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Comprehensive Analysis of Ecological Restoration Technologies in Typical Ecologically Vulnerable Regions around the World

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Abstract: Ecosystem degradation is a key issue facing the world. Rapid economic development has been achieved at the cost of degradation and environmental pollution, which has affected human well-being, particularly in fragile ecosystems. To achieve the United Nations sustainable development goals, it is essential to develop technologies to control degradation and restore ecosystems. However, a comprehensive assessment of the different types of degradation, of the methods used in different regions, and of the differences between regions has not been carried out. In this study, we examined databases of international organizations, interviewed experts to evaluate existing methods based on five dimensions, identified restoration technologies (hereinafter referred to as RTs) suitable for different types of degradation, and summarized the restoration effectiveness in different regions. We found 101 RTs around the world and found that the same technology can be applied in different regions. The RTs were dominated by engineering and biological RTs, accounting for 19.2–26.7% and 33.4–34.7% of the total, respectively. 45, 30, and 26 RTs were suitable for controlling soil erosion, sandy desertification, and degraded ecosystem, respectively. The average evaluation index of RTs for controlling these degradation problems are 0.81, 0.78, and 0.73, respectively meaning RTs used to fight soil erosion are more effective. The potential to transfer a technology to other regions and the readiness of the technologies were low for degraded ecosystems, and the ease of use was high for sandy desertification RTs. Although a given technology could be applied to different regions or degradation types, results varied. Our study will help ecosystem managers to deal with specific degradation issues, phases, and severities, and will support the transfer of RTs among regions.

Keywords: ecologically vulnerable region; restoration technology; technical evaluation; effect analysis; ecological restoration

1. Introduction

The United Nations Decade on Ecosystem Restoration is committed to increasing the restoration of degraded and damaged ecosystems from 2021 to 2030. There are five goals connected with land degradation of the Sustainable Development Goals (SDGs), and up to 25% of all land worldwide is seriously degraded, 36% is slightly or moderately degraded but in stable condition, while only 10% is improving [1]. Therefore, in the United Nations 2030 agenda, land degradation is listed as a global environmental challenge that must be addressed by the international community in conjunction with climate change and biodiversity loss [2].

Intensive human activities and climate change have caused approximately 60% of global ecosystems to become degraded or the activities in these ecosystems to be deemed unsustainable, The land area prone to desertification has been estimated to be 57–65% of the total land area of dryland ecosystems worldwide [3–5], and the total area affected by soil erosion, desertification, and karst desertification now constitutes at least 25% of the global land area [6], among which, areas that are affected by soil erosion and sandy desertification are 2052.15×10^4 km^2 and 2474.08×10^4 km^2, respectively, occupying 43.88% and 52.89% of degraded land, respectively [7]. In some ecological sensitive countries like the US, China, and India, the land and ecosystem degradation situation is severe, in the United States and Europe alone, poor land management practices cause an estimated 970 million tons of soil loss due to erosion each year [8]. The introduction of agriculture in marginal lands traditionally used for grazing sheep and cattle has caused sandification in large areas of northern China, especially Inner Mongolia and western Xinjiang [8]. India hosts 18% of the world's population and 15% of its livestock but has only 2.4% of the world's land area, high population density has been a major pressure causing land degradation since the 1700s [8]. For instance, 80% of the area is severely impacted by desertification in southern Iran [9]. Thus, Ecological degradation such as soil erosion, sandy desertification, and degraded ecosystem are threats to SDGs achievement and sustainable development, especially in the world's arid and semi-arid areas [10,11]. The extent of anthropogenic changes and damage makes ecosystem restoration an essential part of humanity's survival strategy [12,13].

Due to its fragile natural condition, intensive human activities can more easily cause degradation such as soil erosion, sandy desertification, and ecosystems degradation in ecologically fragile regions, which have exacerbated the severity of any naturally occurring degradation. Consequently, various countries around the world have adopted ecological RTs in order to restore ecologically fragile areas that have been seriously degraded and cannot be restored to their original state by themselves. For example, since the "green wall" of Africa was launched in 2007, more than 11.4×10^6 trees have been planted in Senegal and 2.5×10^4 hm^2 of degraded land has been restored. The three north shelterbelt projects and the Beijing–Tianjin sandstorm source control project have been implemented in China Since the 1950s. Currently, European and American RTs mainly focuses on the development of new materials, such as photovoltaic sand control, new soil improver. What's more, Europe, North America and other regions pay more and more attention to the management RTs, such as natural restoration, grazing exclosures [7,14,15]. These RTs have achieved remarkable results in ecological restoration and have produced a significant influence in the world. However, ecological restoration managers must recognize that ecosystems are dynamic, and that restoration cannot be based on static attributes. thus, it will be necessary to assess the effectiveness of these technologies during different phases of degradation. In addition, it will be necessary to develop effective and easily measured success criteria [16].

At present, while addressing degradation issues such as soil erosion, sandy desertification, and degraded ecosystems, many researchers have investigated the technical aspects of the degradation problem such as the different forms of ecological degradation, the influencing factors, management of interventions, improvement of vegetation cover and productivity, the relationship between the technologies and climate change, and the impact of the technologies on soil quality, atmosphere, water, and biodiversity. However, there are very few studies that analyze and evaluate the efficiency of the RTs, which limits the promotion and application of the most effective RTs more widely [17].

This research aims to (1) identify the most important RTs that are used in the representative ecologically vulnerable 60 regions through various sources such as the literature review and questionnaire surveys, (2) assess the RTs using five-point Likert scales, and (3) analyze the effects of the representative RTs that have been commonly adopted in the ecologically vulnerable 20 regions. It is expected that the findings could be useful for the restoration of degraded land for the world's typical ecologically vulnerable regions.

2. Materials and Methods

In this study, we combined questionnaire-based data with a literature review to summarize and analyze RTs that are used to combat soil erosion, sandy desertification, and degraded ecosystem in ecologically fragile regions; the latter category included degraded forest, grassland, and wetland. From economic and social perspectives, the economic and sociological causes of ecological degradation, and the principle behind RTs [18], we divided the technologies into biological, engineering, agricultural, and management RTs by referring to the research of Zhen and Xie [19].

2.1. Questionnaire Survey

The questionnaire that can be found in Supplementary materials, which includes the personal information of the respondent, the description of the degradation, and the ecological RTs and their evaluations that have been implemented. In September 2017, we attended the 13th Conference of the Parties to the United Nations Convention to Combat Desertification (Ordos, Inner Mongolia), during this time, we conducted semi-structured interviews based on convenience sampling to obtain expert opinions on the application status of different globally important RTs and their assessment. The interview participants included government representatives and researchers who have been involved in work considering three types of degradation and their ecological restoration, and we obtained 105 completed questionnaires. In July 2018 and November 2020, we conducted questionnaire surveys, face-to-face interviews, and mailed questionnaires via different platforms related to ecological restoration: Global Land Programme, Global Youth Biodiversity Network, International Knowledge Centre for Engineering Sciences and Technology under the Auspices of UNESCO, and Chinese-German Center for Impact Assessment. We also interviewed individual scientists who are working on ecological restoration. We obtained 78 and 60 completed questionnaires in the two years, respectively. A total of 243 questionnaires were collected from these three surveys, of which 220 were valid, which represents an effective recovery rate of 90.53%. Among them, we obtained 112 valid questionnaires from 15 regions of China and 108 valid questionnaires from 22 other countries in Asia, 6 from Europe, 13 from Africa, 2 from North America, and 2 from Oceania.

