works, we view that “soil leakage” is a hydrological process of infiltration from runoff or rainfall into the subsurface, leading to erosion and degradation of subsurface soils. It is more appropriate than “soil leaching” and “percolation process” in describing the erosion state of karst soils. Reducing soil leakage has become a key task in karst soil maintenance research.

As an agronomic technical measure to effectively regulate soil water-fertilizer recharge and slow down surface water loss, soil mulching is being widely used in the management practices of various land types [13–15], such as agricultural lands, fire-affected areas, rangelands and anthropic sites. Soil mulching measures are ground-covering materials. Soil mulching is mainly divided into natural mulching and synthetic mulching. The mechanism of action of this measure is mainly to reduce the soil erosion intensity by increasing the cover layer. This measure achieves the purpose of increasing another redistribution pathway, which can weaken the damage to surface soil aggregates by raindrops. On the other hand, it can also increase the infiltration of rainfall, thereby reducing surface runoff and the erosion rate. This can not only effectively improve soil surface roughness [16] and vegetation coverage, but also inhibit soil erosion. This method has many advantages in practice (Figure 1). A lot of research on soil mulching has been carried out worldwide to cope with soil erosion [17–19]. Reasonable mulching measures can significantly improve soil erosion and can maintain soil water infiltration and retention after rainfall until saturation, without nutrient loss [20]. The interception process of soil mulching is a complex process. This study has strong practicality, and it also has reference in the study of karst areas, especially for karst groundwater/soil leakage control, which can play the role of an assistant of ecological restoration. Despite the uncertainty of their interactions, it is still necessary to reveal the trade-offs between each functional measure and subsurface leakage in karst areas.

![Figure 1. Properties and advantages of soil mulching in field operations. Its high competitiveness is a combination of multiple fields.](image-url)
Given the seriousness of soil erosion and the variety of mulching, this study review focuses on mulching for interception, particularly its effects on soil erosion and water loss. Meanwhile, with the increasing attention on the research on soil leakage in karst areas, we aimed to supplement this research, so we chose to conduct a review on the interception effects of soil mulching. The purpose is to provide suggestions for more sustainable karst soil management. First, based on the WoS and CNKI databases, this paper provides bibliometric statistics on the year of distribution, the content of distribution and the countries of distribution of the literature. Then, the main global progress and landmark achievements on the interception effect of mulching and means of erosion control are systematically reviewed from these points: theoretical research, mechanism research, technology research and technical demonstration, which are full of insights into controlling soil leakage in karst areas. Following this, the similarities and borrowings between soil erosion and soil leakage in terms of interception are discussed, and five key scientific questions that need to be addressed are proposed. Finally, the final summary and outlook of this review are presented, with the hope to provide some theoretical support for achieving soil conservation goals and ecological benefit enhancement in karst lands, and to provide sustainable insights into controlling soil leakage in karst areas.

2. Methods

2.1. Literature Search

In order to collect relevant data and fully learn the present status of soil mulching in interception and soil erosion globally, we used the WoS and CNKI core databases as the basis for the literature search. These databases can help us target the present research hotspots to search, which is the reason for choosing them.

For WoS, it has a wide range of research areas and a high volume of literature, which satisfies the write-up needs of this review. For CNKI, the research results related to South China Karst are abundant for its typicality. The CNKI database is the main host database of its literature, so it is necessary to review the database. The search process was as follows (Table 1). The time range of the search was the maximum time range of both databases, and the search time was up to 30 June 2022.

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At first, the WoS database was used as the main foreign language search site, and a search was started. The first search was conducted by entering the search string “soil erosion” and “mulching” under the search term “topic”; the second search was conducted by entering the search string “soil erosion” and “interceptions” under the search term “topic”; the third search was conducted by entering the search string “mulching” and “interceptions” under the search term “topic”. This resulted in 701 articles in English.
Then, the CNKI database was used as the main Chinese language search site and a search was started. The first search was conducted by entering the search string “soil erosion”, “mulching”, and “measures” under the search term “topic”, and results were excluded by entering the search string “remote sensing”, “GIS”, “space”, and “engineering” under the search term “topic”; the second search was conducted by entering the search string “soil erosion” and “interceptions” under the search term “topic”; the third search was conducted by entering the search string “mulching” and “interceptions” under the search term “topic”. This resulted in 569 articles in Chinese.

Finally, after reading the articles and excluding duplicate items, a total of 1251 papers were retrieved. The time range of the search was the maximum time range of both databases, and the search deadline was 30 June 2022.

2.2. Selection Criteria

To obtain insights from research into controlling soil erosion in karst areas, we identified and screened the obtained documents through both titles and abstracts using the following three screening criteria: (a) soil erosion prevention and control; (b) mulching measures; and (c) interception effects. Finally, 176 relevant papers were identified. This included 74 foreign papers and 102 Chinese papers. Of these, 127 were journal papers, 11 were Ph.D. theses, 34 were master’s theses and 4 were conference papers. The details are illustrated in Figure 2 below.

![Data selection process](image)

Figure 2. Data selection process. The articles satisfying the eligibility criteria were included in the study. Articles were excluded if they were studies on forest fire restoration, urban traffic pollution, urban landscape, remote sensing information technology, animals, etc.

