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Investigation into the Effects of Different Restoration Techniques on the Soil Nutrient Status in Degraded *Stipa grandis* Grassland

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Abstract: The degradation and desertification of grassland ecosystems have garnered significant attention both domestically and internationally. Grassland restoration techniques are widely considered a principal measure to promote the sustainable utilization of grasslands, with soil nutrient content being a core indicator for assessing the effectiveness of restoration in degraded grasslands. This study aims to explore the differential impacts of various grassland restoration methods on soil nutrient distribution in degraded *Stipa grandis* grasslands. Three major restoration methods, i.e., root cutting, enclosure, and fertilization, were applied in the study area. The soil nutrient content was measured and analyzed under the different restoration methods and at varying depths. The results revealed that under all three restoration methods and at different soil depths (0–10 cm, 10–20 cm, 20–30 cm), the organic matter, total nitrogen, total phosphorus, alkali-hydrolyzable nitrogen, alkali-hydrolyzable phosphorus, and available potassium contents were significantly higher than those in the control group ($p < 0.05$). Furthermore, as soil depth increased, the contents of organic matter and all nutrients gradually decreased. Specifically, regarding the contents of different nutrients, the order of organic matter, total nitrogen, total phosphorus, alkali-hydrolyzable nitrogen, and available phosphorus was as follows: fertilization > enclosure > root cutting > control, while the contents of total potassium and available potassium followed the sequence: fertilization > enclosure > control > root cutting. Additionally, based on the canonical correlation analysis (R^2 = 0.88), the total phosphorus content in soil had the greatest impact on soil nutrients, while vegetation cover and plant height contributed the most to vegetation characteristics. In grassland restoration, the increase in soil total phosphorus led to higher vegetation cover and height, mildly influenced plant diversity and density, and simultaneously promoted biomass accumulation. These research findings provide a solid theoretical foundation for the application of grassland restoration techniques, contributing to the sustainable development of grassland ecosystems.

Keywords: restoration methods; nutrient characteristics; soil organic matter; soil total nutrients; soil available nutrients

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1. Introduction

Grassland degradation and desertification have garnered widespread global attention and are recognized as severe environmental and ecological challenges. Grassland degradation not only leads to land desertification but also gives rise to a range of ecological problems, such as dust storms and soil erosion, causing significant losses to human lives and property [1]. Consequently, the impact of human activities on ecosystems and how to restore damaged ecosystems have become crucial research directions in ecology [2].

In China, natural grasslands face serious challenges, including degradation, soil erosion, and declining productivity, due to both natural factors and unsustainable land use practices. Urgent ecological restoration measures are needed to promote the sustainable management and utilization of grasslands [3]. Since the 1960s, China has implemented a series of restoration and improvement measures, such as enclosures, shallow plowing, rotational grazing, resting pastures, root restoration, and fertilization, to restore degraded grasslands [4]. These measures have provided important theoretical and practical guidance for addressing the ecological restoration of degraded grasslands in China.

Soil fertility can be restored to a certain degree of degradation [5], but different grassland degradation restoration methods often result in soil nutrient redistribution [5]. The changes in soil nutrient content frequently have a significant impact on the effectiveness of grassland vegetation restoration [6]. Therefore, investigating the ecological restoration effects of different restoration methods on degraded grasslands and understanding the relationship between changes in nutrient content and aboveground vegetation after restoration are crucial for selecting and promoting grassland restoration techniques. Different degradation restoration methods often yield varying results in soil nutrient content distribution. For example, fertilization can significantly increase the total nutrient content of soil [6] and plays a substantial role in improving soil fertility and achieving sustainable system productivity [7,8]. In addition, long-term enclosure measures can notably improve soil nutrient status and enhance soil quality [9], making this a reasonable and effective approach for sustainable grassland development that is widely applied in China [10]. Furthermore, root cutting, as another grassland restoration method, often alters soil compaction, bulk density, and porosity, contributing to enhanced soil permeability and increased water-holding capacity during the process of soil nutrient redistribution [11]. However, despite numerous studies demonstrating the varying impacts of different restoration methods on the soil nutrient content, research on the effects of different restoration methods on the soil nutrient content at different depths in the widely distributed *Stipa grandis* grassland type in northern China is relatively limited. Therefore, conducting research on changes in the soil nutrient content after the restoration of degraded *Stipa grandis* grasslands will provide a crucial theoretical foundation for achieving the sustainable utilization and development of this grassland type.

