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Soil C:N:P Stoichiometric Characteristics and Soil Quality Evaluation under Different Restoration Modes in the Loess Region of Northern Shaanxi Province

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Abstract: Vegetation restoration is essential for the stability of the ecological system structure and function in the loess region of North Shaanxi Province. Natural and artificial restoration are the primary modes for vegetation recovery and soil quality improvement in this region. In this study, two adjacent watersheds with similar ecological environment conditions but different restoration modes were selected for research; one watershed is restored naturally (He Gou watershed), and the other is restored artificially (Chai Gou watershed). According to the study of soil stoichiometric characteristics and soil quality after the vegetation restoration in these two watersheds, the results showed: (1) Compared with the natural restoration, artificial restoration was more effective in increasing the content of soil organic carbon and total nitrogen, however, the total phosphorus content of the soil in the natural restoration mode was higher than that in the artificial restoration mode. (2) The ratios of soil C:N, C:P, and N:P showed a decreasing trend with the increase of soil depth at these two restoration modes. (3) In the 0–60 cm soil layer, the soil quality under the artificial restoration mode was better than that of the natural restoration, especially for the soil layer beneath 20 cm. (4) The minimal data set on the soil quality evaluation in the study area included soil organic carbon, capillary water holding quantity, available potassium, soil water content and available phosphorus. It showed a linear relation with the total index data set ($y = 0.829x + 0.058$, $R^2 = 0.76$) and can reflect the soil quality more sensitively than the total indicator data set.

Keywords: natural restoration; artificial restoration; stoichiometric characteristics; soil quality assessment

Citation: Gao, R.; Ai, N.; Liu, G.; Liu, C.; Zhang, Z. Soil C:N:P Stoichiometric Characteristics and Soil Quality Evaluation under Different Restoration Modes in the Loess Region of Northern Shaanxi Province. *Forests* **2022**, *13*, 913. https://doi.org/10.3390/f13060913

Academic Editors: Stefano Carnicelli and Anna Andreetta

Received: 13 April 2022
Accepted: 10 June 2022
Published: 12 June 2022

1. Introduction

Soil is an important natural resource, the critical carrier and the main nutrient origin for the vegetation to exist and grow, and develop [1]. The problems of water and soil loss, severe soil degradation, barren soil and degradation of the ecological system in the loess region of the Northern Shaanxi Province have significantly influenced the vegetation groups, soil fertility and ecological environment conditions [2]. To solve these problems, the Chinese government has implemented numerous forestry ecological projects in this region in recent years, mainly including the program to restore the cultivated land to the forest (grassland), which has improved the ecological environment effectively and produced a remarkable outcome. However, when such projects are implemented, and the sustainability of the forest ecological system is considered, it is highly controversial whether to choose natural or artificial restoration. Some studies have shown that natural restoration can reconstruct the ruined vegetation after the artificial interference stops, relying on the natural seed reservoir and the natural refreshing of protophyte, but it takes a long period [3,4]. In contrast, the artificial afforestation can combine artificial land remediation and the introduction of new species to accelerate the restoration of the destroyed ecological system [5]. Wang et al. [6] have discovered that the quality of the naturally recovered soil in the Danan watershed was better than that under the artificial restoration. The overconsumption of soil moisture due to the high production capacity and nutrient storage capacity of the artificial restoration has caused a low penetration rate of soil and less organic carbon content in the soil. Thus, artificial restoration is less sustainable than its natural counterpart [7,8]. However, Zhang et al. [9] have discovered that the soil restoration quality in the Karst region under the artificial restoration was better than that under the natural restoration. In addition, other studies also showed that artificial restoration could accelerate the vegetation restoration process and promote the soil nutrient accumulation and soil characteristics [10], which proved that it was better than the natural restoration in enhancing the soil quality.

The soil quality comprehensively embodies the physical, chemical and biological characteristics of the soil and is also an important indicator for measuring the soil environment. It also can reflect the management situation and the restoration capacity of the soil in the region [11,12]. Over the years, scholars have conducted extensive studies on soil quality. The soil quality index method has been widely accepted since it is simple and flexible [13,14]. Many scholars have built a data set on quality evaluation of multiple types of soil from different study regions, which promoted the research development in this aspect. For example, Nabiollahi et al. [15] have conducted studies in Kurdistan, Iran and built up the soil quality index based on the quantification of multiple types of soil to distinguish the effects of changes in the slope and land use on the soil quality. Li et al. [16] have studied the black earth region in Jilin Province and selected the most effective soil indicators and the minimal data set to analyze the relationship between the soil quality and the environmental control. The selection of indicators is critical for soil quality evaluation. Each physical, chemical and biological indicator of the soil can become the eventual evaluation factor [17]. During the soil quality evaluation, the appropriate evaluation indicator should be chosen according to the study purpose to reflect the soil production potential and the health level effectively. Using more indicators can help better reflect the comprehensive soil quality. For example, Guo et al. [18] chose 10 soil indicators to assess the soil quality in the two typical agricultural counties (Yu City and Ken Li) located along downstream of the Yellow River. Sefati et al. [19] chose 12 physical, chemical and biological indicators of the soil to characterize the soil quality in the Ahvaz forest in the saline underground water region of Iran and the local riverside parks. Many studies have shown that the elements of carbon, nitrogen and phosphorus in the soil are the important indicators for its quality evaluation [2]. They are the important ecological factors to protect the health of the ecological system and the nutrient circulation; the dynamic balance of their content and their ecological and chemical metrological ratio affects the soil quality and plant growth directly [20–22].

