

Article

Develop a Soil Quality Index to Study the Results of Black Locust on Soil Quality below Different Allocation Patterns

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Abstract: Mining areas are currently a typical ecosystem that is severely destroyed within the world. Over the years, mining activities have caused serious soil damage. Therefore, the soil restoration of abandoned mines has become a vital sustainable development strategy. The ecological environment within the hilly area of the Loess Plateau is extremely fragile, with serious soil erosion; *Robinia pseudoacacia* is the most popular tree species for land reclamation in mining areas within the Loess Plateau. To review the different various effects of *Robinia pseudoacacia* on soil quality below different configuration modes, this paper has chosen two sample plots within the southern dump of the Pingshuo mining area for comparison. The first plot is a *Robinia pseudoacacia-Ulmus pumila-Ailanthus altissima* broadleaf mixed forest, and the second plot is a locust tree broadleaf pure forest. The vegetation indicators and soil physical and chemical properties of the four stages in 1993, 2010, 2015, and 2020 were investigated. Principal component analysis is employed to develop the Soil Quality Index to perceive the changes within the Soil Quality Index over time. It is calculated that the Soil Quality Index of Plot I rose from 0.501 in 1993 to 0.538 in 2020, and Plot II rose from 0.501 to 0.529. The higher the SQI, the higher the reclamation of the mining area. It is found that *Robinia pseudoacacia* within the *Robinia pseudoacacia-Ulmus pumila-Ailanthus altissima* broadleaf mixed forest has higher soil quality improvement than the pure genus *Robinia pseudoacacia* broadleaf forest. This article can demonstrate the changes in the quality of reclaimed soil in the mining area, and can also provide a reference for the selection of reclaimed vegetation in other mining areas.

Keywords: land reclamation; mining area soil; *Robinia pseudoacacia*; principal component analysis; Soil Quality Index; chemical property



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1. Introduction

To satisfy the growing desires of many sectors such as trade, mining activities worldwide have increased and become additionally intense. Up to now, mining areas in China, and therefore the world, have become severe and typical harmful areas [1,2]. The ecological and environmental issues caused by coal mining in mining areas and later ecological restoration have become a hot analysis object, and have attracted widespread attention from researchers, both in China and abroad [3,4]. Mining activities have caused damage to the ecology, inflicting abundant environmental issues such as pollution, vegetation degradation, and land destruction [5–9]. Mining activities additionally scale back the organic matter content and nutrient utilization within the soil [10,11]. From an environmental viewpoint, open-pit mining activities have degraded the land and destroyed the layering and structure of the soil. Its microorganism flora and nutrient cycle are essential for maintaining a healthy and productive scheme [12]. Soil is a crucial part of the terrestrial system, and it is one of the foremost necessary factors for maintaining plant and animal

productivity, supporting human health, and promoting biosphere development worldwide [13]. Soil scientists have repeatedly mentioned that soil and its services should be fully considered in the decision-making process [14,15]. Some scholars have also studied ecosystem services and soil properties [16]. The ecosystem service framework has become very important recently, mainly in terms of conservation and sustainable use, including soil [17], forest [18], landscape [19], watershed [20], and farmland [21]. It has been used to study the productivity of soil and compare it under different management systems [22] and agricultural systems [23]. Additionally, soil is a major environmental issue that affects vegetation restoration. Mining in mining areas can lead to an absence of nutrients within the soil within the mining area and can additionally cause excessive pollutants within the soil and frequently accelerate or inhibit the growth of vegetation [24,25].

To use land sustainably, soil quality is a crucial indicator [26]. It can be used to measure and quantify the sustainability of soil use [27]. Previous studies have shown that underground soil plays an important role in soil quality [28]; soil quality is completely different in different regions because its performance and its reasons for formation are different, or attributable to different types of land or land use [29], therefore soil quality varies between regions [30]. Previous studies have additionally shown [31,32] that some physical or chemical parameters such as wet soil, soil bulk density, and soil organic carbon will mirror changes in artificial soil quality.

For the analysis of soil quality, the foremost vital issue is to see a group of sensitive attributes that will mirror the operation of the soil. These attributes will be used as quality indicators [33,34]. Research in recent years has shown that the Soil Quality Index (SQI) has been utilized in several aspects of soil quality assessment, such as the impact of land-use modification, forest management, and ecological restoration [35,36]. SQI is outlined [37] because of the ability of the soil to supply the nutrients required to take care of crop yields throughout the expansion stage of plants within the system. SQI calculation methods [38] embrace professional opinions and Principal Component Analysis (PCA), and PCA has been additionally widely employed in recent years [36]. Recently, Zhang et al. studied [39,40] the influence of vegetation varieties on soil quality within the Loess Plateau of China and introduced the Soil Quality Index technique into their analysis. The SQI has currently been used in assessing the standard of soils of varied scales and locations [41–43]. The foremost effective use of the SQI at this time is in a variety of static and dynamic soil properties [28,38,44]. Worldwide Soil Organic Matter (SOM), nitrogen (N), phosphorus (P), potassium (K), and soil pH mostly mirror the static characteristics of the soil, and they are often referred to as variables usually employed in the SQI [45,46].

Robinia pseudoacacia has been the most widely used plantation tree species since the commencement of the People's Republic of China, and it has been effective in widely used in greening activity. *Robinia pseudoacacia* is expansive in its native area [47], but it is invasive in other areas where it has been introduced [48,49]. *Robinia pseudoacacia* has been widely employed in vegetation restoration in many degraded areas because of its rapid growth and ability to fix nitrogen [50,51]. Due to its strong adaptability, strong stress resistance, and strong drought resistance, its distribution area in China is getting larger and larger, and it has now become a native tree species in China [52]. Nitrogen-fixing plants can affect the dynamic characteristics of the community, particularly for those habitats with poor nutrient surroundings [53]. In the 1950s, *Robinia pseudoacacia* was planted for the first time in the Loess Plateau [54]. After many years of development, a large area of vegetation has been restored in the hilly area of the Loess Plateau [55]. *Robinia pseudoacacia*, as a representative style of forest vegetation within the loess hilly region, is of significance for the development of a far better ecological surrounding within the region.