In this study, four treatment methods, i.e., fertilization, enclosure, root cutting, and control, were selected as the subjects of investigation. Through the use of soil chemical analysis methods, we determined the variations in the soil nutrient content, such as organic matter, nitrogen, phosphorus, and potassium, in grassland soils under different restoration methods, aiming to explore the impact of different restoration techniques on soil nutrient characteristics. The objectives of this study are as follows: (1) to investigate how soil nutrient content changes under different restoration measures, (2) to examine how different soil nutrients vary in soils at different depths under various restoration measures, and (3) to explore the relationship between soil nutrient changes during grassland restoration and the aboveground vegetation community structure. This study provides important theoretical foundations for the selection and promotion of restoration techniques in degraded *Stipa grandis* grasslands and for exploring the mechanisms of grassland restoration.

2. Materials and Methods

2.1. Study Area Description

The study area is located in New Barag Left Banner, Hulunbuir city, Inner Mongolia Autonomous Region, China, with geographic coordinates ranging from 117°33′ to 120°12′ east longitude and 47°10′ to 49°47′ north latitude. The total land area of this region covers approximately 22,000 km^2, with a vast expanse of grasslands spanning 15,384 km^2. According to the grassland survey data from 2010, the total area of grassland degradation in New Barag Left Banner accounted for 65.74% of the entire banner's grassland area. Within this area, degraded areas accounted for 45.34% of the total grassland area, while desertified areas constituted 10.18%. The climate in this region is classified as temperate continental monsoon. Spring is characterized by dryness and strong winds, while summer is relatively mild with concentrated rainfall. Autumn is marked by a sharp drop in temperature. The frost-free period in this area is approximately 110 days, with an annual average temperature of approximately 0.2 °C and an annual precipitation of approximately 280 mm. The predominant soil types are Chernozem and Chestnut soils (the composition of grassland plant community in this area is shown in Table S1).

2.2. Experimental Design

In this experiment, we selected a degraded *Stipa grandis* grassland area in New Barag Left Banner, Hulunbuir city, Inner Mongolia, China. Four study plots were chosen, ensuring their basic uniformity in terms of natural conditions and degradation levels. Each study plot covered an area of 1 hectare. Four different restoration methods were implemented, i.e., fertilization (900 kg of organic fertilizer per hectare), enclosure, root cutting (cutting roots to a depth of 5 cm), and a control group (no intervention, natural grassland management) (Table 1). The initial restoration commenced in August 2021 during the peak of biomass production, and data collection and sampling were conducted during the first year of restoration.

Table 1. Introduction of grassland restoration methods in experimental area.

Experimental Plot of Grassland Restoration	Detailed Description
Fertilization	Applying organic fertilizer to grassland to provide nutrients needed by plants, improve soil nutrition, and increase grass yield
Enclosure	Enclosure to prevent certain human intervention, livestock feeding, trampling, and other external interference, and to give the degraded grassland vegetation recovery opportunities
Root cutting	Under the condition of not destroying the natural grassland vegetation, it is a kind of grassland restoration measure to break the soil and cut the seam on the grassland epidermis
Control group	Degraded grassland

Within each treatment group, three transects were established, with three quadrats arranged along each transect, each treated 9 quadrats, a total of 36 quadrats. The distance between adjacent quadrats was 50 m, and each quadrat measured 1 m × 1 m. The height, coverage (the vegetation coverage was estimated by acupuncture method) and density of each planting cover in the quadrat were measured. The aboveground parts of plants in the quadrat were cut off, and the biomass of different plants was measured. Finally, three holes were drilled in each quadrate to collect soil samples repeatedly. Soil samples were collected at three different depths: 0–10 cm, 10–20 cm, and 20–30 cm. Within each quadrat, soil samples were collected at these three depths and subsequently mixed to create composite samples. These samples were used for the subsequent analysis of soil nutrients and soil properties.

2.3. Measurement Parameters

This study conducted measurements of soil nutrients, including soil organic matter (OM), total nitrogen (TN), total phosphorus (TP), total potassium (TK), alkali-hydrolyzable nitrogen (AN), available phosphorus (AP), and available potassium (AK), among other parameters. For specific data, please refer to Table 2.

Table 2. Soil Nutrient Indicators and Measurement Methods.