At present, most studies on the soil quality evaluation of the loess region in the North of Shaanxi Province focus on assessing the forest soil quality condition after only one restoration mode is applied [23,24]. However, few reports are on the comprehensive comparison between the soil quality under artificial and natural restoration. Hence, this study took Wuqi County, the model county for cultivation land restoration to the forest (grassland) in the loess area of northern Shaanxi, as the research area, based on the soil study after applying different restoration modes. The main purposes of this paper include (1) clarifying the differences in soil carbon, nitrogen and phosphorus content and their stoichiometric ratios between natural and artificial restoration methods; and (2) using the soil quality index method to calculate the soil quality index of the watershed with the two restoration methods, and establish the smallest data set suitable for soil quality assessment in the study area.

2. Materials and Methods

2.1. Overview of the Study Region

The study region is Wuqi County, Yanan City, Shaanxi Province (107°38′37″~108°32′49″ E, 36°33′33″~37°24′27″ N), which is a typical arid and semi-arid region. The total area of the county is 3791.5 km^2, and the water and soil loss area is 3693 km^2, accounting for 97.4% of the total. In addition, it suffers from severe soil loss. The elevation ranges from 1233 to 1809 m, the annual average temperature is 7.8 °C, 96–146 days of the frost-fee period, and the average annual rain precipitations is 478.3 mm, over 64% of which concentrate between July and September. Draught, hail damage, freezing, wind disaster, etc., occur frequently. The natural vegetation belongs to the forest and grassland in the warm temperate zone.

Through field research and literature review, our research team selected Chai Gou watershed and He Gou watershed, which were adopted with different restoration models in Wuqi county, at the same interval of soil organic, total nitrogen, total phosphorus content before returning farmland to forest [25]. Before the farmland was returning farmland and banning, they were all sloping farmland with poor soil that has been cultivated for many years. These two watersheds are adjacent to each other and belong to the same large watershed, and the atmospheric, hydrological, and the topography, geology and soil conditions are basically similar. The Chai Gou watershed carried out artificial land preparation (horizontal ditch, horizontal steps, fish scale pits, V-shaped aggregates). The ecological restoration method combines the engineering measures of afforestation and biological measures. Various types of vegetation were planted, including *Populus simonii* Carr, *Armeniaca sibirica* (L.) Lam, *Pinus tabuliformis* Carr., *Hippophae rhamnoides* L., *Caragana korshinskii* Kom., *Lespedeza bicolor* Turcz etc., while the He Gou watershed began to close the mountains and prohibit grazing, and no artificial measures are implemented, and after years of natural growth, diversified grass vegetation have grown, such as *Artemisia gmelinii*, *Stipa bungeana* Trin., *Phragmites australis* (Cav.) Trin. ex Steud., *Calamagrostis epigeios* (L.) Roth, *Lespedeza daurica* (Laxm.) Schindl., and *Potentilla chinensis* Ser.

2.2. Sample Terrain Design and Sample Collection

By comprehensively investigating the Chai Gou and He Gou watersheds, we established 5 sample zones on the slopes in the two watersheds in August 2016, respectively, with each having 4 sample collection spots (Figure 1), and a total of 40 collection spots were built for sampling investigation. At each sampling spot, three soil profiles with a depth of 60 cm were excavated, and the cutting-ring method was applied for soil sample collection. A total of 3 layers of soil at a depth of 0–20, 20–40 and 40–60 cm were taken vertically down the top, and triplicates from the same layer of the soil were obtained to test the physical characteristics. At the same time, 500 g of mixed soil sample was taken from the same soil layer from the same profile at the same sample collection spot, enclosed in the cloth bags and taken back to the lab to test the chemical characteristics after wind drying.

2.3. Soil Indicator Test

The drying method was applied to measure the natural soil water content (SWC). The "ring-cutting and water immersion" method was used to measure and calculate the soil bulk density (BD), field capacity (FC), caterpillar water holding capacity (CWHC) and total capillary porosity (TCP) [26]. The pH value was measured using the PHS-320 high precision intelligent acidity gauge, and the water-soil ratio was 2.5:1. The potassium dichromate oxidation process combined with the heating method was used to measure the soil organic carbon (SOC). Available nitrogen (AN) was determined using the alkaline hydrolysis—Diffusion absorption method, available phosphorus (AP) was ascertained using the molybdenum antimony anti-colorimetric method, and available potassium (AK) by the flame photometer method. Total nitrogen (TN) was determined using the kjeldah method. Total phosphorus (TP) was identified based on the sodium hydroxide melting-molybdenum antimony colorimetric method [27]. Permanganate titration method was applied to determine catalase (CAT), sucrase (SUC), urease (URE), and alkaline phosphatase activity (ALP) was determined using 3,5-dinitro salicylic acid, sodium hypochlorite, disodium phenyl phosphate hydrate on the spectrophotometer and the colorimetry method [28].