2.2. Statistical Method

Based on SPSS statistical software, this paper adopts the T-test method to test and analyze the five dimensions of 220 questionnaires, so as to judge whether the survey results meet the statistical test standards. The *t*-test formula is as follows:

$$\mathrm{t} = \frac{\mathrm{X} - \mu}{\frac{\sigma_{\mathrm{X}}}{\sqrt{\mu}}}$$

$$\mathrm{X} = \frac{\sum_{i=1}^{n} \mathrm{X}_i}{n}$$

$$\sigma_{\mathrm{X}} = \sqrt{\frac{\sum_{i=1}^{n} (\mathrm{X}_i - \mathrm{X})^2}{n}}$$

Among them, $i = 1 \ldots n$; X represents the sample mean, μ represents the population mean, σ_{X} represents the sample standard deviation, and n represents the capacity (220 was chosen in this study).

The test results show that the p-values of the evaluation results of the five dimensions are all less than 0.01 (Table 1), indicating that the questionnaire results obtained in this paper are statistically significant and provide a basis for further analysis and discussion.

Table 1. Results of *t* test for questionnaire survey.

□	Test Value = 3					
	t	df	Sig.(2-Tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Potential to transfer	17.89	219	0.00**	1.35	1.15	1.55
Easy to use	5.401	219	0.00**	0.43	0.22	0.64
Readiness	15.22	219	0.00**	1.10	0.91	1.29
Effectiveness	17.05	219	0.00**	1.12	0.95	1.30
Suitability	20.96	219	0.00**	1.42	1.24	1.60

2.3. Assessment Method

In the questionnaire, we chose five dimensions for the evaluation of RTs: ease to use, readiness, effectiveness, suitability, and potential to transfer the technology to other regions by referring to the research of Hu and Zhen [20,21] (Table 2). Ease to use represents the skill level required to use RTs successfully. Readiness refers to the integrity and stability level, development and application level, or maturity level. Effectiveness refers to the ecological, economic, and social effects of using these RTs. Suitability refers to the degree of consistency between the RTs and regional development goals, natural conditions, policies, and needs. Potential to transfer refers to the possibility of transferring these RTs for use in other regions. These five dimensions can more comprehensively reflect the quality of RTs.

Table 2. The scoring standard for the ecological RTs.

Dimension \ Score	5	4	3	2	1
Easy to use	Very easy	Easy	Moderate	Difficult	Very difficult
Readiness	Very mature	Mature	Moderate	Immature	Very immature
Effectiveness	Very high	High	Moderate	Low	Very low
Suitability	Very good	Good	Moderate	Low	Very low
Potential to transfer	Very high	High	Moderate	Low	Very low

We used a five-point Likert scale to score the replies, with values ranging from 1 to 5. To further analyze the score for each RTs and eliminate neutral ratings, we reclassified the mean values into four grades: 1.0 to 2.5 was low, 2.5 to 3.5 was relatively low, 3.5 to 4.5 was relatively high, and 4.5 to 5.0 was high.

2.4. Calculation of Evaluation Index

We chose an evaluation index to reflect the restoration effect of each RTs. The evaluation index quantitatively reflects RTs and restoration effects for different areas and different types of degradation. Our index represents the proximity between a technology's score and a perfect score under ideal conditions. The calculation formula is as follows:

$$EI = (\omega_P S_P + \omega_U S_U + \omega_R S_R + \omega_E S_E + \omega_S S_S) \Big/ \sum_i \omega_j S_j$$

where EI is the evaluation index for RTs, which ranges between 0 and 1, with $EI \geq 0.9$ rated as high, $0.65 < EI < 0.9$ rated as medium, and $EI \leq 0.65$ rated as low. S_P, S_R, S_M, S_E, and S_S represent the technical evaluation scores for the potential to transfer the technology to other regions, ease of use, readiness, effectiveness, and suitability, respectively; the ω parameters represent the corresponding weight for $j = 5$ dimensions. Under ideal conditions, the weight totals 5 and the score totals 5. We chose the equal weight method and assigned a value of 1 to all weights.

2.5. Analysis of the Effects of Representative RTs

Based on the results of the evaluation of RTs, we selected 11 RTs that appeared in at least three regions and that had high evaluation index values so that we could compare their effects clearly.

We identified and analyzed the quantitative effects of the above 11 RTs by reviewing the research literature (Table 3). We performed this search in several online databases: the Web of Science (https://www.webofknowledge.com,10/10/2021), Google Scholar (https://scholar.google.com/,10/10/2021), and Scopus (https://www.scopus.com/home.uri, 10/10/2021). We used the keywords and criteria in Table 3. Altogether, we reviewed and analyzed 24 papers from 20 countries or regions with issues of soil erosion, desertification, or degraded ecosystem to compare their effects. The papers retrieved by our literature search are provided in the Supplemental Text.

Table 3. The keywords and criteria for literature search.

Search Criteria 1: Keywords of RTs	Search Results: Countries Name	Search Criteria 2: Effects from Applying RTs in Corresponding Countries
Afforestation/grassland restoration	Slovenia China Senegal	forest cover soil water content Productivity
Plant breeding	Kazakhstan Spain china	vegetation coverage soil water the net benefit
Check dams	China Israel Iran	amounts of interception of sediment vegetation coverage soil water amounts of collected rainfall
Grain for Green	China	soil organic carbon content social benefit (Farmers' income)
Stereo-agriculture	Japan	N and P contents in water crop yield
Fallow/no tillage/ minimum tillage	Central Asia India	crop yield soil organic carbon content
Grazing exclosures	Ukrainian and Kazakhstan China	Biomass soil organic matter and N P content
Natural restoration	China	soil aggregates soil organic matter
Forest improvement	China Kazakhstan	soil's cation exchange capacity and enzyme activity soil organic matter
Agro-forestry	China Zambia	amounts of runoff and sediment yield soil organic matter and N P content grain output
Water-saving Irrigation	China Central Asia	vegetation coverage soil water storage and water-use efficiency crop yield

3. Results

3.1. Analysis of RTs for Different Regions

According to questionnaires, we revealed a total of 101 RTs that have been applied in typical ecologically fragile regions around the world (Figure 1), these include 45 soil erosion RTs (for example forest improvement, terraced slopes, agroforestry, grazing exclosure), 30 sandy desertification RTs (for example protective/buffer forests, straw checkerboards, water-saving irrigation, confined/semi-confined farming), 26 degraded ecosystem RTs (for example aerial seeding, storage reservoirs, contour strip farming, natural restoration). Of this total, 52 were used in Asia, 14 in Africa, 19 in Europe, 9 in North America, and 7 in Oceania.

In Asia, we found 13, 17, 10, and 12 biological, engineering, agricultural, and management RTs, respectively, including artificial afforestation or grassland restoration, terraces, agroforestry, and natural restoration (i.e., protecting the site to allow natural recovery). The engineering RTs accounted for the largest proportion of the total, followed by the biological RTs. In Europe, agricultural RTs account for the largest number (6 RTs, including fallow/no-tillage/minimum tillage and agroforestry), followed by management (5, including confined/semi-confined farming and natural restoration) and engineering (5, including Grain for green and check dams), and biological RTs (3, including artificial afforestation or grassland restoration and plant breeding). We also found 14 African RTs, of which agricultural RTs accounted for the largest number (5, including agroforestry and conservation tillage), followed by biological RTs (3, including plant breeding and protective/buffer forests), engineering RTs (3, including terraces and check dams), and management RTs (3, including grazing exclosures and natural restoration. North America and Oceania reported fewer RTs, with totals of 9 and 7 RTs, respectively. Of these, the biological and engineering RTs accounted for the largest proportion in North America, whereas the management RTs accounted for the largest proportion in Oceania, followed by biological. This analysis suggests that the same technology can be applied to control ecosystem degradation in different regions.