Analysis	Analysis Method
Organic matter (OM)	Potassium dichromate oxidation with external heating method [12]
Total nitrogen (TN)	Dumas combustion method [13]
Total phosphorus (TP)	Alkali fusion–Mo-Sb anti-spectrophotometric method [14]
Total potassium (TK)	Sodium hydroxide fusion-flame photometry [15]
Available nitrogen (AN)	Alkali N-proliferation method [16]
Available phosphorus (AP)	Sodium hydrogen carbonate solution-Mo-Sb anti-spectrophotometric method [17]
Available potassium (AK)	Ammonium acetate solution extraction with flame photometry [18]

At the same time, we measured the vegetation community under different grassland restoration measures related indicators to evaluate different soil nutrients in the process of grassland restoration for the influence of vegetation community structure characteristics. The indices of vegetation community characteristics included D (Simpson diversity index, a community diversity index considering both quantity and evenness of distribution); H′ (Shannon-Wiener diversity index, which reflects the diversity of community species); J′ (Pielou evenness index, which reflects the evenness of species distribution in the community); and MA (Margarlef richness index, which reflects the richness of plant species in the environment) and can be calculated as follows:

$$D = 1 - \sum(Pi)^2 \quad (1)$$

where D: Simpson diversity index; Pi: relative importance value of each species

$$H' = -\sum Pi\ Ln(Pi) \quad (2)$$

where H′: Shannon Wiener diversity index, Pi: relative importance value of each species

$$J' = -\sum Pi\ Ln(Pi)/Ln(S) \quad (3)$$

where J′: Pielou evenness index; Pi: relative importance value of each species; S: number of species

$$MA = (S - 1)/LnN \quad (4)$$

where MA: Margarlef richness index; S: number of species; N: abundance.

2.4. Statistical Analysis of Data

All data were processed using Microsoft Excel 2019 for statistical calculations, data listing, and graph plotting. IBM SPSS Statistics 25 was employed for data analysis, which included analysis techniques such as analysis of variance (ANOVA), Pearson correlation analysis, and canonical correlation analysis.

3. Results

3.1. Overall Characteristics of Soil Nutrients under Different Restoration Methods

In different treatments, the application of fertilizer significantly increased the average contents of soil organic matter, total phosphorus, and available phosphorus ($p < 0.05$) (Figure 1a,c,f). The average contents of total nitrogen and alkali-hydrolyzable nitrogen did not show significant differences among the four treatments ($p > 0.05$) (Figure 1b,e). Furthermore, there were significant differences in the average contents of total potassium and available potassium between the fertilization treatment and the enclosure, root cutting, and control groups ($p < 0.05$) (Figure 1d,g). Moreover, under different restoration methods, the coefficient of variation for each soil nutrient indicator ranged from 4.46% to 36.97%, indicating a moderate level of spatial variability. Notably, the spatial variability of alkali-hydrolyzable nitrogen was most pronounced, while the spatial variabilities of total potassium and available potassium were relatively weaker (Figure 1h).