3. Results

3.1. Data Categorization

3.1.1. Annual Distribution of Literature

The search results indicate that the relevant research in foreign languages started earlier, nearly 30 years before China, and they have a lot of experience. Although China started relatively late, the literature results have been rising rapidly in the last decade with the support of the nation. Figure 3 indicates this quantitative trend.
By organizing the 176 documents by year, it was found that the distribution of the literature can be divided into three stages. The first stage is from 1965 to 1993. In this stage, integrated research on the interception of soil mulching and karst soil leakage prevention was still in its infancy, and the first study appeared in 1965 [21]. There were only five relevant papers in this stage, all of which focus on soil mulching interception and soil erosion. The second stage is from 1993 to 2010, where the range of soil mulching types gradually expanded, and the filtering techniques were also summarized systematically. The number of studies studying the movement rules of soil moisture under karst mulching increased significantly. There was also a rapid and fluctuating growth in related research. The third stage is from 2010 to the present. After collation, it was found that related studies are more focused on the theoretical research of soil leakage while focusing on the mechanism research of soil mulching in the water infiltration process, with the highest annual number in 2020. Compared to the previous stages, the results of this research are showing an efficient growth trend.

![Figure 3. Trends in the annual distribution of literature related to soil mulching and soil erosion. (a) The trend of the literature in the WoS database; (b) the trend of the literature in the CNKI database; (c) the trend of the total literature in both databases. The deadline is 30 June 2022.](image)

3.1.2. Classification of Literature Contents

The contents of 176 related papers were organized and categorized in four directions: theoretical research, mechanism research, technology research and technical demonstration, and then summarized (Figure 4). Theoretical research includes the theoretical research of mulch, the regularities and characteristics of soil erosion land, etc.; mechanism research includes the function and response research of soil erosion land; technology research includes the technology creation of soil erosion control, the program model of karst background, etc.; technology demonstration includes the production practice in some areas, the model construction and demonstration, etc.

Of these, the proportion of theoretical research was the highest, with 51.14% of the total results from the literature. This was followed by 30.68% for mechanism research, 11.36% for technology research and 6.82% for technical demonstration. There is a lack of technical demonstration studies on soil leakage interception by soil mulching.
3.1.3. Distribution of Literature Areas

In the 74 selected foreign language studies (Figure 5), the research on soil mulching interception mainly focused on Europe, America and China, among which the European literature mainly studied mulching crop yield or soil organic matter. As for the soil mulching research on China, the water interception and soil-fixing function of soil mulching were mainly studied through simulation experiments and field monitoring, and soil leakage was also analyzed by the aboveground vegetation types combined with regional climate, precipitation and other influencing factors. In addition, Australia, Brazil and Russia also produced some research, while Yugoslavia, Cuba, Jamaica, Norway and other countries produced a small amount of research.

In the 102 selected Chinese language studies (Figure 6), the karst in southern China was the most studied. Additionally, the main research units, mainly universities and scientific research units that focus on the karst environment, were located in areas with large karst land, followed by the Loess Plateau region and the red soils.

Figure 4. Classification of literature contents, as expressed in percentages.

Figure 5. The global spatial distribution of the collected data. China and the United States are the main countries in this study, followed by India.
Figure 6. (a) The spatial distribution of this study in the provinces of China, where the red dots represent cities in the province (these cities are the main cities in the province), and the numbers near them indicate the number of documents from this province; (b) a karst landscape in southern China; (c) the number of studies in the three main regions of this research field in China.

3.1.4. Classification of Mulching Research

According to the nature of the mulch, it can be divided into two types, namely, nature-based and synthetic-based mulch. Nature-based mulch includes vegetative residues, biological geotextiles, gravel and crushed stones, and synthetic-based mulch includes plastic sheeting, super-absorbent polymers and biochar, according to the extracted database and global classification.

Currently, more than 65% of the literature has examined natural mulches in the macroscopic–global classification, while between 30 and 35% has studied synthetic mulches. Additionally, among such micro-studies, organic mulches have received more attention, especially natural mulches that enhance organic matter such as corn stover. The reason for this is their high efficiency and low cost. This highlights the importance of mulching measures for global soil erosion management. Soil mulch improves soil quality in many environments and has a positive effect on water use, flow production, sand production and effectiveness. Table 2 reflects this effect and reports some meaningful metrics.
Table 2. The quantitative effects of mulching on soil erosion. We collected 12 experimental reports from the published literature of the last decade, reporting on the global practice of soil mulching in different environments. Their indicators are indicative. The listed literature relates to forest fire restoration, tillage systems in mixed forests, and potential impacts of mulch types on crop yields, surface runoff, soil erosion, etc. In which, they report: (a) spatial location (Sl), (b) spatial scale (Ss), (c) measurement method (Mm), (d) mulch type, (e) mulch application rate (Ar), (f) erosion rate (Er), (g) sediment concentration (Sc), (h) sediment concentration reduced (Sc-reduced), (i) runoff reduced (R-reduced), (j) infiltration rate (Ir), and (k) crop yield (Cy). For the Ss variable, they report: very fine (< 1 m²), fine (1–1000 m²), hillslope (1000 m²–1 ha). For the Mm variable, they report: simulation (S), rainfall simulation (RS), runoff plot (RP), and silt fence (SF). For the mulch type variable, reporting: control (C), cotton geotextiles (CG), straw mulching (SM), leaf litter mulching (LM), plastic mulching (PM), cobblestone mulching (CM), rice straw mulch (RM), grass mulching (GM), wood mulching (WM), mechanical tillage (MT), mulching with prunings + no-tillage (MP + NT). The references are reported in chronological order.

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* The experimental report of Giménez et al. (2010): different from other mulches, this item (CG) is an 8 mm cotton geotextile, which cannot be expressed using the mulch application rate (Ar). * The experimental report of Shao and Yang (2011) does not provide the specific mulch application rate (Ar), but rather a ratio, expressed as a multiple between 0 and 1. * The comparative state of crop yield in this experiment. “↑” is an increase in crop yield. “↓” is a decrease in crop yield.