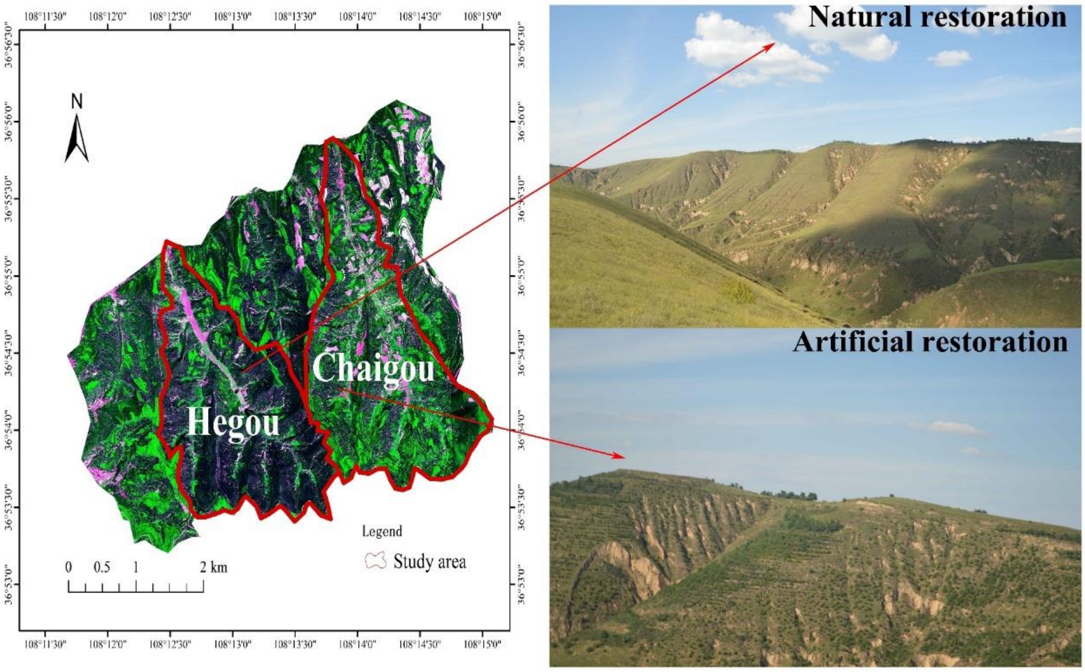

Figure 1. Sample location spot graph.

2.4. Soil Quality Evaluation Method

A total of 16 indicators of the physical, chemical and biological characteristics of the soil were selected as the preliminary indicators for the soil quality evaluation. The principal component analysis (PCA) method was used to perform the dimensionality reduction and grouping of the 16 soil indicators. The principal components whose characteristic value was $\geq$1 were extracted, and those with an indicator load >0.5 were grouped together. If the load of one indicator is greater than 0.5 at different principal components, the indicator would be merged into the group with a relatively low correlation with the other groups. The Norm values of each indicator group were calculated, and the indicators were retained if the value was within 10% range of its maximal Norm value. If there was only one indicator in the group, it would be instantly included in the minimal data set of soil quality evaluation. If multiple indicators were retained in the group, whether the indicator would be used would be determined by its correlation with other indicators. If the remaining indicators showed irrelevance or negative relevance, they would be retained and those which had the highest correlational coefficient with the other indicators would be included into the minimal data set of soil quality evaluation. Eventually, the minimal data set of soil indicators which significantly influences the soil quality evaluation was filtered [29].

The Norm value is calculated as follows:

$$N_{ik} = \sqrt{\sum_{i}^{k}(U_{ik}^{2}M_{k})} \tag{1}$$

where N_{ik} is comprehensive loading of soil variable i on the first k principal components; U_{ik} is the loading of soil variable i on PCk; M_k is the eigenvalue of the principal component.

To avoid the error caused by subjectivity which may influence the determination of the soil quality evaluation indicators, the principal component analysis (PCA) is used to determine the weights of each evaluation indicator. After analyzing the major component of the participating indicators, the common factor variance of them was obtained and divided by the adding that of each indicator to play as the weight of each participating indicator.

In the vague comprehensive evaluation, the membership degree of the valuation indicator was determined by the membership function it belongs to. The membership function usually contains an ascending membership function and a descending one, which is shown as follows, respectively [30]:

$$f(x) = \begin{cases} 0.1, x \leq L \\ 0.9 \times \dfrac{x-L}{U-L} + 0.1, L < x < U \\ 1, x \geq U \end{cases} \tag{2}$$

$$f(x) = \begin{cases} 1, x \leq L \\ 1 - 0.9 \times \dfrac{x-L}{U-L}, L < x < U \\ 0.1, x \geq U \end{cases} \tag{3}$$

where $f(x)$ is the membership degree of the soil indicator; x is the actual mean of a certain soil indicator; L, U is the lower and the higher thresholds of the actually measured indicator, respectively.

The soil quality evaluation indicator (SQI) was calculated with the weighted evaluation method. The higher SQI value indicates a better restoration effect of the soil quality. Here is the formula:

$$SQI = \sum_{i=1}^{n} R_i \times F(x_i) \tag{4}$$

where SQI is the soil quality evaluation indicator; R_i is the weighted value of each indicator; n is the number of evaluation indicators; $F(x_i)$ is the membership degree value of each evaluation indicator.

2.5. Data Handling

Excel 2016 was adopted to prepare the data and calculate the relevant indicators. SPSS 22.0 was applied for the single factor variance analysis and principal component analysis and t test. Origin 2018 was for the Pearson relevance analysis and graphing, and ArcMap 10.3 software for mapping.