So far, a large number of scholars have studied the impact of various vegetation restoration methods on soil quality. This has widely confirmed the response of soil to numerous management strategies [42,56]. Understanding the impact of vegetation restoration on soil quality can be used to form higher management strategies to revive soil function in degraded ecosystems. However, most studies investigate the link between totally dif-

ferent monoculture forests and their soils, and there are few studies on mixed forests containing identical species. Therefore, this paper has developed a Soil Quality Index to analyze the changes in soil quality over time in the *Robinia pseudoacacia* pure forest and the *Robinia pseudoacacia-Ulmus pumila-Ailanthus altissima* mixed forest by determining the soil indicators.

2. Materials and Methods

2.1. Study Sites

The Pingshuo mining area is the largest and most progressive coal mining enterprise in China; it is located in the Pinglu District, Shuozhou town, Shanxi Province (Figure 1). The geographic coordinates are 39°23′–39°37′ N, 112°10′–113°30′ E, and it has a typical temperate continental monsoon climate. The altitude in the area is 1300–1400 m, the annual average temperature is 5.4–13.8 °C, the average annual precipitation is 428.2–449 mm, 67% of the annual precipitation is concentrated in the period of June–August, the zonal soil in the study area is in the transition zone between chestnut soil and chestnut cinnamon soil, and the main zonal soil is chestnut soil. The parent material of soil formation is usually loess alluvium, proluvial, slope deposit, and a few aeolian sediments. The parent material is typically the weathering product of granite and gneiss. The soil in this area is sandy, the soil is dry, and the ventilation is good. Due to poor natural conditions, extensive farming has been carried out, making the soil barren. The organic matter content of the cultivated soil is generally 5.0–9.0 g/kg, and some is less than 5.0 g/kg. The total nitrogen content is generally 0.3–0.6 g/kg and the available phosphorus content is generally 5.0–8.0 mg/kg; a few are higher than 10 mg/kg, and the low is only 2.0–3.0 mg/kg. The content of available potassium is generally 50–90 mg/kg, and a few exceed 100 mg/kg. Vegetation is mainly dominated by herbs such as *Stipa capillata*. With a long history of development and a high farming index, the natural vegetation in this area is severely destroyed, and large grassland communities are rarely seen. Generally speaking, it is an agricultural farming landscape.

The Antaibao Open-pit Coal Mine is located in the northern part of the Pingshuo mining area and is the oldest coal mine in the Pingshuo mining area. The mining area is 36.24 km², with 974 million tons of geological reserves. Preparations began in 1982, construction started in July 1985, and the mine was completed and put into production in September 1987. The area of the Antaibao South Dumping Site is 178.21 hm². Vegetation reconstruction started in 1993, and it is one of the earlier reclaimed areas of the Antaibao Mine. The platform covers 1m of soil and the area of reclaimed woodland is 128.21 hm². The main types of vegetation are *Robinia pseudoacacia*, *Pinus tabuliformis*, *Ulmus pumila*, *Caragana microphylla*, and *Hippophae rhamnoides*, etc. At present, the south dump has shaped an arbor-shrub-grass multi-level and multi-type natural layout, which essentially covers the bare surface of the dump, and its ecological atmosphere has been effectively remodeled. Except for water in the first 3 years and pest control in the first 5 years, management measures such as artificial watering and fertilization have not been adopted so far.

2.2. Vegetation Survey and Analysis

The selected area during this study comes from the permanently fastened observation sample plot of the south dump of Antaibao Open-pit mine in the Pingshuo mining area. Four years, 1993, 2010, 2015, and 2020, were picked to investigate the dynamics of vegetation. We picked areas that were higher than 1.3 m and had survived within the four years of analysis, and picked two plots for comparison (see Figure 2). Both plot area units are one square measure (100 × 100 m) of flat land. Plot I is a *Robinia pseudoacacia-Ulmus pumila-Ailanthus altissima* broad-leafed mixed forest, and Plot II is a *Robinia pseudoacacia* pure broad-leafed forest (Table 1). The planting density of the two plots is the same. In every survey, all *Robinia pseudoacacia* in Plots I and II were monitored.