3.2. Main Progress and Landmark Achievements

3.2.1. Theoretical Research

(1) Types of soil mulching

Natural mulch, as the name implies, is taken from nature. Synthetic mulch, on the other hand, is an industrial product made from a variety of organic organisms that have
been processed through various production processes. Both can be used to retain soil moisture, regulate soil temperature, suppress weeds and reduce soil erosion and compactness. The difference is that natural mulches are affected by time and gradually decay to organic matter. Synthetic mulches generally have a longer “shelf life”. However, individual mulches also show variability. An economic evaluation study of wheat-maize systems in northwestern India by Hari Ram et al. showed that wheat yields after straw mulching treatment remained essentially the same as those of maize, although wheat water use efficiency was significantly higher than that of maize [34], in the sense that the increase in water use efficiency through ground mulching, a conservation tillage measure, was a feedback mechanism to the state of subsurface leakage, compared to the blank treatment [35]. Agata Novara et al. analyzed the soil water status of Mediterranean ecosystems from a soil perspective, and the analysis showed that ground mulch measures were helpful for the quality of products in both vineyards and olive groves in the system [36]. Wu et al. showed that multi-season continuous straw mulching had a yield-increasing effect on dry-season crops (wheat, oilseed rape, etc.). However, its unreasonable operation may still increase the hydraulic conductivity of the soil layer [37]. In general, mulch measures are functionally complementary and can compensate for the shortcomings of a certain type. “Natural + synthetic” mulching is reasonable in terms of the rules of change and leads to a virtuous cycle in the farm ecosystem. Therefore, the optimal combination technique is also very important in agricultural selection and decision making.

(2) Characteristics of soil mulching

There are differences in the degree of soil development in soil erosion areas around the world, and the actual interception process is affected by the external environment, topographic location, soil properties, etc. Comparing different interception measures, land with organic mulch has the most obvious interception effect.

The role of soil mulching in improving soil’s physical properties and interception of water in cultivated land has been proved by a lot of practice [38,39]. First, with the increase in organic coverage, the contents of soil organic carbon, mineral nitrogen, available potassium and exchangeable potassium tend to increase [40–42], which can better promote soil development. The improvement of the soil moisture environment is another important aspect of organic mulching to improve the soil environment. Organic mulch can not only provide soil with a buffer from high and low temperatures but also enhance soil water-holding capacity by improving soil bulk density, porosity and aggregate stability and stabilize soil moisture status [43–46]. It has been found that, under different water stresses, the effect was most obvious under moderate water stress [47]. Therefore, by studying the interception law of soil mulching in soil leakage, it can be reasonably used in areas with soil leakage characteristics, which is essential to provide interception services.

(3) Soil infiltration performance and types of soil mulching

On land (aboveground) where soil erosion occurs, the most important factors affecting soil infiltration performance are soil total porosity and non-capillary pores [48]. The differences in soil permeability coefficients are mainly caused by differences in soil moisture content, soil porosity and soil bulk density [24]. Since soil mulching, the “biological cushion flow” also has the function of water transport, it participates in the interception process and directly interferes with the hydrological process and water storage capacity of the soil layer [49,50]. This is mainly reflected in the interception of rainfall in the vertical direction and the blocking of water flow in the horizontal direction. First, the choice of mulching type is fundamental, since it drives the application rate, cost and effectiveness of mulching. There is a correlation between different soil covers and slope water infiltration rates [51]. Second, the amount of mulching also directly affects soil moisture evaporation, soil moisture infiltration and soil moisture runoff status [52]. The effects of different amounts of mulching on soil properties are different. Soil evaporation decreases with an increase in the mulching amount, and soil infiltration increases with an increase in the mulching amount. In general, an appropriate amount of soil mulching can reduce surface runoff and increase soil available water content [53]. Third, different tillage methods or
mixed mulching forms have different damage levels to structures such as soil aggregates in the plough layer [54,55], which in turn disturb the degree of soil leakage, resulting in unequal soil conservation benefits.

With the improvement in the level of research, a large number of studies have reported discussions of soil mulching. In the process of water retention and improvement of soil physical and chemical properties, corn straw, biochar, plant litter and plastic film mulches have more comprehensive advantages [56,57]. Researchers emphasized the service relationship of mulching measures with ecological restoration, highlighting the importance of ground mulching measures to reduce surface water leakage. However, differences in the researchers’ choice of regions quickly led to unstable results, with most studies at the descriptive stage. Similar studies can be extended to other karst regions. The results are yet to be verified.

(4) Rainfall infiltration water and karst soil mulching

On land (underground) where soil erosion occurs, experts have summarized the characteristics of and changes in infiltrated water at different depths by comparing the differences in soil properties of various layers in the karst area, pointing out that rainfall infiltration water is a key issue in the control of soil leakage. If the duration of continuous rainfall is long enough, the stable infiltration rate and total infiltration rate of homogeneous soil are independent of the rainfall intensity, but the instantaneous infiltration rate is greatly affected by the rainfall intensity and rainfall time [58]. Destruction of the vegetation cover on the surface changes the soil structure and reduces the permeability [59,60]; rainfall activity increases soil erosion above ground; the hydrochemistry of surface water, soil water and groundwater changes accordingly, and nutrients are lost with the water [61]. With the passage of time, after precipitation falls to the surface and infiltrates into the ground, the chemical characteristics of the water change significantly, and its pH value and various ion concentrations will continue to increase over time. In karst areas, the intact forest and rocky mountain areas are protected by a superior covering layer [62], which reduces underground infiltration, weakens the erosion of soil by raindrops, reduces the damage of rainfall to soil aggregates in various layers and intercepts the subsurface flow in the soil of karst cultivated land, reducing the residence time of infiltrated water in the soil. Rainfall processes interact with most topsoil mulches, and although vertical seepage cannot be avoided after mulching measures, the soil infiltration performance is significantly improved [63], which can also make the coverage of the comprehensive benefits of ecological restoration more ductile and practical. Understanding the rainfall infiltration properties of soils is important for studying soil erosion, soil moisture trajectories and soil mulching interception laws [64].