3. Results

3.1. The Content of Carbon, Nitrogen and Phosphorus in the Soil and Their Respective Stoichiometric Characteristics under Different Restoration Modes

Table 1 shows that there is basically no significant difference in the data statistics of soil carbon, nitrogen and phosphorus contents under different restoration modes in the study region, but both the SOC and TN content under the artificial restoration is higher than that of the natural restoration, while the TP content is lower. The content of SOC, TN and TP decreases as the depth of soil layers increases, which presents a significant vertical distribution pattern. In the soil layer 60 cm down from the top of the soil, the degrees of vertical spatial content variability of SOC and TN under two restoration modes are both higher than that of TP, wherein the content variability of carbon and phosphorus is at a high degree. The spatial variability degree of SOC and TN content in the soil under artificial restoration is higher than that under natural restoration.

Figure 2 shows that the ratios of C:N, C:P, and N:P in the two watersheds decrease with the increase of the soil layer depth. Under the natural restoration, the mean values of the ratios of C:N, C:P and N:P are 9.84, 6.58 and 0.72, respectively, and are 7.30, 7.31 and 0.99 under the artificial restoration. Except for the C:N ratio of the artificial restoration mode, which is significantly lower than that of the natural restoration mode ($p < 0.05$), the rest of the stoichiometric ratios of the artificial restoration mode are higher than those of the natural restoration mode, the difference of C:P between the two restoration modes is not significant, but the N:P difference was significant ($p < 0.05$). According to the Wilding variability degree classification standard based on the soil characteristic variability coefficients [31] (the variability coefficient <15% as small variability; 16–35%, as medium variability; >36%, as high variability) and under the two restoration modes, the variability of the ratio of C:N is medium, and the variability degrees of the ratios of C:P and N:P are high.

Table 1. The SOC, TN and TP content.

Sample Area	Total Nutrients	Soil Depth/cm	Mean g/kg	Maximum g/kg	Minimum g/kg	Coefficient of Variation %
Natural restoration model	SOC	0–20	4.67 ± 1.26 a	7.03	2.36	39.81%
		20–40	3.34 ± 1.08 a	5.22	1.65	
		40–60	2.82 ± 1.28 a	7.31	0.87	
	TN	0–20	0.48 ± 0.15 a	0.81	0.27	40.82%
		20–40	0.38 ± 0.15 b	0.67	0.12	
		40–60	0.32 ± 0.13 a	0.55	0.12	
	TP	0–20	0.56 ± 0.07 a	0.69	0.4	10.4%
		20–40	0.54 ± 0.05 a	0.64	0.41	
		40–60	0.54 ± 0.05 a	0.61	0.41	
Artificial restoration mode	SOC	0–20	4.42 ± 2.01 a	8.22	1.37	50.99%
		20–40	3.92 ± 1.88 a	7.6	1.29	
		40–60	3.07 ± 1.67 a	6.13	0.49	
	TN	0–20	0.6 ± 0.26 a	1.18	0.2	46.23%
		20–40	0.53 ± 0.22 a	1	0.19	
		40–60	0.42 ± 0.20 a	0.84	0.18	
	TP	0–20	0.52 ± 0.06 a	0.62	0.39	10.41%
		20–40	0.51 ± 0.05 a	0.6	0.43	
		40–60	0.51 ± 0.05 a	0.61	0.39	

Note: SOC, soil organic carbon (g kg^{-1}); TN, total nitrogen (g kg^{-1}); TP, total phosphorus; (g kg^{-1}). Different lowercase letters indicate that soil indicators of the same soil layer are significantly dif-ferent between the two restoration modes (p < 0.05). Same as below.

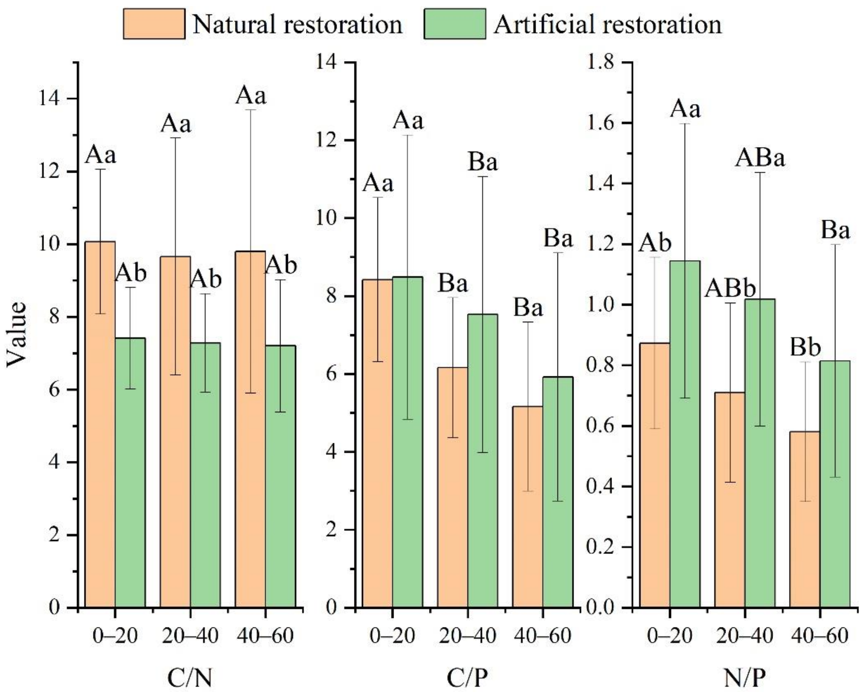

Figure 2. The metrological measurement comparison of SOC, TN and TP in soil. Note: Different capital letters indicate significant soil index differences between different soil layers using the same restoration method (p < 0.05).