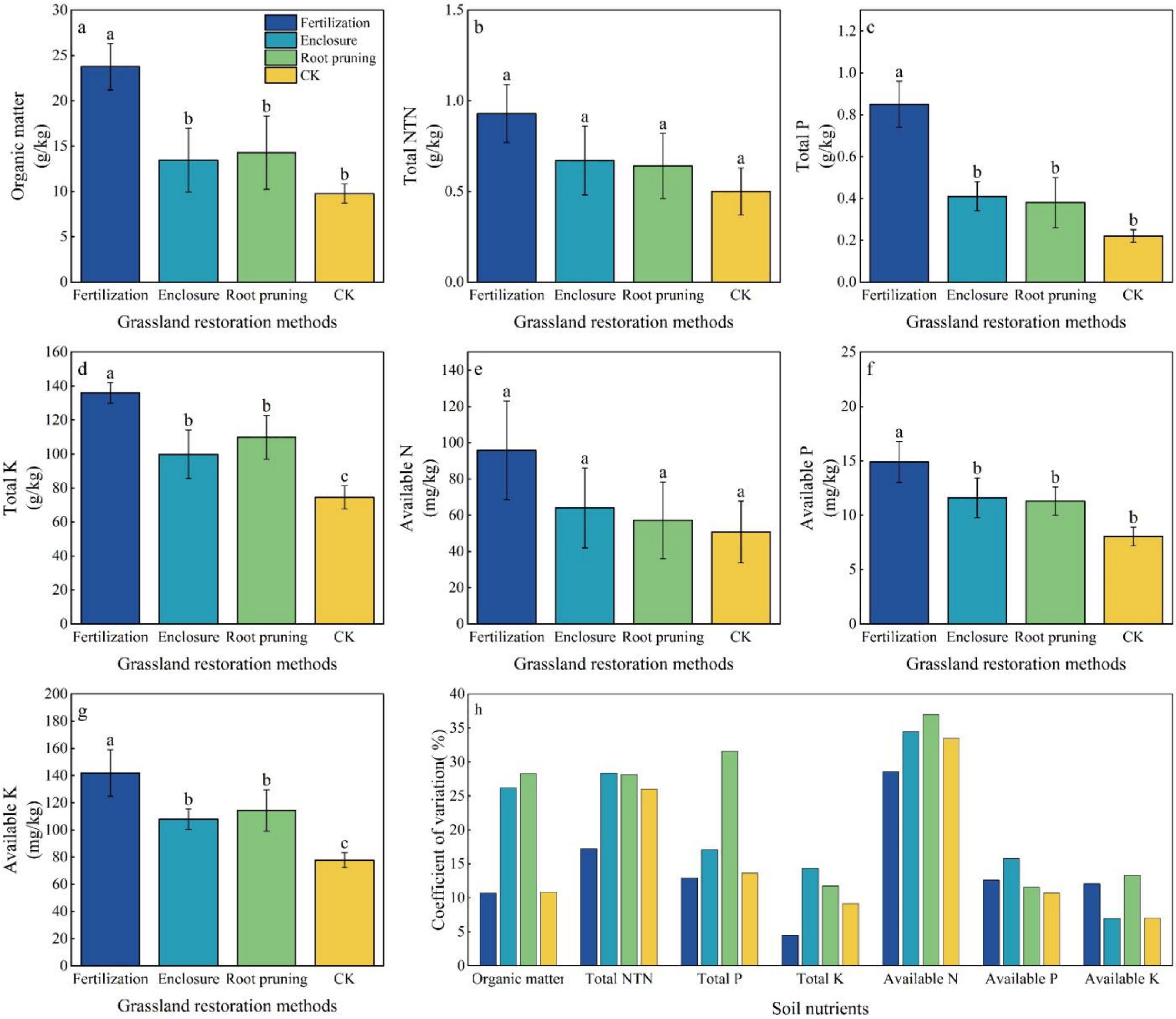

Figure 1. Soil Nutrient Content and Coefficient of Variation in the 0–30 cm Soil Layer under Different Restoration Methods. (**a**–**g**) Soil nutrient content under different restoration methods. (**h**) Coefficient of variation of the soil nutrient content under different restoration methods. Where there is an identical marking letter, the difference is not significant, and where there is a different marking letter, the difference is significant. Significant level: $p < 0.05$.

3.2. Influence of Different Restoration Methods on the Soil Nutrient Content

3.2.1. Soil Organic Matter

Under different restoration methods, the soil organic matter content exhibited a gradual decrease with increasing soil depth (Figure 2). Restoration efforts resulted in a significant increase in the organic matter content across all soil layers. Specifically, in the 0–10 cm soil layer, the organic matter content in the fertilization treatment was significantly higher than that in the control treatment ($p < 0.05$), with an increase of 57.52%. In the 10–20 cm soil layer, the organic matter content in the fertilization treatment was significantly higher than that in the enclosure, root cutting, and control treatments ($p < 0.05$), with the highest increase reaching 62.44%. Similarly, in the 20–30 cm soil layer, the organic matter content in the fertilization treatment was significantly higher than that in the enclosure, root cutting, and control treatments ($p < 0.05$), with the highest increase being 56.60%. These results indicate that the fertilization treatment had a significant positive impact on the organic matter content at different soil depths, increasing the soil organic matter content, which contributes to improving soil quality and promoting ecosystem restoration.