3.2.2. Mechanism Research

(1) The coupling relationship between soil mulching and soil erosion control

There is a coupling relationship between mulching measures and most soil erosion events. Mulching has been shown to confer several beneficial effects. Ground cover mulching leads to changes in sand, clay and many ecological environmental conditions, which have a positive effect on the mode and effect of soil erosion control, and areas with better soil conditions tend to have stronger vegetation-carrying capacity [65]. In addition, it should be noted that the returning mulching is relatively stable and does not easily change with environmental driving factors. Different regions have different requirements for ground cover types [66,67]. When researchers build farmland ecosystems, it is even more necessary to screen out the best plan based on the local comprehensive situation, focus on the typical characteristics of each soil erosion area and clarify the weights of specific impact indicators or elements. Some studies have proved that ground mulching measures have the functions of ecological environment structure adjustment and system service and are feasible solutions for soil erosion control [68–71]. The results provide a reference for the control of soil leakage and expand the overall understanding of the two types of loss and the comparison of effects, mainly concerning the quality of soils, water (runoff water, surface
water and subsurface water), plants (edible and non-edible agricultural crops) and wildlife. The selection of different mulching types will be crucial in the study of leakage resistance and control. In general, organic covering materials such as natural litter have strong water-holding properties and are more valuable for selection or reference. These results improve the understanding of soil leakage and soil erosion processes.

(2) Important factors affecting karst soil leakage

Factors such as the erosion environment, rainfall, soil properties, ground cover and human activities have a great impact on soil leakage in karst areas. First of all, the special two-dimensional and three-dimensional erosion environment of the surface and underground is the fundamental factor that causes the form of soil erosion in karst areas to be different from other areas. Highly permeable soil layers result in a low soil water-holding capacity, providing a unique erosion environment for special soil erosion in karst areas [72,73]. Second, rainfall is the main driving force of soil leakage in karst areas [74], and its water infiltration is positively correlated with the increase in rainfall intensity. Third, the comprehensive characteristics of the soil itself are an important cause of underground leakage. For example, when the same quality and amount of straw are mulched, the water permeability of sandy soil is better than that of loam soil, but the anti-erosion effect is inferior to that of loam soil [27]. Therefore, it must be clarified that the soil macropore morphology is the key factor to control soil leakage, and artificial laying and adding of mulching can first collect macropore priority flow [75], ease the internal structure of the soil and play a role in the interception of leakage in the underground hydrology process. Fourth, the compact layer of the mulching affects the flow process in the subsurface flow [76,77]. Finally, an important driving force affecting karst soil leakage is human factors. The high population density and the prominent contradiction between humans and land have resulted in the destruction of surface vegetation. In production practice, the negative impact of human activities is relatively large. The monitoring results of the lost modulus in different parts of a micro-geomorphic unit indicated that the 137Cs area activity and loss ratio were highly disturbed by unreasonable human cultivation [78,79].

Some studies can confirm that, in addition to excluding uncontrollable components, such as rainfall intensity and seasonal differences, laying mulches can buffer soil erosion changes; moreover, when the farmland ecosystem faces disturbances, it can maintain its service function and can achieve the expected goals of increasing crop yield or increasing the added value of agricultural products. This plays an important role in achieving the goal of soil conservation in karst areas and improving economic benefits.

(3) Carbon storage and soil storage capacity

During the water cycle in karst areas, water brings the soil covering the rock surface into the “binary” double-layer hydrological network [80], which is the environmental medium that causes soil erosion and leakage. After the hydraulic connection between the surface water and groundwater system, it is difficult for precipitation to stay on the surface for a long time, the hydrological process changes rapidly and soil erosion and leakage increase. By analyzing rainfall characteristics, surface vegetation and its impact on mulching, and by linking the characteristics of mulching itself, rainfall intensity and types of vegetation near the surface, the mechanism of action of karst soil can be elucidated. First of all, the spatial relationship usually produced by leakage must also be accompanied by a “chain effect” of occurrence. Carbon storage is a sensitive indicator of the effective yield of land crops, and underground leakage clearly indicates that soil CO2 leakage has occurred. The soil microbial community also reflects different degrees of environmental adaptability to the soil CO2 concentration [81], and there are also differences between different colonies. Therefore, other losses caused by karst soil loss also need to be paid attention.

However, the increase in water use efficiency is a feedback mechanism to the state of subsurface leakage. Researchers found that, although microbial activity began to increase after autumn sowing and mulching, it reduced runoff and precipitation infiltration rates,
which are very effective in reducing the soil erosion risk [30]. Secondly, karst underground soil layers vary in soil structure, water infiltration and storage capacity with different surface vegetation types, and studies have shown that most precipitation penetrates through the soil mulching, and that the mulching with crops has a higher water storage capacity in the topsoil [82]. This measure also exhibits strong carbon sequestration potential [35,83]. When individuals or similar species are considered, differences are also shown at the functional scale, and corresponding land adaptation assessments are required [84–86].