3.2. The Soil Quality Evaluation after Using Different Restoration Modes

3.2.1. The Statistical Features of the Soil Indicators under Different Restoration Modes

Table 2 shows that the soil in the study region is weakly alkaline. Under the artificial restoration mode, the field capacity, natural water holding content, available nitrogen, available potassium, organic carbon content and the activity of sucrase and urease in the field are higher than those under the natural restoration mode, however, the other soil indicators show a higher level under the natural restoration mode, and there are significant differences in soil field capacity, available phosphorus, available potassium and sucrase between the two restoration modes ($p < 0.05$).

Table 2. The statistical features of soil indicators under different restoration modes.

Soil Indicator	Restoration Pattern	Mean g/kg	Maximum g/kg	Minimum g/kg	Coefficient of Variation %
BD	Natural	1.26 ± 0.04 a	1.37	1.11	3.55
	Artificial	1.24 ± 0.11 a	1.64	0.96	9.03
FC	Natural	31.83 ± 2.88 b	38.47	20.06	9.06
	Artificial	35.39 ± 6.75 a	56.22	20.19	19.06
CWHC	Natural	37.60 ± 2.37 a	32.55	45.78	6.31
	Artificial	37.30 ± 4.52 a	47.96	24.42	12.13
TCP	Natural	52.77 ± 2.29 a	60.7	48	4.33
	Artificial	51.63 ± 3.61 a	59.65	44.9	7
SWC	Natural	8.86 ± 2.25 a	14.4	2.97	25.42
	Artificial	9.02 ± 3.18 a	15.61	3.65	35.23
AN	Natural	34.32 ± 12.53 a	79.87	16.95	36.51
	Artificial	40.01 ± 17.19 a	91.93	15	42.97
AP	Natural	2.70 ± 1.12 a	7.32	0.88	41.33
	Artificial	1.97 ± 1.07 b	5.76	0.53	54.43
AK	Natural	86.99 ± 22.94 b	155.97	55.45	26.37
	Artificial	109.66 ± 35.81 a	223.87	53.4	32.65
pH	Natural	8.47 ± 0.07 a	8.59	8.3	0.77
	Artificial	8.44 ± 0.14 a	8.72	8.21	1.6
SUC	Natural	5.12 ± 3.68 b	14.59	0.57	71.96
	Artificial	7.96 ± 5.57 a	23.13	0.62	69.96
ALP	Natural	0.91 ± 0.31 a	2.28	0.31	34.33
	Artificial	0.87 ± 0.27 a	1.55	0.15	31.26
CAT	Natural	0.64 ± 0.11 a	0.24	0.9	17.75
	Artificial	0.65 ± 0.12 a	0.9	0.33	18.09
URE	Natural	8.75 ± 4.12 a	19.91	2.26	47.09
	Artificial	9.5 ± 4.80 a	17.05	1.63	50.54

Note: BD, bulk density (g cm^{-3}); FC, field capacity (%); CWHC, caterpillar water holding capacity (%); TCP, total capillary porosity (%); SWC, soil water content (%); AN, alkaline nitrogen (mg kg^{-1}); AP, Available phosphorus (mg kg^{-1}); AK, available potassium (mg kg^{-1}); SUC, sucrase (mg g 24 h); ALP, alkaline phosphatase (mg g 24 h); CAT, catalase (mg g 20 min); URE, urease (mg g 24 h). Same as below. Different lowercase letters indicate that soil indicators of the same soil layer are significantly different between the two restoration modes ($p < 0.05$).

The watershed soil characteristics under different restoration modes have different spatial variability degrees. The spatial variation of physical indicators such as soil bulk density, capillary water holding capacity, and total porosity is relatively small and weak, and the spatial variability degree of the other indicators is larger than 15%. Except for the variability degree of sucrase and alkaline phosphatase that is lower under the artificial restoration mode, the variability degree of the other indicators is higher under the artificial restoration mode than that under the natural restoration mode.

3.2.2. Research on the Minimal Data Set of Soil Quality Evaluation Indicator

From Table 3, the characteristic values of the first five principal components whose characteristic value ≥1 and variance interpretation probability of each principal component is 33%, 15.899%, 10.605%, 10.018% and 8.241%. The cumulative contribution rate is 77.763%. Upon the grouping of the indicators of the absolute load values of which >0.5 in each principal component and calculating the Norm values of each indicator in each group and according to the selection rule that the highest Norm value should be within the 10% range, the following preliminary indicators were chosen: sucrase, urease, organic carbon, alkali-hydrolysable nitrogen, total nitrogen, capillary water holding volume, available potassium, field water holding quantity, moisture content and available phosphorus.

In the relevance analysis on the indicators shown in Figure 3, the correlational coefficients between two indicators in the same group were compared, and it was finalized that the soil quality evaluation indicator minimal data set of this study includes organic carbon, capillary water holding volume, available potassium, moisture content and available phosphorus, and wherein the soil organic carbon and capillary water holding volume were two indicators, with relatively large weights and were essential in the soil quality evaluation.