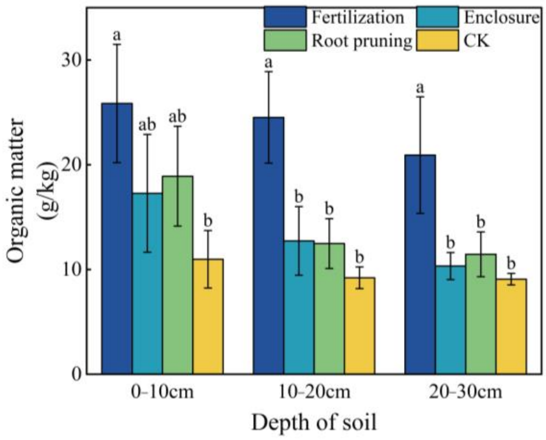

Figure 2. Changes in the soil organic matter content under different remediation methods. Where there is an identical marking letter, the difference is not significant, and where there is a different marking letter, the difference is significant. Significant level: p <0.05.

3.2.2. Total Soil Nutrients

The total nutrient content in soil typically shows a decreasing trend with increasing soil depth. In the 0–10 cm soil layer, the soil in the fertilization treatment exhibited significantly higher total nitrogen and total phosphorus contents than the enclosure, root cutting, and control treatments ($p < 0.05$) (Figure 3a,b). Specifically, the increase in the total nitrogen content reached a maximum of 41.28%, while the increase in the total phosphorus content was as high as 73.12%. Additionally, there were significant differences in the total potassium content among the fertilization, enclosure, root cutting, and control treatments ($p < 0.05$), with the maximum increase in the total potassium content being 38.65% (Figure 3c).

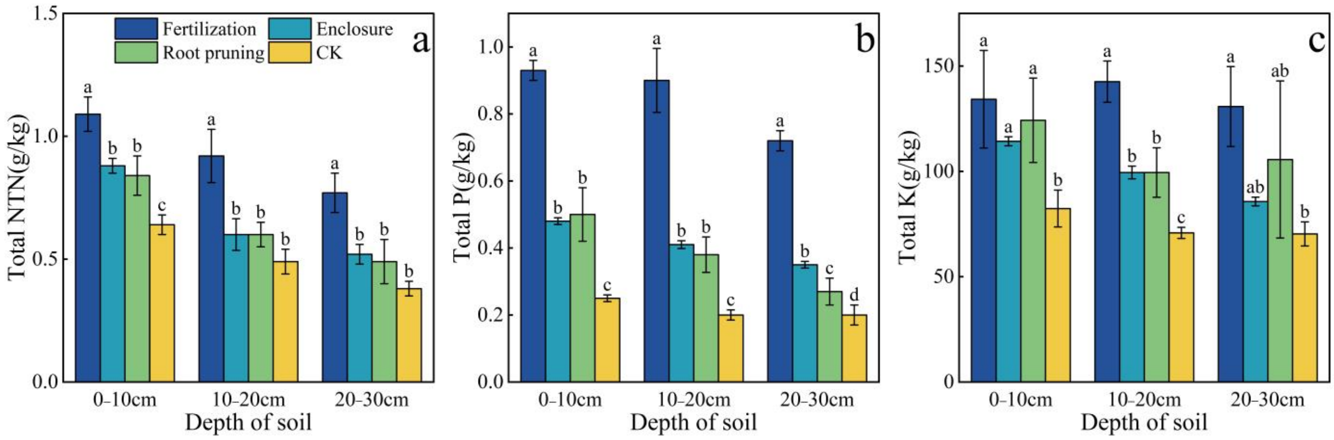

Figure 3. Changes in the Total Nutrient Content under Different Restoration Methods. (**a**) Changes in the soil total nitrogen content under different restoration methods. (**b**) Changes in the soil total phosphorus content under different restoration methods. (**c**) Changes in the soil total potassium content under different restoration methods. Where there is an identical marking letter, the difference is not significant, and where there is a different marking letter, the difference is significant. Significant level: p <0.05.

In the 10–20 cm soil layer, the soil in the fertilization treatment had a significantly higher total nitrogen content than the enclosure, root cutting, and control treatments

($p < 0.05$), with the highest increase being 46.74%. Moreover, there were significant differences in the total phosphorus and total potassium contents between the fertilization treatment and the enclosure, root cutting, and control treatments ($p < 0.05$), with the maximum increase in the total phosphorus content being 77.78% and that in the total potassium content being 50.35%.