3.2.3. Technology Research

(1) Soil erosion engineering technology, biotechnology and farming technology

Engineering technology, biotechnology and farming technology are the three main technical measures for global soil conservation and are important ways to promote soil erosion control and achieve sustainable agricultural development. The choice of technology requires due consideration of climate, topography, soil variability and the impact of management on eroded lands. Common engineering techniques include slope terraces, check dams and fish scale pits, which use the method of changing small terrain to prevent soil erosion on slopes. Common biotechnologies include planting slope stabilization, afforestation and grass cultivation, and closing mountains for afforestation. By increasing vegetation coverage and reducing soil erosion, the Loess Plateau of China adopts and demonstrates biotechnologies for building soil erosion-resistant plant communities. Common farming techniques include contour tillage, contour belt intercropping, furrow and ridge tillage, and no-tillage. These techniques lead to an improvement in soil infiltration efficiency, water-holding capacity and erosion resistance, thereby improving the soil, and farming techniques have been promoted and used in vast arable land.

(2) Mulching technology complementary to karst vegetation

The soil mulching interception process is affected by surface vegetation [87], and there are species differences. Superior vegetation types have a complementary effect on the interception function of soil mulching [88,89], and plant types with a high water absorption rate in the vertical spatial structure are more conducive to improving soil quality and promoting ecological restoration. The water storage performance of aboveground vegetation also affects soil hydrological properties. Based on the Green–Ampt model, researchers have shown that the soil hydraulic conductivity increases with plant growth [90]. This infiltration promotion reduces the impact of rainfall on the surface by increasing the leaf area index and eases the surface hardness, but it is still necessary to avoid the negative impact of excessive soil infiltration promotion, and the infiltration-promoting water can be retained from different perspectives such as landscape configuration, organic coverage and spatial structure. When individual vegetation types or similar species are considered, differences are also shown on the functional scale, with deep-rooted types being more functional in terms of the comprehensive benefits of high yield, soil water retention and improved soil physicochemical properties [84]. Therefore, the leakage resistance control model in karst areas first selects typical local plants and gives full play to the advantages of crops. For example, the water retention rate of a mixed forest of Zanthoxylum bungeanum, paper mulberry and dragon fruit, under the same quality and an equal amount of vegetation cover, was higher than that of other plants [91].

At the same time, reasonable soil mulching measures or patterns have a complementary relationship with surface plants. In the process of supplementing soil organic matter with aboveground plant litter, it can not only achieve rainwater control through ground mulching but also restore the internal structure of the soil to the maximum extent [92]; it also makes full use of rainwater to conserve water sources in the field and assists the promotion of mulching measures in farmland planting. This move helps maximize the role of soil mulching in karst areas and also improves the service capacity.

(3) Covering technology corresponding to karst terrain and slope position
In recent years, models for predicting runoff and soil seepage under various rock inclination angles have been established in karst areas [93]. By adopting different models of mulching treatment technology for different terrains and slope positions, it is shown that scientific and reasonable resistance and control technology can slow down the rate of soil erosion, leakage and interception of water in different terrains. The soil control measures used in other areas in karst areas have achieved certain results on surface soil erosion, but there is no practical solution for underground soil leakage. Most importantly, measures to control underground leakage should be taken on the basis of reducing human-made damage to the ecological environment, focusing on prevention rather than a cure [94]. Furthermore, taking into account the topography and landform characteristics of karst rocky desertification areas, it is one of the current priorities to carry out soil control work according to local conditions. The steep slopes in karst rocky desertification areas are heavily reclaimed and are the main areas where rocky desertification occurs. Traditional agricultural utilization and farming methods should be changed to avoid ploughing, migration or soil disturbance as much as possible [95].

3.2.4. Technical Demonstration

The form of soil mulching and the adaptability of vegetation are very important in the karst soil development stage and the soil leakage response stage. In the current relevant demonstration studies, in order to facilitate comparison and reduce deviations, the soil mulching mostly uses dead ground coverage that does not have living phenomena, and the vegetation uses more mature typical plants in production practice. For example, in dry-land orchards, “Red Star” apples were selected as typical test plants to reflect differential responses to different soil mulches [96]. However, some vegetation species have extreme characteristics that are difficult to adjust in nature, which may affect the process of soil mulching interception and interfere with the research results [97,98]. Affected by the characteristics of the karst soil structure, there are differences in nutrient conservation, and the application scope of technology demonstration is small. At present, in the karst areas of southern China, the Huajiang model with Chinese prickly ash, dragon fruit and honeysuckle as industries and the Huajiang model with mulberry, sericulture and edible mushroom cultivation as industries have been established.

The development conditions of karst soil in different regions are different, and the corresponding leakage conditions are different. The land has significant karst features due to erosion (chemical dissolution, gravitational erosion and water erosion), and the vertical erosion of the regional seepage water leads to the enlargement of soil pores, disturbing or aggravating the damage to the karst soil. Coupled with the spatial heterogeneity of the karst underground itself, the influencing factors are complex, which makes it difficult for some soil mulches to be promoted in the field, which is not conducive to the adjustment and restoration of the regional ecological structure. At present, there is a lack of methods to maintain the stability of karst underground leakage. The differences can be analyzed according to the changes in leakage. Additionally, there are obvious differences in the performance and applicability of different soil mulching materials in different regions, so it is necessary to summarize the adaptability relationship between mulching, time and space, select a reasonable “mulching + crop” matching mode, propose the best solution and promote it according to local conditions. Regional resistance control technology should take into account the actual local conditions and consequences, directly expand the technology promotion and indirectly strengthen the soil improvement in karst areas [99,100]. Soil mulching is relatively stable and varies little with environmental drivers. Moreover, restraining and controlling technology according to local conditions will help to promote the improvement in crop yield. It is of great significance to promote the sustainable development of the ecological environment to carry out research and technical demonstration of soil leakage patterns under soil mulching.
4. Discussion

This paper presents a discussion and analysis on the basis of many related research results. This paper systematically reviewed the research progress of soil mulching interception and soil erosion prevention and classified 176 studies in terms of annual quantity, content and country. The results show the similarities and reference of soil erosion control and karst soil leakage control, focusing on the landmark achievements of theoretical research, mechanism research, technology research and technology demonstration.