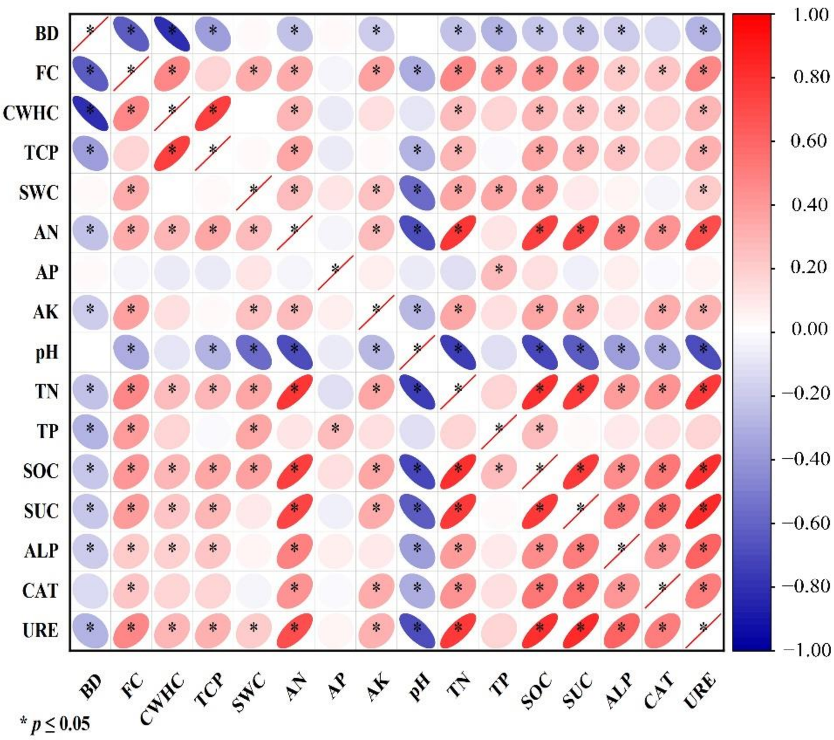

Figure 3. Correlation analysis on the soil indicators.

Table 3. The indicator weight of soil quality evaluation.

	1	2	3	4	5	Classing	Norm Value	Weight 1	Weight 2
SUC	0.885	0.106	0.191	−0.033	−0.112	1	2.033	0.068	
URE	0.870	0.177	0.177	0.078	0.074	1	1.999	0.067	
SOC	0.842	0.146	0.176	0.257	0.143	1	1.934	0.068	0.235
AN	0.817	0.181	0.056	0.227	−0.062	1	1.878	0.061	
TN	0.799	0.144	0.237	0.329	−0.142	1	1.837	0.068	
ALP	0.678	0.141	−0.070	−0.227	0.216	1	1.558	0.047	
CAT	0.653	−0.013	0.315	−0.360	0.067	1	1.499	0.053	
CWHC	0.144	0.956	0.096	−0.023	−0.002	2	1.524	0.076	0.240
BD	−0.055	−0.813	−0.418	0.118	−0.085	2	1.297	0.069	

Table 3. *Cont.*

	1	2	3	4	5	Classing	Norm Value	Weight 1	Weight 2
TCP	0.325	0.757	−0.315	0.094	−0.093	2	1.208	0.064	
AK	0.271	−0.039	0.692	0.076	−0.023	3	0.902	0.045	0.158
FC	0.234	0.459	0.679	0.208	0.077	3	0.884	0.062	
SWC	0.154	−0.042	0.187	0.867	0.173	4	1.098	0.068	0.182
pH	−0.746	0.009	−0.013	−0.548	0.003	4	0.944	0.069	
AP	0.041	−0.095	−0.114	0.012	0.865	5	0.993	0.062	0.185
TP	0.006	0.185	0.405	0.253	0.636	5	0.731	0.054	
Eigenvalue	5.280	2.544	1.697	1.603	1.319				
Variance contribution rate (%)	33.000	15.899	10.605	10.018	8.241				
Accumulative contribution rate (%)	33.000	48.899	59.504	69.522	77.763				

3.2.3. The Differential Characteristics of Soil Quality under Different Restoration Modes

From Table 4, based on the soil quality evaluation of the total and minimal data sets, the surface soil quality indicators (0–20 cm depth) under the natural or artificial restorations show few differences. That means that compared with the natural restoration mode, the artificial one will not improve the surface soil quality. However, it can significantly improve the soil quality with a depth below 20 cm.

From Figure 4, according to the linear fitting of the minimal and the total data sets based on the formula: $y = 0.829x + 0.058$, $R^2 = 0.76$, they show a significant positive relevance. Combined with soil quality index, it can be found that the minimum data set of soil quality evaluation index can effectively replace all index data sets.