In the 20–30 cm soil layer, the soil in the fertilization treatment had a significantly higher total nitrogen content compared to the enclosure, root cutting, and control treatments ($p < 0.05$), with the highest increase being 50.65%. Additionally, there were significant differences in the total phosphorus content among the fertilization, enclosure, root cutting, and control treatments ($p < 0.05$), with the maximum increase in the total phosphorus content being 72.22%. Furthermore, the soil in the fertilization treatment exhibited a significantly higher total potassium content than that in the control treatment ($p < 0.05$), with the highest increase being 46.24%.

3.2.3. Soil available Nutrients

The content of soil available nutrients generally decreases with increasing soil depth. In the 0–10 cm soil layer, the soil in the fertilization, enclosure, and root cutting treatments exhibited a significantly higher alkali-hydrolyzable nitrogen content compared to the control treatment ($p < 0.05$) (Figure 4a), Following the restoration treatments, the content of alkali-hydrolyzable nitrogen increased by 56.88, 18.63, and 7.63 mg/kg, respectively. Additionally, there were significant differences in the available phosphorus and available potassium contents among the fertilization, enclosure, root cutting, and control treatments ($p < 0.05$) (Figure 4b,c), with the contents of available phosphorus and available potassium increasing by 3.75–7.81 mg/kg and 47.64–77.36 mg/kg, respectively.

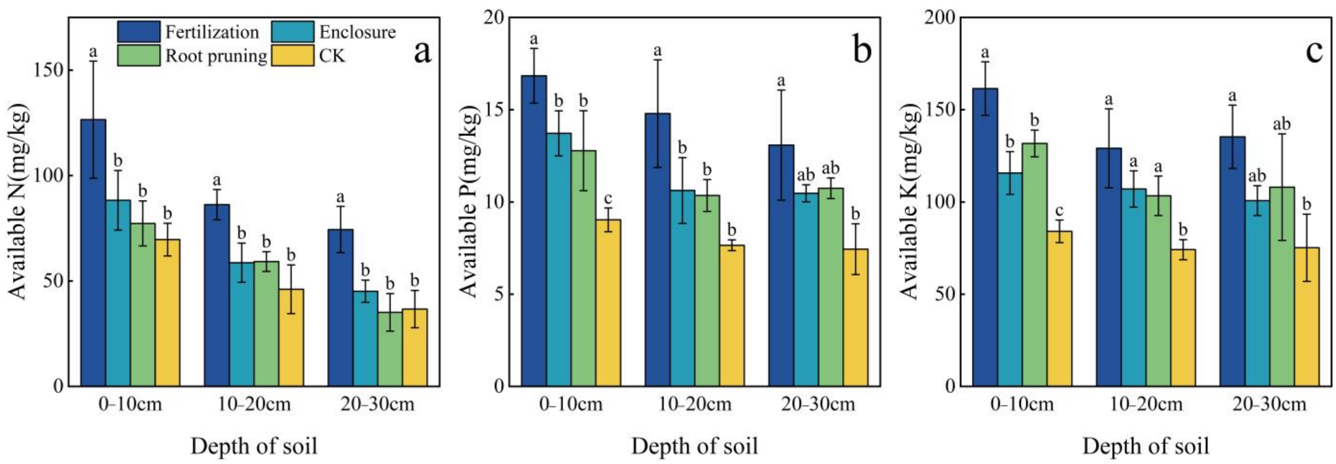

Figure 4. Changes in the Available Nutrient Content in Soil under Different Restoration Methods. (**a**) Changes in the soil alkali-hydrolyzable nitrogen content under different restoration methods. (**b**) Changes in the soil available phosphorus content under different restoration methods. (**c**) Changes in the soil available potassium content under different restoration methods. Where there is an identical marking letter, the difference is not significant, and where there is a different marking letter, the difference is significant. Significant level: $p < 0.05$.

In the 10–20 cm soil layer, the soil in the fertilization treatment had significantly higher contents of alkali-hydrolyzable nitrogen and available phosphorus than the enclosure, root cutting, and control treatments ($p < 0.05$). The contents of alkali-hydrolyzable nitrogen and available phosphorus increased by 13.15–40.15 mg/kg and 2.70–7.14 mg/kg, respectively. Furthermore, the soil in the fertilization, enclosure, and root cutting treatments had a significantly higher available potassium content than that in the control treatment ($p < 0.05$), with the available potassium content increasing by 29.18–54.92 mg/kg.