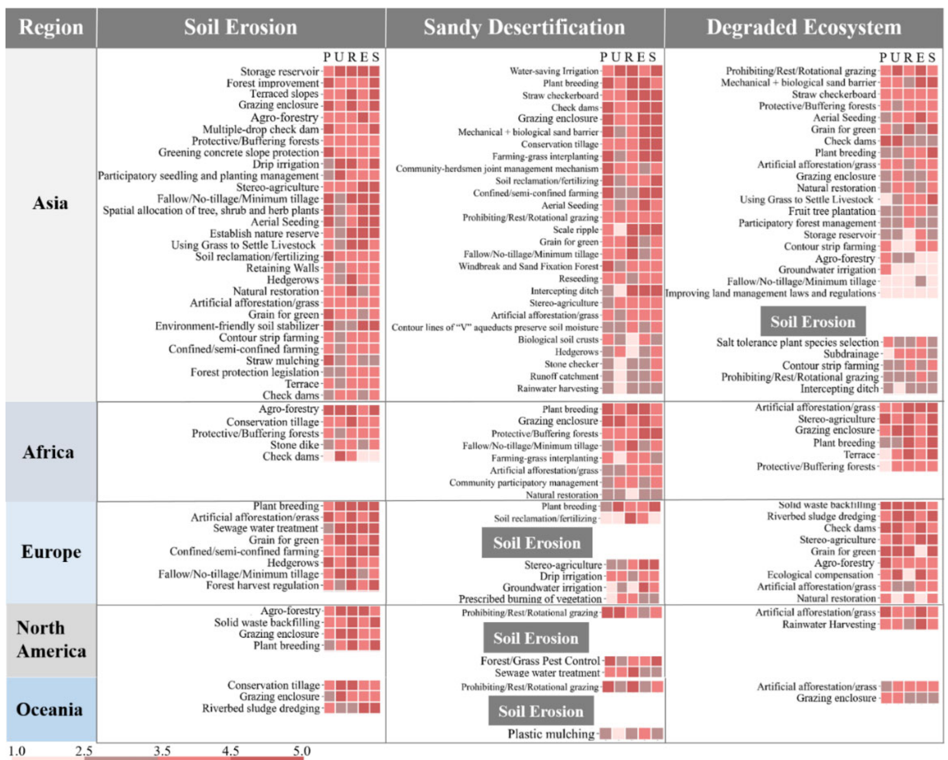

Figure 1. Comparison of evaluation results of RTs in typical regions surveyed. The column labels have the following meaning: P represents potential to transfer the technology to other regions; U represents ease of use; R represents readiness; E represents effectiveness; and S represents suitability.

3.2. Evaluation of RTs

There are various RTs used to control soil erosion, sandy desertification, and degraded ecosystems, and their results, as represented by the evaluation index, are different. This session presents relevant results.

3.2.1. RTs for Soil Erosion Control

We found 11 main biological RTs (including forest/grassland pest control, forest improvement, and plant breeding), 15 main engineering RTs (including storage reservoirs, terraced slopes, and check dams), 9 main agricultural RTs (including agroforestry, fallow/no-tillage/minimum tillage, and stereo-agriculture), and 10 main management RTs (including the establishment of nature reserves, grazing exclosure, and confined/semi-confined farming). Engineering RTs are mostly used to combat soil erosion, accounting for 33.4% of the total, followed by biological, management, and agricultural RTs, accounting for 24.4, 22.2, and 20.0%, respectively.

The evaluation index was calculated for each of the RTs and the results are listed in Supplemental Table S1. It can be found that RTs with high, medium, and low indexes are 7, 34, and 4 respectively. The RTs with high indexes included forest/grassland pest control (biological), storage reservoirs (engineering), forest improvement (biological), terraced slopes (engineering), sewage water treatment (engineering), agroforestry (agriculture), and plant breeding (biological). This emphasizes that biological and engineering RTs were relatively effective for the control of soil erosion. Although there were many management RTs, their indexes were all less than 0.9, indicating that their ability to combat soil erosion could be improved.

3.2.2. RTs for Sandy Desertification Control

For combating sandy desertification, we found 8 main biological RTs (including plant breeding, protective/buffer forests, windbreaks, and sand fixation forests), 10 main engineering RTs (including straw checkerboards, check dams, and mechanical + biological sand barriers), 6 main agricultural RTs (including water-saving irrigation, conservation tillage, and farming-grass interplanting), and 6 main management RTs (including grazing exclosure, community-herders joint management mechanisms, and confined/semi-confined farming). Engineering RTs accounted for 33.3%, which were the largest proportion of total RTs, followed by biological, management, and agricultural RTs, which accounted for 26.7, 20.0, and 20.0%, respectively.

There are 5, 13, and 4 RTs had high (0.92), medium (0.78), and low (0.60) evaluation indexes, respectively (Supplemental Table S2). The RTs with a high index included straw checkerboards (engineering), grazing exclosure (management), check dams (engineering), water-saving irrigation (agriculture), and plant breeding (biological). The agricultural RTs had the highest mean index (0.81), followed by management (0.80), biological (0.77), and engineering (0.75) for sandy desertification control. Thus, agricultural activities have an important impact on sandy desertification, and choosing more effective agricultural RTs could significantly improve sandy desertification, especially in arid and semi-arid agropastoral zones.

3.2.3. RTs for Degraded Ecosystem Control

There are 5 main biological RTs (including fruit tree plantations, aerial seeding, and protective/buffer forests), 9 main engineering RTs (including mechanical + biological sand barriers, straw checkerboards, and storage reservoirs), 5 main agricultural RTs (including contour strip farming, agroforestry, and stereo-agriculture), and 7 main management RTs (including natural restoration and participatory forest management) for the degraded ecosystem, respectively. That is engineering RTs accounted for the largest proportion of total RTs for control degraded ecosystem (34.7%), followed by management, biological, and agricultural RTs, which accounted for 26.9, 19.2, and 19.2%, respectively.

Supplemental Table S3 lists the score and evaluation index of each RT for the degraded ecosystems. Results indicate that engineering RTs had the highest mean index (0.83), followed by biological (0.76), management (0.68), and agricultural (0.62) RTs. Results also show that there are 3, 14, and 4 RTs with high, medium, and low index values, respectively, and solid waste backfilling (engineering RTs), riverbed sludge dredging (engineering RTs), and stereo-agriculture (agriculture RTs) had higher indexes. The engineering RTs not only have a high quantity among total RTs but also have a higher index, which leads to them being most applicable to control degraded ecosystems.

3.2.4. Comparative Analysis of RTs for Control of Soil Erosion, Sandy Desertification, and Degraded Ecosystem

Based on the results of RTs and their scores (Supplemental Tables S1–S3) and the classification method mentioned above as part of Section 2.3 the number of RTs with high and low scores for the three types of degradation are shown in Figure 2. The results show that there are 10, 6, 2, and 3, 0, 4 RTs with high and low scores in terms of potential to transfer among the soil erosion, sandy desertification, and degraded ecosystem, respectively (Figure 2), which indicates that the RTs for restoring soil erosion and sandy desertification have relatively reasonable potential to transfer while RTs for restoring degraded ecosystems need to be further improved. In terms of ease to use, there are 4, 2, and 5 RTs with high scores in combatting soil erosion, sandy desertification, and degraded ecosystem, respectively, and 2, 4, and 4 RTs with low scores, which shows these RTs are easiest and most difficult to use for combatting degraded ecosystems and sandy desertification, respectively. In terms of readiness, we found 15, 7, and 4 RTs with a high score in terms of combatting soil erosion, sandy desertification, and degraded ecosystems, respectively, and 1, 3, and 6 RTs with a low score, which means these RTs will require improvement to combat degraded ecosystems. For effectiveness, there are 10, 11, 6 (high scores), and 0, 0, 4 (low scores) RTs with high and low scores among the RTs applied for restoring soil erosion, sandy desertification, and degraded ecosystems, respectively. This indicates that the effectiveness of these RTs is more satisfactory among the five dimensions. In terms of suitability, the number of RTs having high and low scores for combatting soil erosion, sandy desertification, and degraded ecosystem are 14, 10, 7 (high cores) and 0, 0, 3 (low scores), respectively, which suggests that the suitability of every RT is satisfactory.