In the following content, we will explore these similarities and references and summarize five key scientific questions to be answered.

(1) Aiming at the problems of karst soil mulching diversity, unstable water closure methods, etc.:

Different soil mulches have different structural characteristics and different effects on underground leakage and runoff. Soil mulching has the function of adjusting the environmental structure of the soil layer in the area [101] and is a feasible solution for alleviating karst underground leakage. The research shows that by setting up a variety of mulching species, the overall understanding and effect comparison between different soil mulching species can be expanded, and most of the soil mulching species provide a theoretical basis for intercepting soil moisture and improving soil quality. Tables 3 and 4 reflect this comparison. Figure 7 shows the specific soil mulching techniques.

Table 3. Average (avg) and standard deviation (SD) values of some soil physical properties computed for each mulch. Here, the effective use of soil mulching in the karst region of southern China is shown, reporting the following types of soil conservation techniques: (a) control (C), (b) superabsorbent polymer + cobblestone mulching (SAP+ CM), (c) grass mulching (GM), (d) inner shell of walnut mulching (WM), (e) straw mulching (SM). Direct comparisons were made for each mulching during the rainy season in 2022. The variables compared were the following soil moisture constants: (a) mulch application ratio (i.e., specific value) (Ar), (b) soil bulk density (Sbd), (c) total porosity (Tp), (d) saturated hydraulic conductivity (Shc), (e) capillary moisture capacity (Cmc), (f) field capacity (Fc), (g) sand, (h) silt, (i) clay. The method used to obtain these data is the ring knife method. The depth of the soil layer to obtain these data is 0–180 cm.

<table>
<thead>
<tr>
<th>Area</th>
<th>Type</th>
<th>Ar (kg·m⁻²)</th>
<th>Sbd (g·cm⁻³)</th>
<th>Tp (%)</th>
<th>Shc (%)</th>
<th>Cmc (%)</th>
<th>Fc (%)</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>1</td>
<td>1.39 ± 0.11</td>
<td>47.96 ± 3.50</td>
<td>20.68 ± 20.27</td>
<td>33.35 ± 3.84</td>
<td>33.51 ± 4.01</td>
<td>43.29 ± 5.00</td>
<td>7.15 ± 1.29</td>
<td></td>
</tr>
<tr>
<td>SAP + CM</td>
<td>1</td>
<td>1.34 ± 0.06</td>
<td>49.84 ± 2.01</td>
<td>14.51 ± 11.52</td>
<td>34.86 ± 2.84</td>
<td>35.06 ± 2.92</td>
<td>51.93 ± 10.74</td>
<td>42.21 ± 10.04</td>
<td>5.86 ± 0.90</td>
</tr>
<tr>
<td>GM</td>
<td>1</td>
<td>1.35 ± 0.05</td>
<td>49.34 ± 1.81</td>
<td>17.47 ± 11.39</td>
<td>35.01 ± 2.79</td>
<td>35.05 ± 2.70</td>
<td>48.46 ± 2.43</td>
<td>44.96 ± 1.26</td>
<td>6.98 ± 1.55</td>
</tr>
<tr>
<td>WM</td>
<td>1</td>
<td>1.34 ± 0.06</td>
<td>49.71 ± 1.92</td>
<td>19.76 ± 17.42</td>
<td>33.69 ± 2.64</td>
<td>33.81 ± 2.60</td>
<td>44.67 ± 5.03</td>
<td>47.05 ± 5.03</td>
<td>8.28 ± 0.02</td>
</tr>
<tr>
<td>SM</td>
<td>1</td>
<td>1.38 ± 0.06</td>
<td>48.41 ± 2.07</td>
<td>14.93 ± 8.18</td>
<td>33.97 ± 2.04</td>
<td>34.01 ± 1.92</td>
<td>40.63 ± 1.69</td>
<td>50.28 ± 1.69</td>
<td>9.09 ± 1.11</td>
</tr>
</tbody>
</table>

* The environment used in the above table is I: Bijie Salaxi research area in Guizhou, China. Here, the karst area accounts for 74.25% of the total area [102]. Terrain element I: plateau mountain. The study area has a subtropical humid monsoon climate. The soil type of the karst sample plots is mainly yellow earth. The main vegetation is wormwood, clover and poplar.
Table 4. Average (avg) and standard deviation (SD) values of some soil chemical properties computed for each mulch. Here, the effective use of soil mulching in the karst region of southern China is shown, reporting the following types of soil conservation techniques: (a) control (C), (b) super-absorbent polymer + cobblestone mulching (SAP+ CM), (c) grass mulching (GM), (d) straw mulching (SM). Direct comparisons were made for each mulching during the rainy season in 2022. The variables compared were the following soil nutrient: (a) mulch application ratio (i.e., specific value) (Ar), (b) soil organic matter (SOM), (c) total nitrogen (TN), (d) total phosphorus (TP), (e) total potassium (TK), (f) available nitrogen (AN), (g) available phosphorus (AP), (h) available potassium (AK). The methods used to obtain these data are experiments and instrument detection. The depth of the soil layer to obtain these data is 0–180 cm.