In the 20–30 cm soil layer, the soil in the fertilization treatment exhibited a significantly higher alkali-hydrolyzable nitrogen content compared to the enclosure, root cutting, and control treatments ($p < 0.05$). The alkali-hydrolyzable nitrogen content increased by 37.73 mg/kg and 8.45 mg/kg in the fertilization and enclosure treatments, respectively. Additionally, the soil in the fertilization treatment had significantly higher available phosphorus and available potassium contents compared to the control treatment ($p < 0.05$), with the contents of available phosphorus and available potassium increasing by 5.64 mg/kg and 60.12 mg/kg, respectively.

3.3. Correlation between Soil Nutrients and Vegetation Community

There was a positive correlation between soil nutrients and the vegetation diversity, Simpson diversity index (D), species richness (SR), vegetation cover (VC), plant height (PH), and plant biomass (PB) (Figure 5a). Furthermore, during grassland restoration, total nitrogen and alkali-hydrolyzable nitrogen showed the strongest positive correlation (r = 0.91), indicating a high capacity for plants to absorb nitrogen from the soil. This was followed by available phosphorus (r = 0.832) and available potassium (r = 0.825) (Figure 5b).

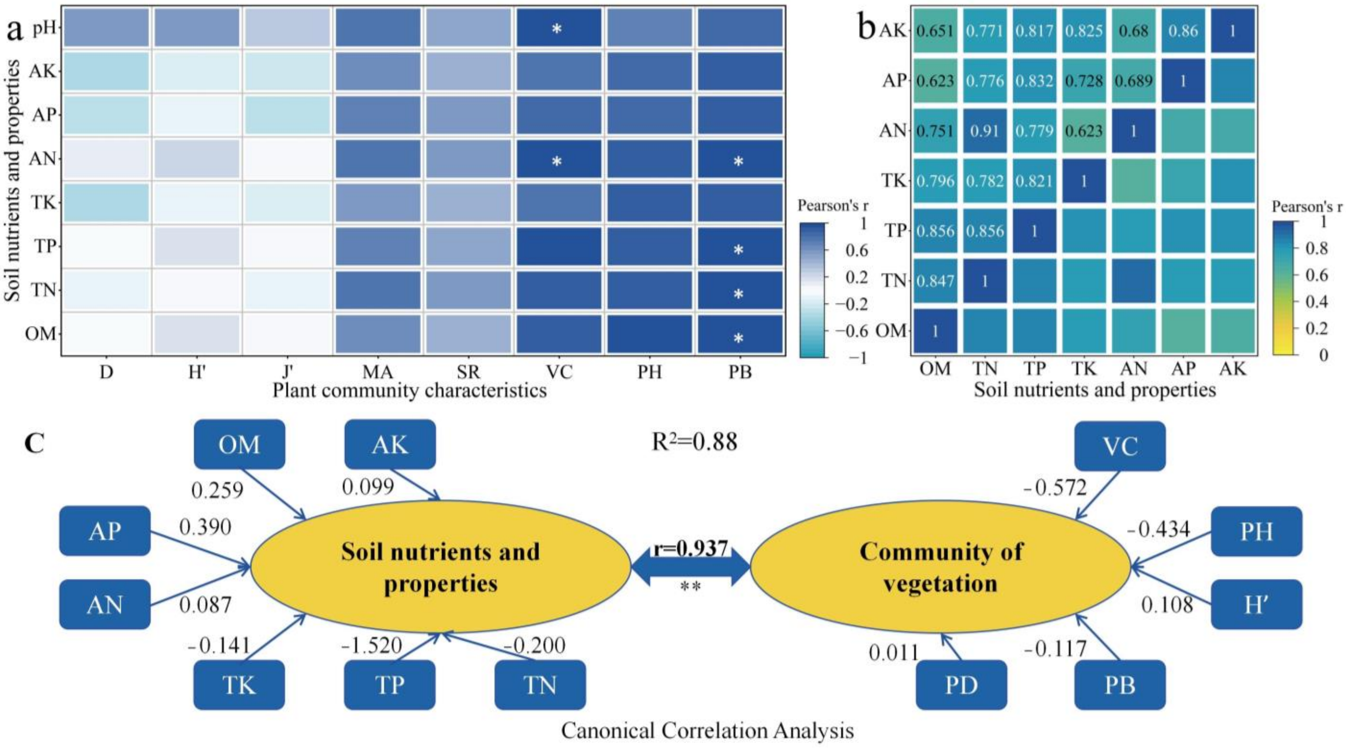

Figure 5. Correlations between Soil Organic Matter, Various Nutrients, and Vegetation Community in the Soil Restoration Process; (**a**) Correlations between soil nutrients and vegetation community structure during the soil restoration process (*, $p \leq 0.05$; **, $p \leq 0.01$); (**b**) Correlations between various soil nutrients during the soil restoration process; (**c**) Canonical correlation analysis between soil nutrients and vegetation community structure during the soil restoration process (**, $p \leq 0.01$). AN, Available nitrogen; AP, available phosphorus; AK, available potassium; TN, Total nitrogen; TP, Total phosphorus; TK, Total potassium; OM, Organic matter; D, Simpson diversity index; H′, Shannon-Wiener Diversity Index; J′, Pielou evenness index; MA, Margarlef richness index; SR, Species Richness; VC, Vegetation Cover; PH, Plant Height; PB, Plant Biomass.

In the canonical correlation model ($R^2 = 0.88$) explaining the mutual relationship between soil nutrients and vegetation (Figure 5c), it was evident that the soil nutrient content was significantly positively correlated with the vegetation community characteristics, among which the total phosphorus content in the soil had the largest contribution (standard loading coefficient of −1.520), while vegetation cover (VC) and plant height (PH) contributed the most to the vegetation community characteristics (standard loading coefficients of −0.572 and −0.434, respectively). This suggests that an increase in the soil total phosphorus content during grassland restoration primarily leads to an increase in vegetation cover and height, a slight decrease in plant diversity (standard loading coefficient of 0.108), a decrease in vegetation density (standard loading coefficient of 0.011), and an increase in plant biomass (standard loading coefficient of −0.117).

4. Discussion