The above results from the questionnaire analysis indicate that RTs for restoring degradation vary. Findings from the literature can be used to validate the results in various ways. for instance, RTs like forest improvement [22,23] for soil erosion control, straw checkerboard [24,25] for restoring desertification, as well as stereo-agriculture [26–28] for degraded ecosystem have been widely adopted in 18 regions with vulnerable ecosystem conditions as indicated in our study, implying that these RTs have high potential to be transferred and used in many places. Meantime, these three RTs are easier to use, because they have low requirements in terms of the external environment, so the application can be guaranteed successfully without the help of additional equipment. For the readiness of the RTs, Austria began to control soil erosion through forest improvement at the end of the 19th century [4]. Since 1316, Germany, Demark, Hungary, Austria, Egypt, France, and Poland have implemented the straw checkerboard RTs, which shows that they have a long history of development, indicating high maturity. For the effectiveness of RTs, the soil's cation exchange capacity, enzyme activity, and vegetation cover increased by 16.2%, 25.7%, and 11%, respectively in regions that have applied forest improvement [22,23]. Straw checkerboards are widely used for transportation route protection and habitat recovery in arid and semi-arid regions [25], they not only can increase soil organic carbon values by 64% [29] but can also increase the roughness of the sandy surface by 400–600 times and reduce the wind velocity by 20–40% at a height of 0.5 m [24]. Stereo-agriculture has been demonstrated to receive 10.0–56.7% lower pesticide input compared with other's agroecosystems, increasing the grain yield and gross income by 54.8% and 61.6%, respectively [28], and decreasing CH_4 emission by 15–30% [27]. For suitability, these three RTs are highly adaptable to natural conditions, while their input and maintenance costs are lower than others. The cost of forest improvement and straw checkerboard was 916.2 US$/ha and 963.5 US$/ha, respectively, while the cost of stereo-agriculture was 1190 US$/ha, which was higher than forest improvement and straw checkerboard [30].

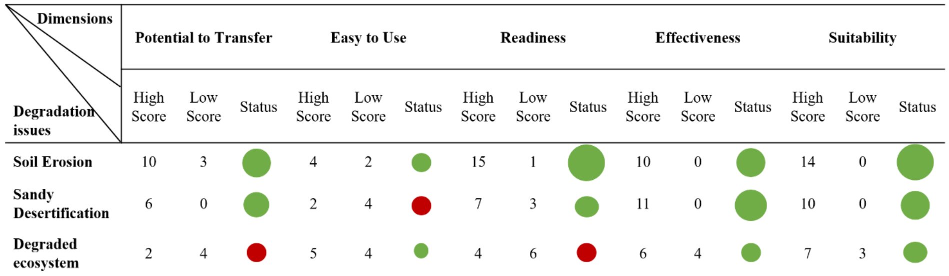

Figure 2. Comparison of RTs with high and low scores for the five dimensions. Green circles represent ratings with more high scores than low and indicate that RTs are satisfactory; red circles represent ratings with more low scores than high and indicate that RTs require improvement. Larger circles represent better (green) or worse (red) situations. Supplemental Tables S1–S3 summarize the data used to generate the scores.

The average evaluation index of RTs for controlling soil erosion, sandy desertification, and degraded ecosystems are 0.81, 0.78, and 0.73, respectively, the RTs to control soil erosion have higher values than those to control sandy desertification, which was greater than those for the degraded ecosystem. In terms of five dimensions, the potential to transfer and the readiness of the currently implemented RTs were lowest for the degraded ecosystems. The RTs for sandy desertification had low ease of use, so the technology must be improved, and transfers of the improved RTs to other regions need to be promoted. The effectiveness and suitability of RTs in terms of combatting the three types of degradation were all relatively high, and the engineering RTs had the largest number of high index values, as they have achieved good results. The second-highest values were for management RTs, but only one RT achieved a high index to control sandy desertification and degraded ecosystems, indicating that we still lack appropriate management RTs. Biological RTs had the largest number of applications and the best effect to combat soil erosion. Agriculture and management RTs had good effects to control sandy desertification but had poorer effects to control soil erosion and degraded ecosystems.

3.3. Comparing the Effects of Commonly Applied RTs

We also found that a given technology could be commonly applied to different regions or degradation types but that the effects varied (Figure 1). For example, agroforestry has been used in Guinea, Jerusalem, Canada, and Sri Lanka with variable success (Figure 3). The Guinea short rotation coppice technology can achieve economic benefits of US$11 to US$20 per person daily [31]. However, it has been difficult to encourage farmers to participate, to publicize the method, and to subsequently manage and protect the crops. The soil water content in Jerusalem was improved to 24.6% by reducing the soil water loss by 34 to 89%, and the amount of soil erosion was reduced by 45 to 94% [32], but the width of the intercropping areas reduced the restoration effect, so the high costs will require selection of reasonable intercropping widths and match them with suitable tree species. The soil organic matter content, available phosphorus content, and total exchangeable potassium content in Sri Lanka were increased by 22, 20, and 69%, respectively [33]. In addition, forest leaf litter significantly increased crop (tea) yields, by 13 to 21% [34] Canada has tested the use of tree species for intercropping. The survival rate of red oak and sugar maple can be as high as 100% [35], but 63% of these hardwoods and 55% of the hybrid poplars developed defects such as branched trunks, freeze-cracking, and tilting of the tree trunks, leading to unstable productivity and creating obstacles in adoption of this technology by local farmers. Thus, the effects of RTs can be geographically specific, and some technologies cannot be directly replicated in countries other than where they were developed without modification to account for local conditions. Therefore, efforts to combat ecological degradation cannot ignore regional differences and must be carried out in a way that accounts for local conditions, social and economic development levels, public awareness, and actual needs.

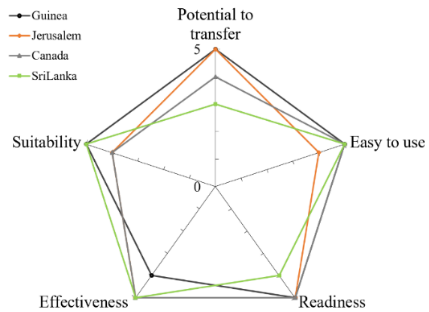

Figure 3. Comparison of evaluation results for agroforestry RTs in selected countries.

From the RTs summarized in Figure 1, we selected 11 RTs that appeared in at least three regions and that had high evaluation index values so that we could compare their effects (Table 4). Afforestation/grassland restoration has been widely used in the world's degraded regions to improve soil quality by improving vegetation cover, but seedling mortality can be high, and there is an opportunity cost from using the land and the water consumed by the vegetation for this purpose; these factors can greatly reduce the effectiveness of the ecological restoration [36]. Moreover, although this technique has been used in different regions, the effectiveness varied widely. For example, the maximum increase of the soil water content reached 118.5%, and the per-hectare tree yield increased by 1.8 to 4.3 times in China's Gansu and Xizang provinces after implementation of these RTs [37], and forest cover increased to 95% in Slovenia [38], but in Iran, the vegetation cover remained low due to improper selection of the tree species [36].