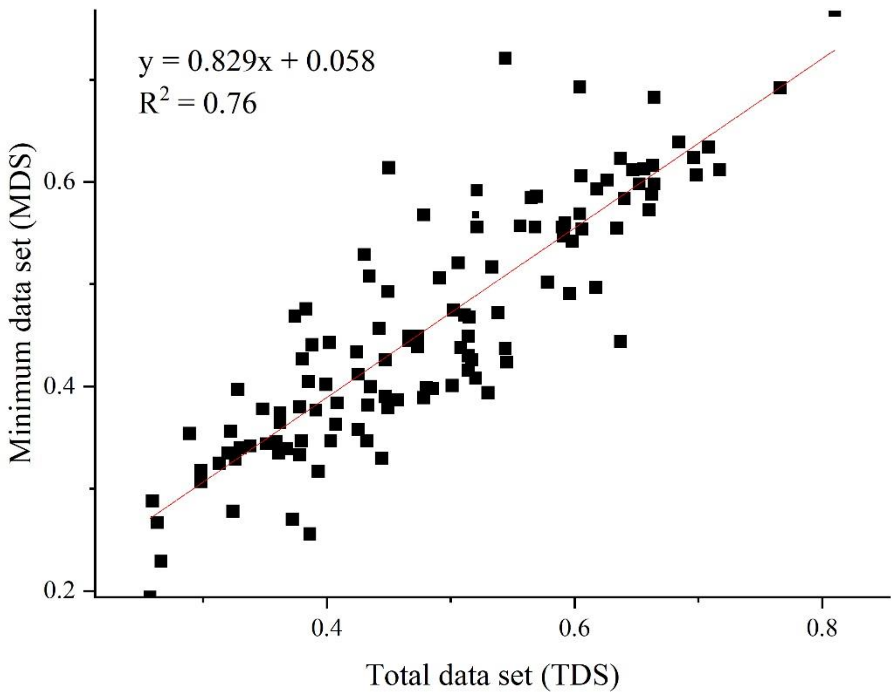

Figure 4. Soil quality linear fitting.

Table 4. The soil quality evaluation results.

Restoration Pattern	Soil Depth	All Index Data Sets	Mean	Coefficient of Variation%	Minimum Index Dataset	Mean	Coefficient of Variation %
Natural restoration model	0–20 20–40 40–60	0.55 0.45 0.40	0.47	22.59	0.50 0.43 0.41	0.45	24.65
Artificial restoration mode	0–20 20–40 40–60	0.54 0.51 0.47	0.51	26.8	0.48 0.47 0.47	0.47	25.56

4. Discussion

4.1. The Differential Analysis of the Carbon, Nitrogen and Phosphorus Content in the Soil and Stoichiometric Characteristics of Soil under Different Restoration Modes

In the study, the total phosphorus content in the soil under the natural restoration mode is higher than that under the artificial restoration mode, while the organic carbon content and the total nitrogen of the former are lower than that of the latter (Table 1). This is mainly because the phosphorus in the soil is formed after rock weathering and stays relatively stable [32,33] and most vegetation in the natural restoration region are herbal plants, the biomass of which is comparatively low, and the phosphorus consumption needed for the growth is at a low level. Yu et al. [34] have found that the natural restoration mode promotes phosphorus reservation in the soil while the artificial one has the opposite effect. The organic carbon in the soil mainly comes from litter, eroded matters and secretion of the roots. In the artificial restoration region, a vast area is planted with *Robinia pseudoacacia*, *Populus simonii* and *Hippophae rhamnoides*, which increase the carbon content of the soil. In the meantime, the plant rhizobia can fix the nitrogen in the air to enrich the nitrogen element in the soil [35], which causes the relatively high organic carbon and total nitrogen content under the artificial restoration mode.

In the study, the values of all the other chemical metrological indicators except the ratio of C:N under the artificial mode are higher than those under the natural restoration mode (Figure 2), and the stoichiometric ratios of soil carbon, nitrogen and phosphorus in this study area were lower than the national average of China [36]. Studies showed that soil C:N ratio reflected the mineralization rate of soil organic matter, and the soil C:N of the artificial restoration mode (7.3) in this study area was slightly lower than natural restoration mode (9.84). Therefore, the mineralization rate of soil organic matter in artificial restoration watersheds was higher than natural restoration watersheds. Soil C:P ratio can measure the potential of microbial mineralized soil organic matter to release phosphorus, and absorb and retain phosphorus from the environment [37]. Studies have shown that vegetation growth can be limited by total phosphorus, especially in artificial restoration watersheds [38,39]. The results of this study showed that the total phosphorus of artificial restoration watersheds was lower than natural restoration, and vegetation restoration may be affected by total phosphorus in the future. Soil N:P ratio can reflect the balance of soil nitrogen and phosphorus [40]. Compared with natural restoration, artificial restoration had a wider source of soil nitrogen, and resulting in higher soil N:P ratio in artificial restoration mode. At the same time, the results showed that the overall performance of soil nitrogen in these two restoration models in the study area was relatively lacking and the nitrogen and phosphorus were unbalanced.

4.2. The Different Analyses of Soil Indicators under Different Restoration Modes

The study showed that the field capacity under the artificial restoration mode is higher than that under the natural one (Table 2), which indicates that the better soil water source reservation capacity and soil maintenance and water reservation capacity of the artificial mode. Yu et al. [41] have found that the water reservation effect under the artificial restoration is better than that of the natural restoration mode during the study of Yangtze

River Watershed. In the meantime, the artificial restoration mode can better increase the content of available nitrogen, available potassium, and organic carbon and promote sucrase and urease activity than the natural restoration mode (Table 2). This is largely relevant to the litter, eroded matters and root system secretions. The studies by Chang et al. [42] have shown that the root system biomass quantity is the biggest source of soil nutrients. The sucrase can characterize the degree and level of soil fertility, and urease participates in the decomposition and synthesis of the remains of the animals and plants and the activity process of the microorganisms [43]. The high content of the available nitrogen, available potassium and organic carbon in the Chai Gou watershed was higher, all of which prove that the soil nutrient supply capacity is better under the artificial restoration mode. During the study on the semi-arid loess region in the small watershed, Yang, Wen, Yang, Li, Wei and Zhang [8] found that soil fertility capacity under the artificial restoration is better than that under the natural one. In addition, the former produces a better production capacity, nutrient storage capacity and circulation function. According to the study, the soil bulk density, capillary water holding quantity, total porosity and the other physical indicators have rather low spatial variability, which belongs to the weak variability (Table 2). The main reason for that is that the spatial variability of the soil physical features is mainly controlled by the climate, matrix and terrain [44]. In addition, the similarities in the exogenic force allow the lower spatial variability degree within the local range of the soil physical characteristics.