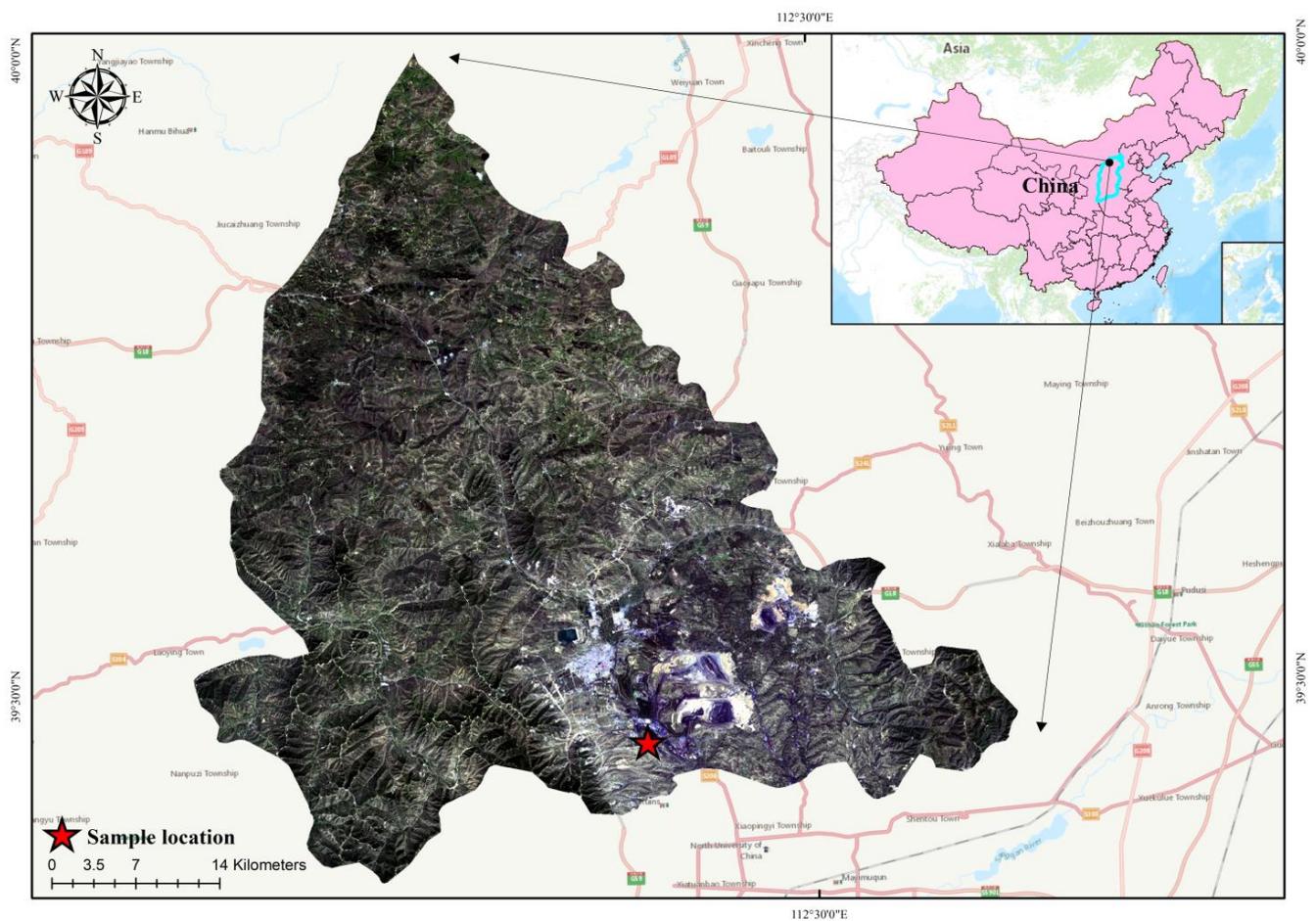


Figure 1. Geographical location of the study area.

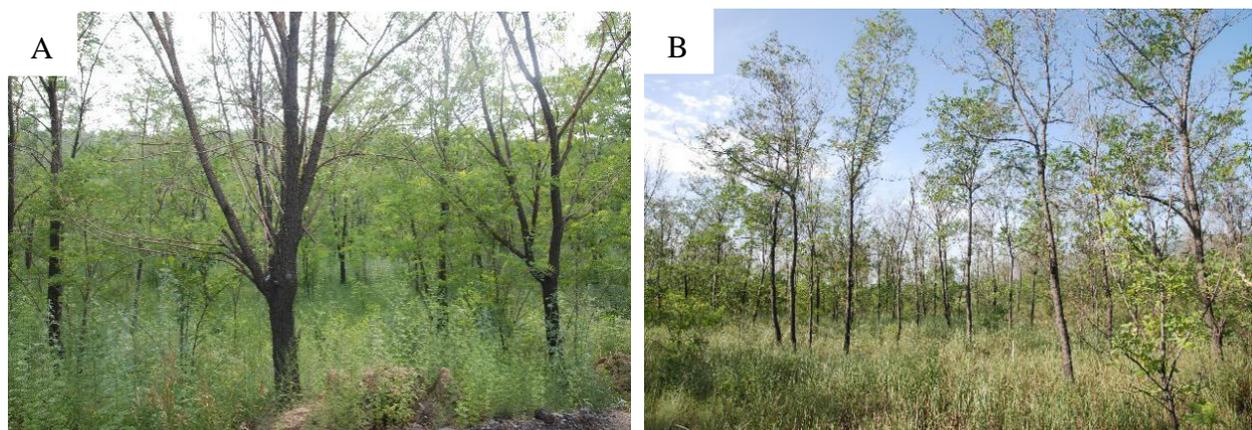


Figure 2. The landscapes of two sampling plots. (A): S I; (B): S II.

We tended to divide the 1 hm^2 plot into one hundred quadrats of 10 m \times 10 m, and every quadrat was divided into four small plots of 5 m \times 5 m (Figure 3). Within the two plots, we investigated diameter at breast height (DBH), height (TH), canopy length (CL), and width (CW) of *Robinia pseudoacacia*.

Forest Science (CTFS) soil sampling set up, and combined with the particular state of affairs of the study area, the particular sampling methodology is: divide the 1 hm² sample plot into nine grids (the grid size is 30 m × 30 m); take the node of every grid to be the point of reference for sampling, then randomly choose one from the eight directions (north, northeast, east, southeast, south, southwest, west, and northwest) of every point of reference within the chosen directions, 2 m, 5 m, and 15 m from the point of reference within the chosen direction; randomly choose 2 locations for extended sampling. Therefore, a total of 96 sampling points were set up in Plots I and II (Figure 4).