Table 4. Summary of the effects and issues for each RT commonly applied.

RTs	Effects	Issues	References
Afforestation/ grassland restoration	(1) The yield of grassland increased to 218.95 g/m^2, which was 1.8 to 4.3 times that of natural grassland. (2) Soil water content to a depth of 10 cm increased by 244.9%. (3) Forest cover increased to 95%.	Improper selection of seedlings resulted in high mortality, and the effect of ecological restoration was greatly reduced	Wade et al. [36] Hu et al. [37] Kusar & Komac [38]
Plant breeding	(1) Vertical cover can reach 95%. (2) Topsoil water content was 22 to 30% higher than that of natural vegetation. (3) The net benefit increased to 466.32×10^9 RMB/year.	High costs.	Akhmedenov [39] Lopez-Vicente & Wu [40] Cao et al. [41]
Check dams	(1) The interception of sediment reached 1.11×10^6 t, accounting for 26.4% of the total soil erosion. (2) Vegetation cover, herbaceous vegetation cover, and soil water increased by 57, 426, and 68%, respectively. (3) The maximum rainfall that can be collected is 135 M m^3	Costly to maintain and only a temporary solution without regular sediment removal.	Bai et al. [42] Helman & Mussery [43] Toosi et al. [44] Wen & Zhen [45]
Grain for Green	(1) The soil organic carbon content to a depth of 20 cm increased by 8.6 to 26.4%. (2) Farmers' self-produced food decreased by more than 40%.	Low-income groups may return to cultivation of the formerly protected land.	Yang et al. [46] Liu et al. [47]
Stereo-agriculture	(1) N and P contents in the surface water increased by 14.8 and 15.5%, respectively. (2)Yield increased by 27%, protein content increased by 25%, and there was no risk of heavy metals accumulating in the soil.	Higher costs.	Phung et al. [48]
Fallow/no tillage/ minimum tillage	(1) Crop yields increased by 50% and the income-output ratio increased by 28%. (2) The soil organic carbon content increased with increasing fallow duration and decreased with increasing soil depth, with the highest value reaching 2.0%.	Need a long fallow period, with a minimum of 20 years to compare with intact forest.	Chen et al. [49] Laskar et al. [50]

Grazing exclosures	(1) The biomass, Margalef species richness index, and Shannon–Weiner diversity index increased by 13, 3.09, and 1.80 times, respectively. (2) The maximum increases of soil organic matter, N, and P in the 10- to 20-cm soil layer were 243.6, 93.9, and 69.0%, respectively, and significantly improved soil fertility. (3) The height of the herbaceous vegetation was 17.25 times that of grazed grassland.	Suitable for slightly degraded areas; moderately and severely degraded land should be restored by combination of natural recovery and planting.	Hu et al. [37] Ronkin et al. [51]
Natural restoration	(1) Soil aggregates reached their maximum value (32.5%) compared with planting, which enhanced the soil's ability to resist erosion. (2) The soil organic carbon content to a depth of 20 cm improved by0.27 to 4.50 g/kg	Requires at least decades to reach the carbon storage potential of the mature forest. Farmers' willingness to participate is relatively low, as this may damage their livelihoods.	Dou et al. [52] Hu et al.[53]
Forest improvement	(1) The vegetation cover increased by 11.0% and the air temperature was nearly 1 °C lower than that of the surrounding areas. (2) The soil's cation exchange capacity and enzyme activity increased by 16.2 and 25.7%, respectively.	This RT led to leaching of soluble salts in the rhizosphere, but pH did not change drastically.	Xu et al. [22] An et al. [23]
Agro-forestry	(1) This RT could reduce runoff by 56.6% and sediment yield by 72.4% (2) The potential soil carbon content was 0.7 to 1.6 t $ha^{-1}year^{-1}$, and the deposition of N, P, and K was 34 to 83 kg $ha^{-1}year^{-1}$, 1.8 to 4.3 kg $ha^{-1}year^{-1}$, and 10 to 26 kg $ha^{-1}year^{-1}$, respectively. (3) Grain output increased by 7 to 12 times.	Affected by many factors, such as rainfall conditions, management modes, and vegetation types.	Zou et al. [54] Yengwe et al.[55]
Water-saving Irrigation	(1) The vegetation cover increased from 1.7% to 82.7%. (2) Soil water storage and water-use efficiency to a depth of 200 cm increased by 13.7 and 17.2%, respectively. (3) The crop yield increased by 54.3%.	Excessive or inefficient irrigation has led to severe salinization of farmland in arid areas.	Li et al.[56] Zhang et al. [57] Chen et al. [49]

Check dams can effectively intercept sediment being transported down a slope and in one study, increased vegetation cover, the cover of herbaceous vegetation, and soil moisture by 57, 426, and 68%, respectively [41,43]. However, the storage capacity of check dams is limited by the geographical conditions and by their design, and it becomes necessary to regularly remove the deposits that have accumulated in the reservoir uphill of the dam to retain the dam's effectiveness [45,49], so the maintenance cost can be high.

Water-saving irrigation has been widely used in the world's semi-arid and arid regions to improve vegetation cover, biomass, yield, and soil quality by increasing the soil water content. However, it requires a high investment in technology, and the efficiency of the irrigation will directly affect the effectiveness. Excessive or inefficient irrigation can also lead to salinization of the soil in arid areas [45]. Therefore, before these RTs can be used in an area, they must be improved and optimized to account for local conditions, and the solution for one region cannot be directly implemented in another region. For example, Israel has used these RTs in greenhouses, desert regions, and green areas because the national groundwater supply is managed as a single network. Kazakhstan introduced water-saving irrigation technology that was developed in China's Xinjiang Province, and the yield of potato, cotton, tomato, wheat, and sugar beet increased by 2.8, 2.0, 1.5, 3.5, and 4.7 times, respectively [58]. On the other hand, Iran used excessive or inefficient irrigation water, and not only did they not achieve ecological restoration but they also encountered serious salinization of farmland [45].

Natural restoration refers to a process in which land is protected against further disturbance and the ecosystem is allowed to recover naturally. So long as the degraded region has not reached a threshold and passed into an alternative stable state, this RT can be very effective. For example, parts of China's Loess Plateau have been allowed to recover naturally, and the soil organic carbon content and soil aggregates increased by 0.27 to 4.50 g/kg and 32.5%, respectively, compared with afforestation areas, and these changes enhanced the soil's ability to resist erosion [52].

4. Discussion

There are many basic RTs that have been developed to deal with different types of ecosystem degradation, and various countries and regions have applied, demonstrated, and promoted these methods for use in ecological restoration projects, but there have also been many cases in which ecological restoration failed or performed poorly. The reasons for these failures include lack of technology or knowledge to support optimal application and management of the approach, as well as climate, insufficient land, labor, investment, or related resources [59].