<table>
<thead>
<tr>
<th>Area</th>
<th>Type</th>
<th>Ar (kg·m⁻²)</th>
<th>SOM (g·kg⁻¹)</th>
<th>TN (g·kg⁻¹)</th>
<th>TP (g·kg⁻¹)</th>
<th>TK (g·kg⁻¹)</th>
<th>AN (mg·kg⁻¹)</th>
<th>AP (mg·kg⁻¹)</th>
<th>AK (mg·kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>1</td>
<td>0.77 ± 0.12</td>
<td>0.56 ± 0.03</td>
<td>12.78 ± 0.19</td>
<td>61.66 ± 3.24</td>
<td>11.94 ± 1.32</td>
<td>161.92 ± 4.87</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAP + CM</td>
<td>16.02 ± 2.80</td>
<td>1.06 ± 0.11</td>
<td>0.68 ± 0.09</td>
<td>13.43 ± 1.14</td>
<td>82.69 ± 2.87</td>
<td>16.62 ± 0.38</td>
<td>288.05 ± 2.52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GM</td>
<td>17.16 ± 0.81</td>
<td>1.19 ± 0.07</td>
<td>0.70 ± 0.04</td>
<td>14.67 ± 0.88</td>
<td>107.85 ± 3.19</td>
<td>12.65 ± 0.54</td>
<td>268.87 ± 3.38</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SM</td>
<td>15.61 ± 1.98</td>
<td>1.05 ± 0.10</td>
<td>0.66 ± 0.15</td>
<td>12.15 ± 0.92</td>
<td>81.33 ± 2.96</td>
<td>13.77 ± 0.71</td>
<td>297.80 ± 3.16</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* The environment used in the above table is II: Huajiang research area in Guizhou, China. Here, the karst area accounts for 87.92% of the total area [102]. Terrain element II: plateau canyon. The study area has a subtropical humid monsoon climate. The soil type of the karst sample plots is mainly yellow earth, krasnozem and lateritic red soil. The main vegetation is honeysuckle, sticktight and ageratum.

Figure 7. Five soil conservation techniques (mulching) used in karst environments in southern China. In this figure, (a) control (C), (b) super-absorbent polymer + cobblestone mulching (SAP+ CM), (c) grass mulching (GM), (d) inner shell of walnut mulching (WM), (e) straw mulching (SM). (f) is the super-absorbent polymer (SAP) used in technique (b), which is not presented as a separate soil conservation technology. They all correspond to nature-based mulching, except for the super-absorbent polymer in item (b)/(f), which is an organic material. It needs to be pointed out that this organic material has no destructive effect on the environment. These tests were conducted in 2022.

However, at present, in order to maintain the stability of farmland ecosystems in some areas, the types of soil mulching with a poor comprehensive response are directly avoided. For ground mulching with high satisfaction, quantification of indicators, such as the change in the thickness of the mulching, is carried out, which brings limitations to the
selection of soil mulching. Simultaneously, there are disputes over the optimal interception effect [103], karst ground mulching research and its extension methods are seldom evaluated [104] and there are still problems of interference from external conditions [52]. Additionally, due to the particularity of the karst underground structure [72], the research on the relationship between soil mulching and karst soil leakage is relatively weak. There are complexities in the form of karst innovative soil mulching interception. The selection of mulching materials is a matter that requires long-term planning. Thence, choosing different soil mulches for laying, comparison and analysis and then establishing the corresponding knowledge of the soil leakage structure can deepen the mechanism analysis of karst areas, as well as the structural characteristics and interception characteristics of soil mulching, and expand the overall understanding. In general, organic mulch materials, such as natural foliage, have strong water-holding properties and are more selective or referential in karst mixed agroforestry bureaus.

(2) Aiming at the problems of a few studies on the karst soil mulching interception process, and the combination of soil mulching and karst soil leakage is not deep enough: The underground structure of karst areas has a certain complexity and heterogeneity, which causes great uncertainty for practical research. Additionally, most of the existing studies on karst erosion, soil mulching to intercept and the relationship with soil leakage focus on model construction, erosion processes, simulation experiments and analysis, while the technical demonstration of subsurface leakage is rarely focused on. Interception control methods are also less studied, and their cross-sectional studies are not comprehensive. These require a lot of research in the exploration stage. Due to the different rainfall characteristics and the degree of development of sloping farmland, the amount of soil leakage will also vary greatly, and there is considerable controversy over the form of soil leakage at different research scales [105–107]. Existing research focuses on the influencing factors of soil mulching on the mechanism of soil leakage, but the results are few, and the research is relatively weak and lacks systematicness. Future research directions can pay more attention to the impact of soil mulching on soil leakage in karst areas. Through the in-depth understanding of the soil leakage mechanism of each link and quantitative research, the conditions and reasons that restrict the main leakage factors can be analyzed, which is more conducive to scientific understanding of soil mulching interception characteristics and driving mechanisms. Future research should also consider the use of information technology as well, such as long-term positioning, testing and updating of the analysis standard of underground leakage strength. This is very important for the in-depth understanding of soil structure characteristics in karst areas.