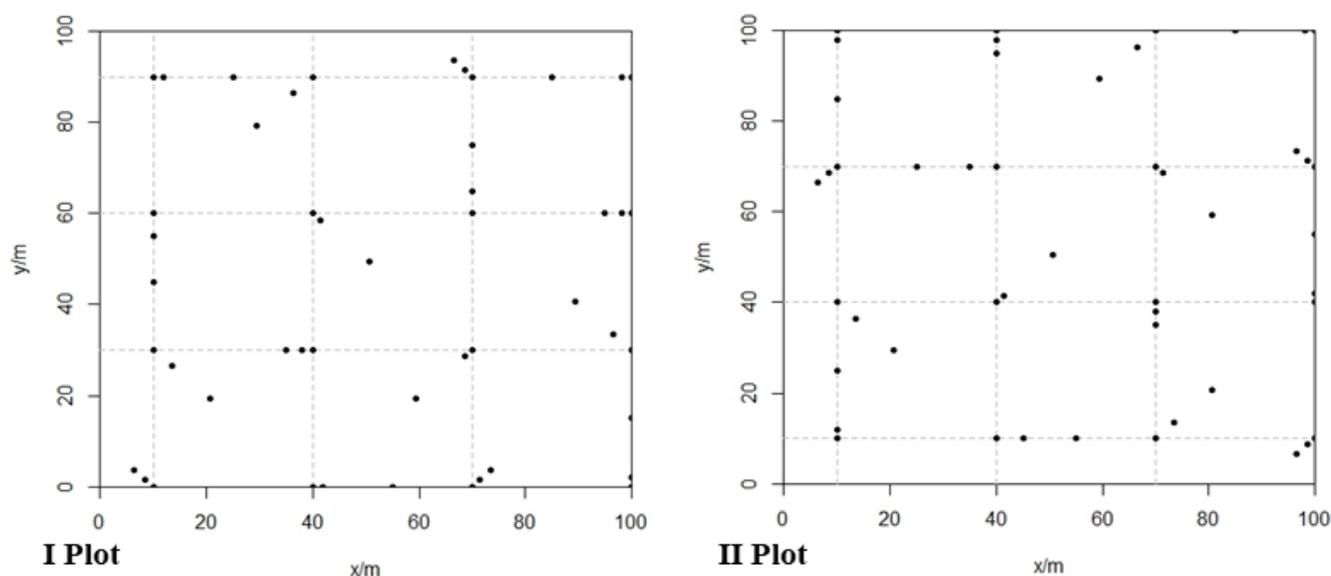


Figure 4. The spatial distribution of soil sample in the plots.

Before sampling, the litter on the surface of the sampling site was first removed, so that, at 20 cm apart, three soil samples with a depth of 0–10 cm could be collected with a soil auger (the diameter of the soil auger is 5 cm). The three soil samples were mixed and placed into a ziplock bag; the weight of the soil sample in each ziplock bag was 500 g. The obtained soil samples were dried in an oven at 105 °C for 48 h before testing, and stones with particles larger than 2 mm were separated from the dry soil (using a 2 mm sieve). The soil indicators tested during this study comprised pH scale, organic matter, total nitrogen, available phosphorous, and available potassium. The soil pH scale was measured by the potentiometric technique, the organic matter was measured by the potassium dichromate method–external heating method, the total nitrogen was measured by the Semi-micro Kjeldahl method, the effective phosphorus was measured by the 0.5 mol/L NaHCO₃ extraction-molybdenum antimony colorimetric method, and the available potassium was measured by the 1 mol/L NH₄OAc extraction-flame emission spectrometry method.

2.4. Soil Quality Index

To determine the Soil Quality Index (SQI), this paper used Principal Component Analysis (PCA) to pick acceptable variables [59–61], then analyzed and confirmed the weights of every variable to be employed in the calculation of SQI [28,62]. We used the five soil chemical indicators (SOM, TN, AP, AK, and pH), antecedently tested by soil sampling, to run PCA. Underneath the principal component (PC) of the run, we left variables with a high load factor. When keeping multiple variables on one principal component, we used correlation to work out whether or not these variables would be utilized in the SQI. If the correlation was too high, it was deleted from the SQI [63], if the high load factors were irrelevant or the correlation was low, then we tended to believe that every one of those factors was vital and that we could keep all the factors within the SQI. Finally, the weighted

summation methodology was employed to calculate the Soil Quality Index (SQI). The ultimate SQI equation supported PCA is as follows:

$$SQI = \sum_{i=1}^n (W_i \times S_i) \quad (3)$$

where W_i is the weighting factor of the indicators derived from the PCA conducted, S_i is the score of indicator, and n is the number of selected variables.

2.5. Statistical Analysis

For all analyses, we tended to use Microsoft excel and SPSS Statistics 20.0. We used a one-way analysis of variance (ANOVA) to check the average values of the assorted indicators of the vegetation and soil within the mining area. The distinction between individual means that were tested by Duncan's multiple range test (DMRT), and also the significance level, was $p < 0.05$. Principal component analysis was employed to work out the index weight of the soil.

3. Results and Discussion

3.1. Changes in Soil Properties

Figure 5 shows the dynamic changes of physical and chemical soil properties within the two plots from 1993 to 2020 for which we have done a polynomial fitting. All starting points in the figure are the same, which are the original soil content before the vegetation restoration in 1993. Improving soil quality is extremely necessary because it will leave reasonable agricultural productivity and environmental quality for future generations [64]. Underlying this premise, soil organic matter is a very important indicator to be considered within the analysis. It can be seen from Figure 5 that the soil organic matter content increased sharply after 2005. The organic matter content of Plot I increased from 16.69 g/kg in 1993 to 65.5 g/kg in 2020, with a rate of growth of 292.48%, and also the rate of growth of organic matter content in Plot II was 217.33%. The growth rate of Plot I is more than that of Plot II.

In 2016, Lei et al. [65] found that it takes 23 to 25 years for soil index values to return to their initial level in vegetation restoration areas. In this paper, the soil nitrogen content in each plot was inflated after 27 years of reclamation. In 2015, the N content of the two plots tended towards the initial landform, which is analogous to the results of H. Lei et al., 2016.

The variations in soil characteristics between vegetation types are primarily associated with AP, AK, and the soil pH scale [66]. A crucial indicator for evaluating soil health is the pH scale, particularly in mine soil, which has a significant impact on key soil processes [67]. Analysis additionally shows that the foremost appropriate pH scale value for soil is 6–7. In the soil PH fitting of this paper, it was found that the soil PH of the two plots area were each at the alkalinescent level; however, this decreased to variable degrees by 2020. The soil PH value of Plot I dropped sharply from 1993 to 2010, but by 2020 it was the same as Plot II. Though the PH value has not reached the foremost appropriate value, each plot has slightly improved.

The most restrictive nutrient within soil for plant growth is nitrogen, followed by phosphorus, though this is plentiful within soil [68]. The phosphorus content within the soil in the two plots has been decreasing over time. Plot I reduced from 28.3 mg/kg in 1993 to 3.77 mg/kg in 2020, and Plot II reduced from 28.3 mg/kg to 4.19 mg/kg. The reduction rates were 86.68% and 85.19%, respectively, indicating that there is a significant shortage of phosphorus within the Pingshuo mining area, particularly within the degraded or accumulated soil, where the phosphorus content is incredibly lacking, and recovery is incredibly troublesome [69].