We found that biological RTs, such as forest/grassland pest control, forest improvement, and plant breeding, were relatively effective for the control of soil erosion, this is similar to the results from Lal (2004) [4], that agricultural RTs, such as straw checkerboards and check dams that have been applied in US, China, Ethiopia, Italy, Iran, and Spain [60], had an important impact on sandy desertification, and that engineering RTs, such as solid waste backfilling, riverbed sludge dredging, and stereo-agriculture, provided good control of the degraded ecosystem. This is mostly because soil erosion is a primary cause of land as well as ecological degradation [12,61], and by accounting for natural conditions and the need for sustainable development of the region that is experiencing erosion, biological measures should be the first measures that are widely adopted for restoration, also due to its environmental soundness. The ecological environment is easily disturbed by human activities, especially in fragile ecosystems such as those in arid and semi-arid agropastoral zones [51], so adopting more suitable agricultural RTs could significantly reverse sandy desertification while maintaining production. Ecosystems have a certain capacity for self-recovery, so protecting degraded ecosystems from further degradation to allow natural recovery should be prioritized whenever and wherever possible [62], since it is both effective and low cost, and has been used with considerable success in China.

We also found that different RTs had different effects in the same region and that the same technology had different effects in different regions. This means that each technology is specific to the region where it was developed, at least to some extent. Hu et al. [37] compared the effectiveness of three RTs to control soil erosion on the Qinghai-Tibet Plateau: fencing enclosures, planting of *Salix cupularis* to create a sand control barrier, and combining the sandy barrier with the planting of grasses. The fencing was suitable for lightly desertified grassland, but heavily desertified grassland required a combination of planting of the shrubs with the planting of grasses. This illustrates how different technologies have different effects in the same area, which is consistent with our conclusions. Check dams are constructed across a flow channel to prevent soil and water loss, and they are especially widespread throughout China [60], northern Ethiopia [63], and Iran [64]. However, the effectiveness of check dams differs in these regions, for instance, the check dam system can significantly reduce surface runoff by 60%, and up to 85.5% of the rainy season sediment was blocked in the Chinese Loess Plateau [60], a significant proportion of runoff discharge volume was abstracted in the gullies treated with check dams and vegetation (8–18%) in northern Ethiopia [63], the trapped sediments by check dams includes 10–80% sand and 6–40% silt in the south-west of Iran in the Fars Province [64]. Therefore, the design, selection, and application of RTs must focus on the specific type of degradation that must be controlled, how far it has advanced (i.e., its severity), and its drivers, as well as on local economic, cultural, policy, and institutional contexts [65]. To identify suitable restoration measures, it is necessary to perform a technology needs assessment for the project area before importing technologies developed under different conditions [19].

The questionnaire-based survey adopted in this study is relatively subjective, therefore, field survey, plot investigation, and experimental methods need to be applied in a future study. Due to the limited scope of our survey, we did not obtain an even distribution of expert opinions from a range of fields of research, nor did we obtain a globally representative sample. In future research, experts from more areas of expertise and from more regions of the world should be surveyed. In addition, due to differences in the core issues that different experts pay attention to, responses to the questionnaire were subjective to a certain extent, and this may have led to inaccuracy in our ranking of the solutions. This problem needs additional attention so we can improve the quality of the responses in future studies.

5. Conclusions

In this study, we combined questionnaire research with a literature review to identify the most commonly applied RTs for ecological restoration, and their effectiveness at controlling soil erosion, sandy desertification, and degraded ecosystem. We found 101 RTs that have been applied for restoring ecosystems degradation in typical ecologically fragile regions around the world, which include 45 soil erosion RTs, 30 sandy desertification RTs, and 26 degraded ecosystem RTs, respectively. RTs that have been applied in the soil erosion regions are most effective, such as forest/grassland pest control, storage reservoirs, forest improvement, terraced slopes, agroforestry, and plant breeding, followed by RTs to control sandy desertification and degraded ecosystem, which include straw checkerboards, grazing exclosures, check dams, water-saving irrigation, plant breeding for sandy desertification and solid waste backfilling, riverbed sludge dredging, and stereo-agriculture for degraded ecosystems. In addition, the average evaluation indexes of RTs for controlling soil erosion, sandy desertification, and degraded ecosystem are 0.81, 0.78, and 0.73, respectively, which means the RTs for controlling soil erosion are the most effective, followed by sandy desertification and degraded ecosystem. Engineering and biological RTs account for 19.2–26.7% and 33.4–34.7% of total RTs, respectively, indicating the dominance of these RTs. Finally, we found that the same technology could be applied in different regions or to control different degradation types, but the effectiveness varied. Therefore, ecological management and restoration choices cannot ignore the differences between regions, and it is necessary to choose a method of ecological restoration that accounts for the local conditions.

Supplementary Materials: The following are available online at www.mdpi.com/article/10.3390/su132313290/s1, Table S1 Application and evaluation of RTs to combat soil erosion in typical regions, Table S2 Application and evaluation of RTs to combat sandy desertification in typical regions, Table S3 Application and evaluation of RTs to combat degraded ecosystem in typical regions, Questionnaire for assessment of ecological RTs, Literature Reserch Supplemental Text.