4.3. The Soil Quality Analysis under Different Restoration Modes

The soil quality evaluation minimal data set filtered by the study included organic carbon, capillary water holding quantity, available potassium, moisture content and available phosphorus (Table 3 and Figure 3). Organic carbon is the critical indicator of soil quality and overall soil production [45]. Capillary water holding quantity can reflect the soil capillary water reservation capacity and water collection capacity, and the soil porosity development status and indicate the porosity structure and water holding status of the soil to some extent [46]. The moisture content of the soil is the crucial factor influencing plant growth and many ecological environment processes [47]. The content of the soil available potassium and phosphorus is an important indicator to reflect the soil fertility and intensity of the nutrient supply. Studies have proved that vegetation restoration can effectively improve the soil nutrient content [48]. According to the study, soil organic carbon and capillary water holding quantity are essential indicators in the soil quality evaluation, with a relatively high weight value, which is similar to the previous study result [49]. The minimal data set on the Yellow River Delta Region collected by Wu et al. [50] includes soil total nitrogen, available phosphorus, available potassium, soil organic nitrogen, soil salinity and pH. Based on these results, organic carbon, capillary water holding quantity, potassium, moisture content and phosphorus are frequently included in the soil quality assessment minimal dataset. Hence, the minimal data set selected by the study has a representative significance for the different soil quality evaluations in the studied region. Compared with the total data set, the minimal one had a higher variability coefficient, which means the latter can reflect the soil quality more sensitively, which is similar to the results of the previous study. The study of Andrews et al. [51] and Liu et al. [52] have shown that the minimal data set can represent the total data set. The study of Rahmanipour et al. [53] has shown that the minimal data set evaluation is better than that based on the total data set.

The soil quality decreased with the increase of the soil layer depth (Table 4), which is consistent with the previous result [54]. For the soil layers from 20–40 and 40–60 cm in the study region, the soil quality under the artificial restoration mode is better than that under the natural one (Table 4), which shows that the former is more effective on the soil improvement for the deeper layer. The reason is that the root and surface system is deeper under the artificial restoration than that under the natural restoration. All the soil quality evaluation results based on the total and the minimal data sets demonstrate that the artificial restoration mode produces better soil quality than natural restoration

(Table 4). Liu, et al. [55] pointed out that the indicator level under the artificial mode was obviously higher than that of the natural restoration mode, including vegetation biomass, coverage, and average height during the study of the vegetation groups under the different restoration modes. These studies all have proven the feasibility of the artificial vegetation restoration mode, which can increase the biomass in the short term and improve the local soil quality significantly. Although the effect of the artificial restoration mode is remarkable, in the future artificial restoration process, we suggest that the planting density should be reasonably controlled based on the local soil and water carrying capacity, and a more reasonable vegetation configuration should be selected for better ecological restoration.

5. Conclusions

The study showed that under two restoration modes, the ratios of C:N, C:P and N:P decreased with the increase of the soil layer. Under the artificial restoration mode, except for the ratio of C:N, all the other chemical metrological ratios were higher than those of the natural restoration mode. In addition, the former can effectively improve the organic carbon and total nitrogen content in the soil, however, the total phosphorus content of the soil in the natural restoration mode was higher than that in the artificial restoration mode. The artificial restoration model has stronger spatial heterogeneity for most soil indicators, and the variation degree is higher than that of the natural restoration model. The current artificial restoration mode can better restore the soil quality, especially for the soil layers below 20 cm. In addition, the minimal data set of the studied region, including organic carbon, capillary water holding quantity, available potassium, moisture content, and available phosphorus, can reflect the soil quality more sensitively. Therefore, the artificial restoration mode can improve the soil quality of the study area when promoting the growth of vegetation biomass and quickly achieving greening. In addition, it can be used in the ecological restoration of the study area, but the appropriate density of afforestation and the mode of vegetation configuration need further research.

Author Contributions: Conceptualization, R.G., N.A. and Z.Z.; methodology, R.G., N.A., G.L., C.L. and Z.Z.; writing—original draft preparation, R.G.; writing—review and editing, N.A. and R.G.; supervision, N.A., G.L. and C.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Shaanxi Natural Science Basic Research Project (2021JQ-626), IWHR Research & Development Support Program (SC0145B012022, SC0202A012018) and the National Natural Science Foundation of China (32060297, 31370541).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: We are very grateful to Liu Guangliang, director of the Ecological (forest) Park Management Office of Wuqi County, for his help in field sampling, and we thank reviewers and editors for their reviews of this manuscript.

Conflicts of Interest: The authors declare that they have no known competing financial interest or personal relationships that could have appeared to influence the work reported in this paper.

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