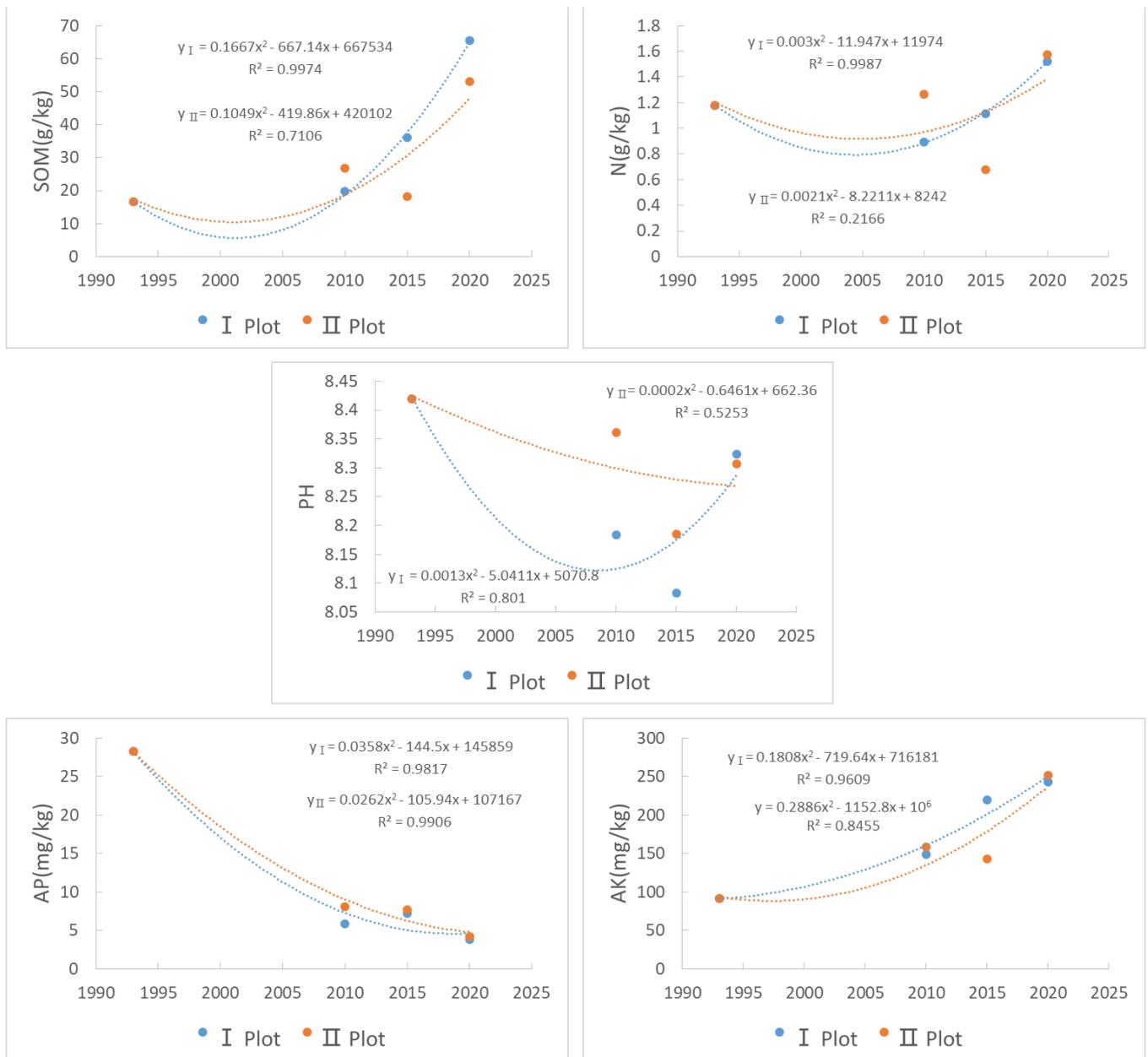


Figure 5. Soil index dynamics.

Due to its special structure and composition, the K content of mine soil is usually low [70]; this is additionally the case within the early stages of reclamation of the area studied during this article. However, with the passage of time, the available potassium content of the two plots showed an increasing upward trend. It can be seen from Figure 4 that the offered available potassium content of the two plots increased moderately before 2005, and increased considerably after 2005. Before 2020, the content of available potassium in Plot I is higher than that in Plot II.

3.2. Changes in Vegetation Indices

One artificial restoration measure regarding vegetation restoration is to show the land turning from non-vegetation or non-tillable land into plant-covered land, and it has been used as a good measure of a revived damaged natural ecosystem [71]. This has attracted additional attention from society and has become a popular topic in ecological analysis. Previous studies have shown that vegetation plays a major role in raising the physical and

chemical properties of soil in mining areas [72,73], and there are also other findings [74]; within the natural restoration method of vegetation, dominant woody plants are a crucial index to boost soil structure. Generally, woody vegetation is employed to enhance soil fertility; among these, legumes have the most optimum effect [75,76].

This paper focuses on *Robinia pseudoacacia* species and studies the changes of assorted plant indicators in *Robinia pseudoacacia-Ulmus pumila-Ailanthus altissima* mixed forest and pure *Robinia pseudoacacia* forest compares them with reclamation time (Figure 6). It can be seen from the figure that the vegetation indicators (height, diameter at breast height, canopy area, and biomass) increase over the years of reclamation. In the two plots, the vegetation indicators of *Robinia pseudoacacia* showed an increase; in Plot II, the plant height and biomass were more than that of Plot I before 2015 and were equivalent by 2020. Plant diameter at breast height from 1993 to 2020 was considerably higher in Plot II than in Plot I, whereas the canopy area of plants was higher in Plot I than in Plot II from 1993 to 2020; however, it was equivalent in 2020. It can be seen that, within the land reclamation, the height, diameter at breast height, and canopy area of *Robinia pseudoacacia* within the Plot II sample area were beyond those within Plot I. This confirms that there are different species within the Plot I sample area that need decent soil nutrients throughout the growth process, and therefore keep within the limits the growth rate of the *Robinia pseudoacacia*.