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References

1. United Nations Convention to Combat Desertification. *The Global Land Outlook*, 1st ed.; UNCCD: Bonn, Germany, 2017.
2. Higgs, E.S. What is good ecological restoration? *Conserv. Biol.* **1997**, *11*, 338–348.
3. Lal, R.; Baker, R.S. Global overview of soil erosion. *Soil Water Sci. Key Underst. Our Glob. Environ.* **1994**, 39–51, doi:10.2136/sssaspecpub41.c5.
4. Lal, R. Carbon Sequestration in Dryland Ecosystems. *Environ. Manag.* **2004**, *33*, 528–544, doi:10.1007/s00267-003-9110-9.
5. Millennium Ecosystem Assessment. *Ecosystems and Human Well-Being: Synthesis*; Island Press: Washington, DC, USA, 2005.
6. Lal, R.; Lorenz, K.; Hüttl, R.F.; Schneider, B.U.; von Braun, J. *Recarbonization of the Biosphere: Ecosystems and the Global Carbon Cycle*; Springer: Dordrecht, The Netherlands, 2012.
7. Zhen, L.; Hu, Y.F.; Wei, Y.J.; Luo, Q.; Han, Y.Q. Trend of ecological degradation and restoration technology requirement in typical ecological vulnerable regions. *Resour. Sci.* **2019**, *41*, 63–74. (In Chinese)
8. Orr, B.J.; Cowie, A.L.; Castillo Sanchez, V.M.; Chasek, P.; Crossman, N.D.; Erlewein, A.; Louwagie, G.; Maron, M.; Metternicht, G.I.; Minelli, S.; et al. *Scientific Conceptual Framework for Land Degradation Neutrality. A Report of the Science-Policy Interface*; United Nations Convention to Combat Desertification (UNCCD): Bonn, Germany, 2017.
9. Sharma, L.K.; Raj, A.; Somawat, K. Spatio-temporal assessment of Environmentally Sensitive Areas (ESA) in The Thar Desert India, to combat desertification under UNCCD framework. *J. Arid. Environ.* **2021**, *194*, 104609.
10. Cross, A.T.; Nevill, P.G.; Dixon, K.W.; Aronson, J. Time for a paradigm shift towards a restorative culture. *Restor. Ecol.* **2019**, *27*, 924–928.
11. Zhen, L.; Liu, X.L.; Li, F.; Wei, Y.J.; Hannes, K. Consumption of Ecosystem Services and Eco-Compensation Mechanism in Ecological Sensitive Regions: Progress and Challenges. *Resour. Sci.* **2010**, *32*, 797–803. (In Chinese)
12. Hobbs, R.J.; Norton, D.A. Towards a conceptual framework for restoration ecology. *Restor. Ecol.* **1996**, *4*, 93–110.
13. Waters, C.M.; Orgill, S.E.; Melville, G.J.; Toole, I.D.; Smith, W.J. Management of Grazing Intensity in the Semi-Arid Rangelands of Southern Australia: Effects on Soil and Biodiversity. *Land Degrad. Dev.* **2017**, *28*, 1363–1375.
14. Jiang, C.; Guo, H.W.; Wei, Y.P.; Yang, Z.Y.; Wang, X.C.; Wen, M.L.; Yang, L.; Zhao, L.L.; Zhang, H.Y.; Zhou, P. Ecological restoration is not sufficient for reconciling the trade-off between soil retention and water yield: A contrasting study from catchment governance perspective. *Sci. Total Environ.* **2021**, *142139*, 754, doi:10.1016/j.scitotenv.2020.142139.
15. Zhen, L.; Wang, J.J.; Jiang, Z.D.; Liu, X.Y.; Zhang, C.Y.; Ma, J.X.; Xiao, Y.; Xie, Y.S.; Xie, G.D. The methodology for assessing ecological restoration technologies and evaluation of global ecosystem rehabilitation technologies. *Acta Ecol. Sin.* **2016**, *36*, 7152–7157. (In Chinese)
16. Hobbs, R.J.; Harris, J.A. Restoration ecology: Repairing the earth's ecosystems in the new millennium. *Restor. Ecol.* **2001**, *9*, 239–246.
17. Li, W.H. Evaluating Ecological Restoration Technology: A New Era for Ecosystem Protection in Vulnerable Ecological Regions in China. *J. Resour. Ecol.* **2017**, *8*, 313–314.
18. Liu, B.Y.; Liu, Y.N.; Zhang, K.L.; Xie, Y. Classification for soil conservation practices in China. *J. Soil Water Conserv.* **2013**, *27*, 80–84. (In Chinese)
19. Zhen, L.; Xie, Y.S. Evaluation method and its application of ecological restoration technology for typical ecological vulnerable regions. *Acta Ecol. Sin.* **2019**, *39*, 5747–5754. (In Chinese)
20. Hu, X.N.; Xie, X.Z.; Guo, M.C.; Wang, J.J. Research on Evaluation Method and Model of Ecological Technology:The Design of Theoretical Model. *J. Nat. Resour.* **2018**, *33*, 1152–1164. (In Chinese)
21. Zhen, L.; Yan, H.M.; Hu, Y.F.; Xue, Z.C.; Xiao, Y.; Xie, G.D.; Ma, J.X.; Wang, J.J. Overview of ecological restoration technologies and evaluation systems. *J. Resour. Ecol.* **2017**, *8*, 315–324.
22. Xu, H.J.; He, H.; Huang, S.L. Analysis of fractional vegetation cover change and its impact on thermal environment in the Hetian basinal area of County Changting, Fujian Province, China. *Acta Ecol. Sin.* **2013**, *33*, 2954–2963. (In Chinese)
23. An, J.; Chang, H.N.; Han, S.H.; Khamzina, A.; Son, Y. Changes in basic soil properties and enzyme activities along an afforestation series on the dry Aral Sea Bed, Kazakhstan. *For. Sci. Technol.* **2020**, *16*, 26–31.
24. Li, X.R.; Xiao, H.L.; He, M.Z.; Zhang, J.G. Sand barriers of straw checkerboards for habitat restoration in extremely arid desert regions. *Ecol. Eng.* **2006**, *28*, 149–157.
25. Taniguchi, T.; Yuzawa, T.; Mao, H.P.; Yamamoto, F.; Yamanaka, N. Plantation soil inoculation combined with straw checkerboard barriers enhances ectomycorrhizal colonization and subsequent growth of nursery grown Pinus tabulaeformis seedlings in a dryland. *Ecol. Eng.* **2021**, *163*, 106191, doi:10.1016/j.ecoleng.2021.106191.
26. Westphal, C.; Vidal, S.; Horgan, F.G.; Gurr, G.M.; Escalada, M.; Chien, H.V.; Tscharntke, T.; Heong, K.L.; Settele, J. Promoting multiple ecosystem services with flower strips and participatory approaches in rice production landscapes. *Basic Appl. Ecol.* **2015**, *16*, 681–689.
27. Ling, L.; Shuai, Y.J.; Xu, Y.; Zhang, Z.S.; Wang, B.; You, L.Z.; Sun, Z.C.; Zhang, H.R.; Zhan, M.; Li, C.F.; et al. Comparing rice production systems in China: Economic output and carbon Footprint. *Sci. Total Environ.* **2021**, *791*, 147890, doi:10.1016/j.scitotenv.2021.147890.
28. Yu, X.; Yuan, S.; Tao, X.; Huang, J.D.; Yang, G.D.; Deng, Z.M.; Xu, L.; Zheng, C.; Peng, S.B. Comparisons between main and ratoon crops in resource use efficiencies, environmental impacts, and economic profits of rice ratooning system in central China. *Sci. Total Environ.* **2021**, *799*, 149246, doi:10.1016/j.scitotenv.2021.149246.