(3) Aiming at the problems of scattered karst land and lack of equipment and methods:

Due to the influence of slope, lithology and other factors [28,108,109], karst areas are scattered, individual areas are small, and the vertical spatial structure gap is large. The comparative study and integrated study of soil mulching are restricted by technical means, and the investigation is difficult. Through in situ monitoring, laboratory analysis and other experiments, it is found that surface runoff is positively correlated with rainfall intensity and slope, while underground runoff is negatively correlated with slope and positively correlated with underground porosity. Meanwhile, the surface vegetation coverage also greatly affects the surface and groundwater hydrological processes [110,111]. Presently, there is a lack of soil mulching monitoring equipment and methods, and a complete system has not yet been established. Expanding the construction of the indicator system can only solve some problems to a certain extent. Therefore, it is necessary to expand the construction of the index system, innovate equipment and methods and systematically reveal the soil leakage mechanism of karst slope farmland.

(4) Aiming at the problems of unstable factors such as extreme weather and soil damage in the process of karst soil mulching interception:

The soil environment and its dynamic balance are important bases for monitoring the interception process. Although soil mulching can moderate the leakage process, there
are differences in the water content and migration process at different soil depths, and the soil dynamic balance is difficult to maintain on a time scale. As a result, it is susceptible to climate change and other unreasonable problems, such as large data fluctuations and natural disaster damage to instruments. As another explanation, changes in rainfall types and land properties make soil hydrological processes and water retention functions different. The degree of leakage in karst areas gradually increases with the vertical depth \([112]\), and the aggregation function of the internal environment declines. At present, there is a lack of soil mulching protection and soil dynamic balance methods, and it is still necessary to collect data objectively and quantitatively and focus on analysis of emergencies. The introduction of soil mulching must be based on site-specific land management and on different environmental conditions, especially under climate change conditions.

(5) Aiming at the problem that soil leakage in karst areas is mainly controlled by the amount of surface runoff and the mechanism of runoff:

The occurrence conditions of leakage in karst areas are closely related to rainfall. Generally, when rainfall exceeds 60 mm, it may lead to a large amount of surface runoff and soil loss on karst slopes. However, the combination of a low rainfall intensity and a long rainfall duration can also produce soil leakage of a general magnitude \([113]\). Moreover, the soil sample collection work in karst areas is divided into dry-season and rainy-season cycles. In contrast, the work content in the rainy season is cumbersome, so the work cycle in the rainy season should be extended in a timely manner. However, real-time monitoring of the rainfall distribution in other time dimensions is still required, and an analysis of the soil mulching interception process on a yearly basis is also required.

5. Conclusions and Future Research

5.1. Conclusions

In this paper, 176 articles were analyzed and classified through literature searches in two databases, WoS and CNKI. After that, we summarized the main progress and landmark achievements in the field of soil mulching interception and soil erosion prevention and control on a global scale. The key points are as follows:

(a) Theoretical research: There is a difference in the nature of the soil mulching; there are differences in the interception characteristics of soil mulching, mainly in physical and chemical properties; the infiltration characteristics under soil mulching need to analyze the soil structure, mulching amount, mulching form and other indicators; the infiltration performance of karst soil is affected by the rainfall intensity. The results can be used to monitor the changes in soil leakage indicators, understand the laws of karst soil leakage links and combine environmental factors to optimize mulching materials and can summarize the configuration mode that is beneficial to the control of soil leakage in karst areas.

(b) Mechanism research: There is a coupling relationship between soil erosion and mulching measures, the main influencing factors of soil leakage in karst areas; carbon storage and soil storage capacity are feedback mechanisms to the state of underground leakage. The results can analyze the differences according to the leakage changes, summarize the adaptability relationship between soil mulching and spacetime and then propose the best solution and prevention plan.

(c) Technology research: The main techniques currently used in soil erosion control are relatively traditional, including engineering, biology and farming techniques; differences in vegetation types lead to small-scale differences in mulching technology of soil leakage control; differences in topography and slope position lead to large-scale differences in mulching technology of soil leakage control. The results can provide technical support for the development of karst industries to reduce soil fragility, while the cost of soil mulching is low and the resources are used sustainably, which is helpful to improve the level of ecological governance.
(d) Technology demonstration: The results can provide suggestions for the development models of industry in karst areas. This will help to improve the economic benefits of karst areas. We discussed five key scientific issues that need to be solved, combined with the current mulching measures, and looked forward to the methods of karst soil leakage resistance and control, so as to point out the future research direction and provide insights into karst soil leakage resistance and control.

To sum up, the main findings of this review are as follows: first, the interception characteristics of soil mulching can produce an effective blockage for soil leakage in karst areas; second, based on the global classification, compared to synthetic materials, natural materials have received more attention.

5.2. Deficiencies and Future Research

Although different search methods and screening strategies to select the literature were used for this review, many uncontrollable reasons lead to the fact that there are still omissions, limiting the scope of the literature selection. First, only two core databases (WoS and CNKI) were used, while other databases such as Scopus also publish literature related to the topics of this study; second, it is difficult to guarantee that the results from two databases will not be biased; finally, the search strings used in this paper do not guarantee sufficient coverage of all relevant literature on the topic of this study.

At present, more and more people have realized that soil mulching measures have strong practicality. However, there is an obvious lack of innovation in resources and environmental research. Additionally, there is still the problem of crop yield reduction caused by some exogenous conditions. Future research can use drip tracking, model simulation experiments and other methods to fit the infiltration process and record the final data results. Then, the structural relationship of the soil layer can be obtained according to the karst leakage change, and the best solution and prevention plan can be proposed after the trade-off analysis. Second, future research should also consider the usage of information technology such as long-term positioning, experiments and updating of analysis criteria for the subsurface leakage intensity, for which we need to promote further adjustment and modification of the construction system in order to establish a coupled model of soil erosion and underground loss in karst areas.

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References