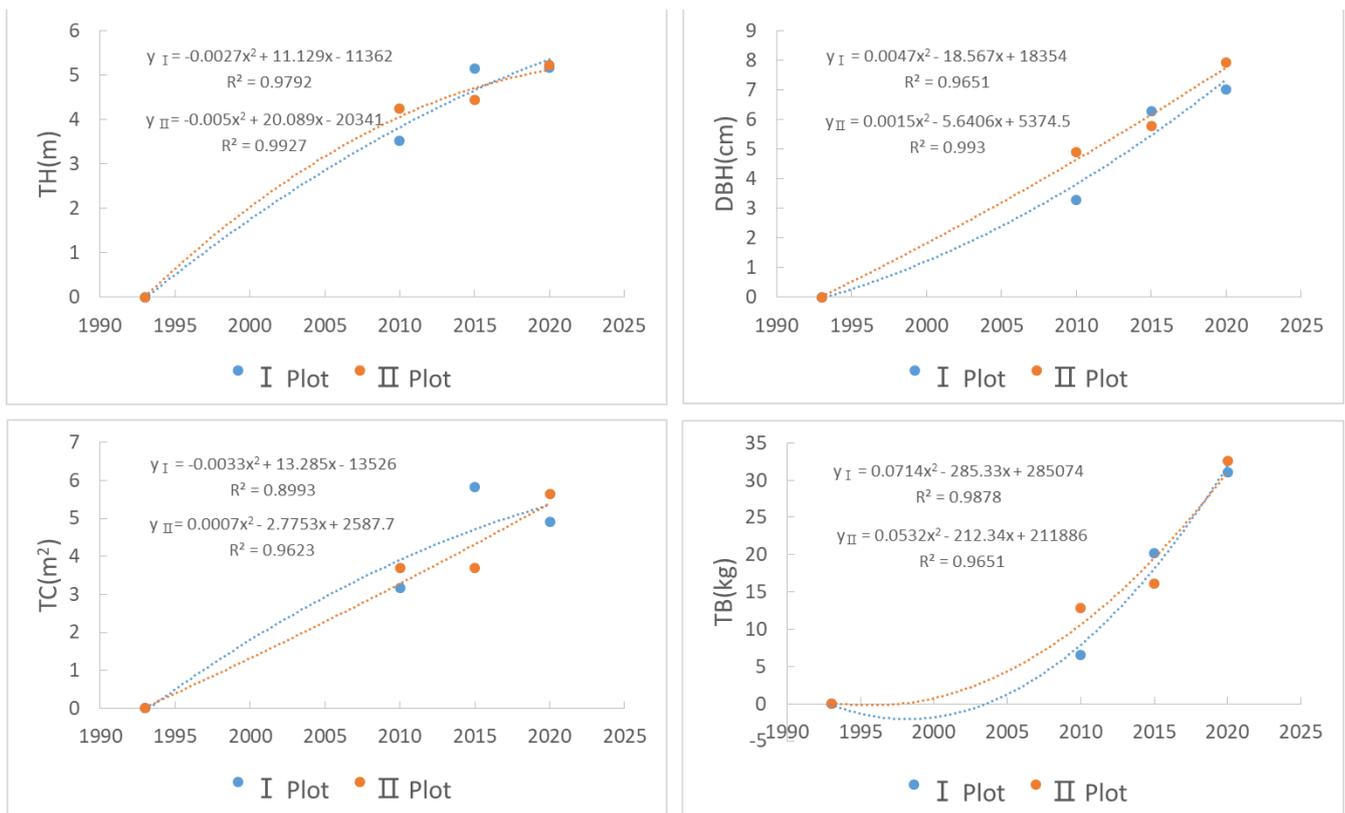


Figure 6. Vegetation index dynamics.

3.3. Soil Quality Index

In some of the literature, there are two main strategies for choosing indicators, one of which is professional opinion [44] and the other is an alternative mathematical-statistical system, such as regression equation and principal component analysis [59,77]. The Soil Quality Index is widely used for analysis because of the dependableness and accuracy of the results [78].

Therefore, this paper conducted principal component analysis on the soil characteristics of the reclaimed land in the Pingshuo mining area to calculate the soil indicators of

the ultimate Soil Quality Index. Two principal components were derived for every year. As a result of there being no significant correlation between every index, five soil indexes were finally determined in step with the weight below every principal element, in essence, all the soil indicators designated during this article: soil pH scale, total nitrogen, organic matter, available phosphorus, and available potassium. According to the weights of the two principal components within the principal element analysis, and therefore the scores of every soil index, the SQI equation was used to calculate the Soil Quality Index of every year within the two plots.

Studies such as those by Ngo-Mbogba [61] have shown that the SQIs of various vegetation sorts are considerably different. Some recent studies have additionally confirmed that different vegetation restoration types have different abilities to enhance soil quality [79,80].

The dynamic changes of the Soil Quality Index over time are shown in Figure 7. It can be seen that the Soil Quality Index of Plot I and Plot II was not modified considerably from 1993 to 2010, and tended to be stable. After 2010, the SQI of each plot rose. The Soil Quality Index of Plot I was once greater than that of Plot II in each year. The Soil Quality Index of Plot I rose from 0.501 in 1993 to 0.538 in 2020, with a rate of 7.48%, and Plot II increased from 0.501 to 0.529; the growth rate was 5.56%. Conjointly, the rate of Plot I used to be greater than that of Plot II.