29. Li, X.; Zhou, R.; Jiang, H.; Zhou, D.D.; Zhang, X.W.; Xie, Y.H.; Gao, W.B.; Shi, J.; Wang, Y.H.; Wang, J.; et al. Quantitative analysis of how different checkerboard sand barrier materials influence soil properties: A study from the eastern edge of the Tengger Desert, China. *Environ. Earth Sci.* **2018**, *77*, 481, doi:10.1007/s12665-018-7653-6.
30. PRC-GEF Partnership on Land Degradation in Dryland Ecosystems, China-Land Degradation Assessment in Drylands. In *Best Practices for Land Degradation cntrol in Dryland Areas of China*; Chinese Forestry Publishing House: Beijing, China, 2008.
31. Nuberg, I.K.; Mitir, J.A.; Robinson, B. Short-rotation coppice agroforestry for charcoal small business in Papua New Guinea. *Aust. For.* **2017**, *80*, 143–152.
32. Salah, A.M.A.; Prasse, R.; Marschner, B. Intercropping with native perennial plants protects soil of arable fields in semi-arid lands. *J. Arid. Environ.* **2016**, *130*, 1–13.
33. Raveendra, S.A.S.T.; Nissanka, S.P.; Somasundaram, D.; Atapattu, A.J.; Mensah, S. Coconut-gliricidia mixed cropping systems improve soil nutrients in dry and wet regions of Sri Lanka. *Agrofor. Syst.* **2021**, *95*, 307–319.
34. De Costa, W.; Surenthran, P. Resource competition in contour hedgerow intercropping systems involving different shrub species with mature and young tea on sloping highlands in Sri Lanka. *J. Agric. Sci.* **2005**, *143*, 395–405.
35. Rivest, D.; Cogliastro, A. Establishment success of seven hardwoods in a tree-based intercropping system in southern Quebec, Canada. *Agrofor. Syst.* **2019**, *93*, 1073–1080.
36. Kusar, D.; Komac, B. A geographical and architectural perspective on Alpine hay meadow abandonment in Bohinj, Slovenia. *Eco Mont-J. Prot. Mt. Areas Res.* **2019**, *11*, 32–42.
37. Hu, J.J.; Zhou, Q.P.; Lu, Y.H.; Lü, Y.H.; Hu, J.; Chen, Y.J.; Gou, X. Comparison study to the effectiveness of typical ecological restoration measures in semi-humid sandy land in eastern Qinghai-Tibetan Plateau, China. *Acta Ecol. Sin.* **2020**, *40*, 7410–7418. (In Chinese)
38. Wade, T.I.; Ndiaye, O.; Mauclaire, M.; Mbaye, B.; Sagna, M.; Guisse, A.; Goffner, D. Biodiversity field trials to inform reforestation and natural resource management strategies along the African Great Green Wall in Senegal. *New For.* **2018**, *49*, 341–362.
39. Akhmedenov, K.M. Analysis of the Afforestation Status in the Arid Conditions of Western Kazakhstan. *Biol. Bull.* **2018**, *45*, 1153–1158.
40. Lopez-Vicente, M.; Wu, G.L. Soil and Water Conservation in Agricultural and Forestry Systems. *Water* **2019**, *11*, 1937, doi:10.3390/w11091937.
41. Cao, S.X.; Suo, X.H.; Xia, C.Q. Payoff from afforestation under the Three-North Shelter Forest Program. *J. Clean. Prod.* **2020**, *256*, doi:10.1016/j.jclepro.2020.120461.
42. Bai, L.C.; Wang, N.; Jiao, J.Y.; Chen, Y.X.; Tang, B.Z.; Wang, H.L.; Chen, Y.L.; Yan, X.Q.; Wang, Z.J. Soil erosion and sediment interception by check dams in a watershed for an extreme rainstorm on the Loess Plateau, China. *Int. J. Sediment Res.* **2020**, *35*, 408–416.
43. Helman, D.; Mussery, A. Using Landsat satellites to assess the impact of check dams built across erosive gullies on vegetation rehabilitation. *Sci. Total Environ.* **2020**, *730*, 138873, doi:10.1016/j.scitotenv.2020.138873.
44. Toosi, A.S.; Tousi, E.G.; Ghassemi, S.A.; Cheshomi, A.; Alaghmand, S. A multi-criteria decision analysis approach towards efficient rainwater harvesting. *J. Hydrol.* **2020**, *582*, 124501, doi:10.1016/j.jhydrol.2019.124501.
45. Wen, X.; Zhen, L. Soil erosion control practices in the Chinese Loess Plateau: A systematic review. *Environ. Dev.* **2020**, *34*, 100493.
46. Yang, F.; Wei, X.R.; Huang, M.B.; Li, C.H.; Zhao, X.F.; Zhang, Z.D. Spatiotemporal variability of soil organic carbon for different topographic and land use types in a gully watershed on the Chinese Loess Plateau. *Soil Res.* **2021**, SR19317, doi:10.1071/SR19317.
47. Liu, Z.; Li, Q.M.; Lan, J.; Abu Hatab, A. Does participation in the sloping land conversion program reduce the sensitivity of Chinese farmers to climate change? *Land Use Policy* **2020**, *99*, 105021, doi:10.1016/j.landusepol.2020.105021.
48. Phung, L.D.; Ichikawa, M.; Pham, D.V.; Sasaki, A.; Watanabe, T. High yield of protein-rich forage rice achieved by soil amendment with composted sewage sludge and topdressing with treated wastewater. *Sci. Rep.* **2020**, *10*, 2045–2322.
49. Chen, T.; Tang, G.P.; Yuan, Y.; Guo, H.; Xu, Z.W.; Jiang, G.; Chen, X.H. Unraveling the relative impacts of climate change and human activities on grassland productivity in Central Asia over last three decades. *Sci. Total Environ.* **2020**, *743*, 140649, doi:10.1016/j.scitotenv.2020.140649.
50. Laskar, S.Y.; Sileshi, G.W.; Pathak, K.; Debnath, N.; Nath, A.J.; Laskar, K.Y.; Singnar, P.; Das, A.K. Variations in soil organic carbon content with chronosequence, soil depth and aggregate size under shifting cultivation. *Sci. Total Environ.* **2021**, *762*, 143114, doi:10.1016/j.scitotenv.2020.143114.
51. Ronkin, V.; Tokarsky, V.; Polchaninova, N.; Atemasov, A.; Koshkina, A.; Savchenko, G. Comparative Assessment of Ecological Plasticity of the Steppe Marmot Between Ukrainian and Kazakhstan Populations: Challenges of the Man-Induced Environmental Changes. *Front. Ecol. Evol.* **2020**, *8*, 00219, doi:10.3389/fevo.2020.00219.
52. Dou, Y.X.; Yang, Y.; An, S.S.; Zhu, Z.L. Effects of different vegetation restoration measures on soil aggregate stability and erodibility on the Loess Plateau, China. *Catena* **2020**, *185*, 104294, doi:10.1016/j.catena.2019.104294.
53. Hu, P.L.; Zhang, W.; Chen, H.S.; Li, D.J.; Zhao, Y.; Zhao, J.; Xiao, J.; Wu, F.J.; He, X.Y.; Luo, Y.Q. Soil carbon accumulation with increasing temperature under both managed and natural vegetation restoration in calcareous soils. *Sci. Total Environ.* **2021**, *767*, 145298, doi:10.1016/j.scitotenv.2021.145298.
54. Zou, X.; Zhu, X.A.; Chen, C.F.; Liu, W.J. Soil and water conservation benefits of agroforestry systems. *J. Yunnan Univ.* **2020**, *42*, 382–392. (In Chinese)
55. Yengwe, J.; Amalia, O.; Lungu, O.I.; De Neve, S. Quantifying nutrient deposition and yield levels of maize (*Zea mays*) under *Faidherbia albida* agroforestry system in Zambia. *Eur. J. Agron.* **2018**, *99*, 148–155.

56. Li, X.B.; Kang, Y.H.; Wang, X.M. Response of soil properties and vegetation to reclamation period using drip irrigation in coastal saline soils of the Bohai Gulf. *Paddy Water Environ.* **2019**, *17*, 803–812.
57. Zhang, W.T.; Sheng, J.D.; Li, Z.; Weindorf, D.C.; Hu, G.Q.; Xuan, J.W.; Zhao, H.M. Integrating rainwater harvesting and drip irrigation for water use efficiency improvements in apple orchards of northwest China. *Sci. Hortic.* **2021**, *275*, 109728, doi:10.1016/j.scienta.2020.109728.
58. He, R.; Li, F.X.; Chen, L.; Ding, L.J. Application effect and prospect of drip irrigation technology on field crops in Kazakhstan. *Mod. Agric. Sci. Technol.* **2010**, *14*, 93–94.
59. Lal, R.; Monger, C.; Nave, L.; Smith, P. The role of soil in regulation of climate. *Philos. Trans. R. Soc. B-Biol. Sci.* **2021**, *376*, 20210084, doi:10.1098/rstb.2021.0084.
60. Wang, T.; Hou, J.; Li, P.; Matta, E.; Ma, L.P.; Hinkelmann, R. Quantitative assessment of check dam system impacts on catchment flood characteristics—A case in hilly and gully area of the Loess Plateau, China. *Nat. Hazards* **2021**, *105*, 3059–3077, doi:10.1007/s11069-020-04441-7.
61. Peng, K.S. Soil and water loss the main reason of deteriorating eco-environment. *J. Hebei Univ. Environon. Eng.* **2000**, Z1, 90–98. (In Chinese)
62. Williams, J. Soils Governance in Australia: Challenges of cooperative federalism. *Int. J. Rural. Law Policy* **2015**, *1*, 40–51.
63. Guyassa, E.; Frankl, A.; Zenebe, A.; Poesen, J.; Nyssen, J. Efects of check dams on runof characteristics along gully reaches, the case of Northern Ethiopia. *J. Hydrol.* **2017**, *545*, 299–309.
64. Hassanli, A.M.; Nameghi, A.E.; Beecham, S. Evaluation of the effect of porous check dam location on fine sediment retention (a case study). *Environ. Monit. Assess.* **2009**, *152*, 319–326.
65. Hobbs, R.J.; Saunders, D. Nature conservation in agricultural landscapes: Real progress or moving deckchairs. *Nat. Conserv.* **2001**, *5*, 1–12.

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