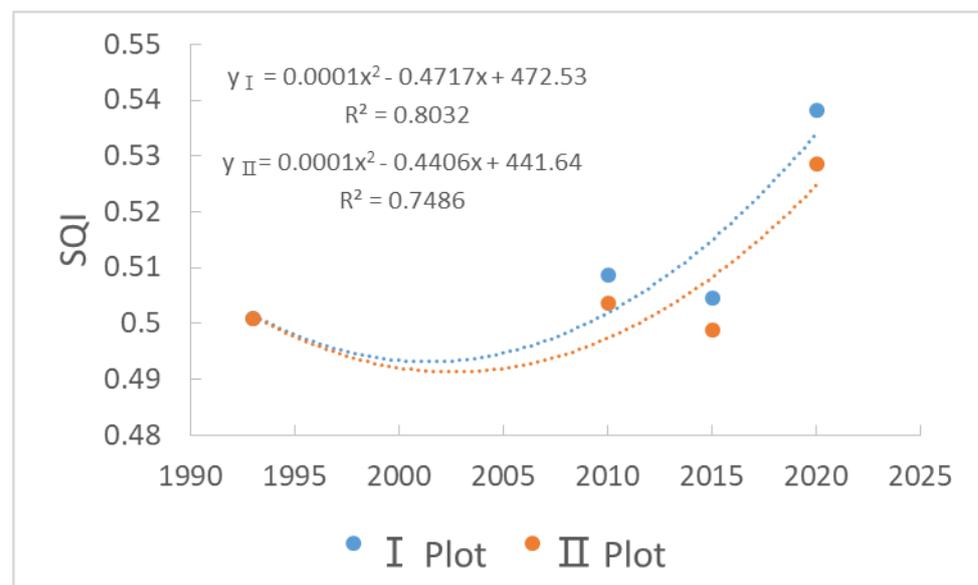


Figure 7. Soil Quality Index dynamics.

It can be seen from Figure 8 that the Soil Quality Index and varied plant indicators within the two plots are positively correlative. Plant height, diameter at breast height, canopy area, and biomass all increased with the rise of SQI, which additionally proves that SQI is useful for the area of study. The quality of the soil determines the growth of vegetation, and vegetation succession will promote the development of soil quality. Therefore, vegetation and reclamation recovery time are the two main reasons for the development of soil quality within the process of vegetation succession.

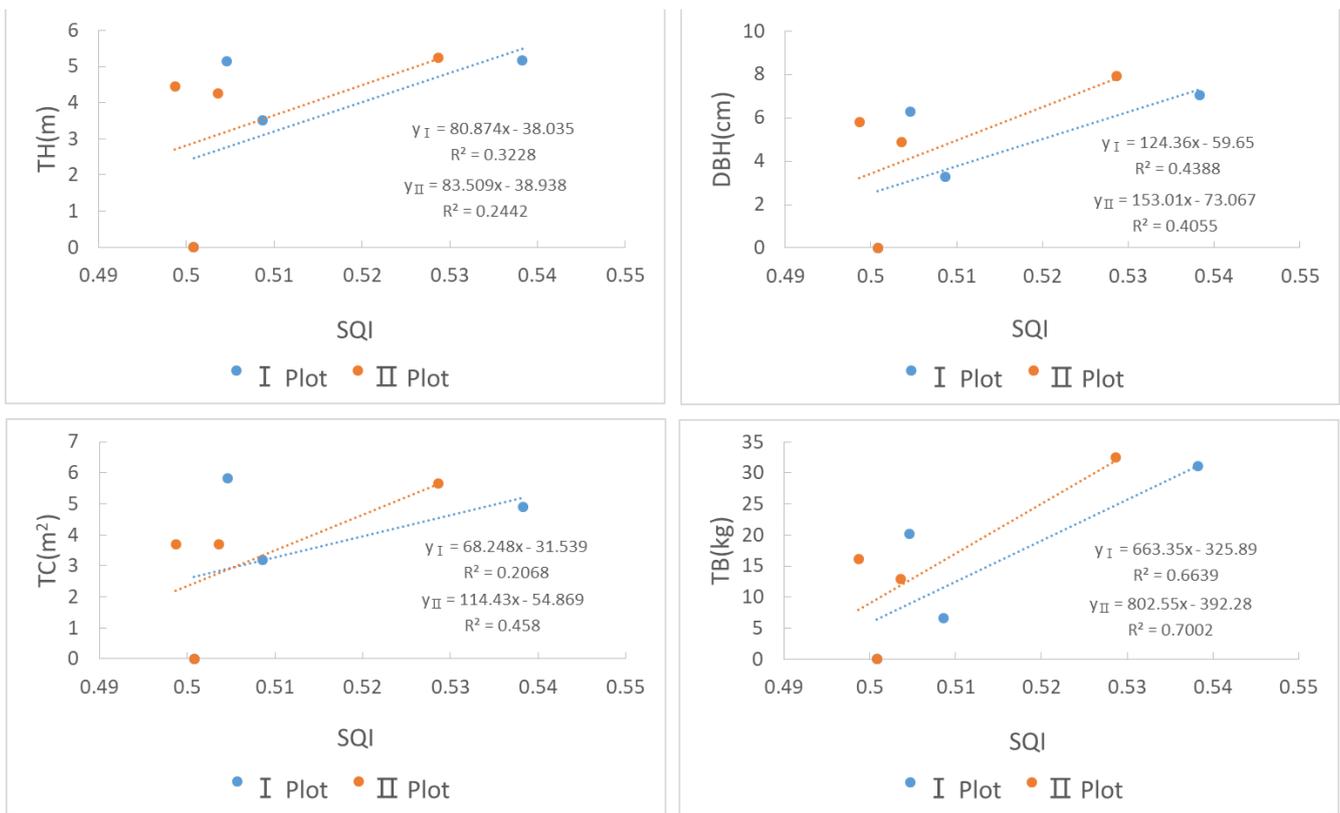


Figure 8. Correlation between Soil Quality Index and plant growth parameters.

Figure 9 shows the dynamic changes of the scores of varied soil index parameters with the length of reclamation. It can be seen from the fitting curve that the soil organic matter and total nitrogen scores are gibbous curves in the two plots, indicating that the SOM and N content scores increase in the early stage of reclamation; however, they tend to decrease in the later stage. By 2020, the SOM and N content scores were similar to those of 1993. The SOM score of Plot I is usually more than that of Plot II; however, the N score of Plot I is more than that of plot II before 2010, and less than that of Plot II in 2010. The soil pH scores of the two plots are different during reclamation. Plot II tends to be stable, whereas Plot I present a concave curve that first decreases and then increases during reclamation. However, in 2020, the soil pH scores are less than those in 1993. In the two plots, the score of available phosphorus is modified very little over time, from 0.204 in 1993 to 0.212 in 2020 in Plot I, and from 0.204 to 0.207 in Plot II, which tended to be stable within the reclamation stage. In the fitting curve of available K, the scores of the two plots are in a rising state in 2005, and tend to be equal in 2020. The AK score of Plot I increased from 0.173 to 0.229, with a rate of growth of 32.43%, and Plot II increased from 0.173 to 0.225, with a rate of growth of 30.24%.

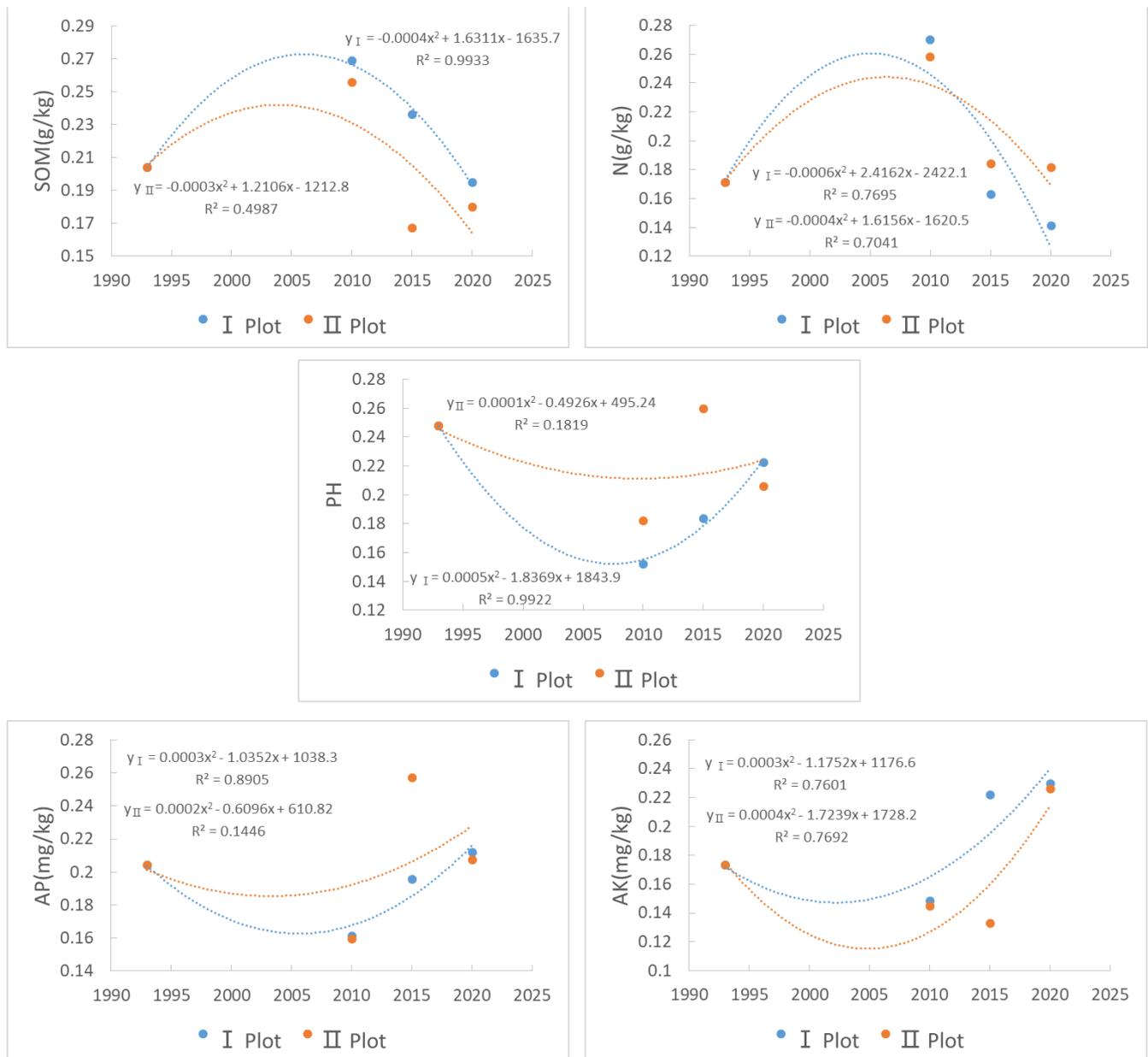


Figure 9. Dynamic score of Soil Quality Index.

4. Conclusions

In this paper, two plots with completely different vegetation configuration patterns with a similar reclamation period were studied. The two plots were compared by the statistics of plant characteristics and physical and chemical soil properties, and also the Soil Quality Index was established by principal component analysis. On the whole, with increasing years of reclamation, the Soil Quality Index of Plot I more than that of Plot II in 2020. Although there was a decrease within the initial stage of reclamation, with the passage of time, the Soil Quality Index rate of increase of Plot I is more than that of Plot II. In short, within the 27 years of land reclamation within the Pingshuo mining area, *Robinia pseudoacacia* in broadleaf mixed forest improved soil quality more than pure *Robinia pseudoacacia* broadleaf forest.

Therefore, the Soil Quality Index calculated based on the five indicators of soil organic matter, total N, PH, available phosphorus, and available K is useful in assessing soil quality and changes within the process of soil reclamation in mining areas. Although it ought to

be verified in every mining area, the SQI established during this article also can be utilized in different mining areas to reclaim the land. This method can be used to evaluate soil quality after land reclamation in other coal mining areas to determine the changes in soil quality during long-term reclamation, and it can also provide a reference for the selection of reclaimed vegetation in other coal mining areas. Besides the assessment of the reclamation status of the mine soil, this indexing approach can be useful as a tool for the selection of plant species and the role of amendments on the improvement of soil function, which will meet ecological restoration goals. Therefore, to promote ecological restoration, we suggest the following: adding appropriate fertilizers for plant growth and reducing the soil pH of alkaline soils. This article only studies the chemical properties of the soil; in the future, it is necessary to conduct a comprehensive study based on the physical properties of the soil, the microorganisms in the soil, and the local climate.

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