4.1. Mechanisms of the Effects of Different Restoration Methods on Soil Organic Matter

The study showed that under different restoration methods, the soil organic matter content decreased with increasing soil depth. This is because surface soils are typically rich in organic matter, while in deeper soil layers, the quantity and secretion activity of plant roots are lower, resulting in relatively less organic matter input. Furthermore, organic matter decomposition is more active at the soil surface due to more favorable conditions in terms of temperature, moisture, and oxygen supply, which are suitable for microbial growth and metabolism. Therefore, soil depth reduces the decomposition of organic matter, especially in deep soil layers [19].

Fertilization often plays a significant role in increasing the soil organic matter content by promoting plant growth, providing essential nutrients for plants, and improving soil physicochemical properties. First, fertilization can increase plant biomass, leading to more plant residues and root systems entering the soil, thereby increasing the organic matter input. Moreover, organic materials in organic fertilizers provide a carbon source for soil microorganisms, promoting microbial growth and activity, which contribute to an increase in soil organic matter [19]. Additionally, fertilization can sometimes alter soil pH, affecting the rate of organic matter decomposition [20]. Furthermore, organic matter has a positive impact on the soil structure and water-holding capacity, which contribute to the accumulation of organic matter.

Enclosures are an effective restoration method that protects vegetation and reduces erosion and human activities, contributing to an increase in soil organic matter. Plant residues are typically the primary source of organic matter, and enclosures provide plants with more opportunities to grow and contribute organic matter [21]. Furthermore, enclosures can reduce the loss of organic matter caused by water and soil erosion. Without enclosures, rainwater may wash away the organic matter-rich topsoil. Therefore, in the absence of excessive disturbance, organic matter can gradually accumulate in the soil, increasing the soil organic matter content.

Root cutting also leads to root decomposition and the accumulation of plant residues, which often increase the soil organic matter content. Additionally, root cutting may stimulate enzyme activity in the soil, leading to the faster decomposition and conversion of organic matter in the soil [22], contributing to the accumulation of organic matter [23]. On the other hand, root cutting destroys plant roots in the short term, causing plant organs to enter the soil and increasing the source of organic matter in the soil. At the same time, root cutting improves soil aeration and reduces soil compactness, thus promoting the propagation of microorganisms [24], which accelerates the decomposition process of plant residues and increases the content of organic matter in the soil.

In conclusion, the impact of different restoration methods on soil organic matter is influenced by various factors, including plant growth, organic matter input, decomposition rate, erosion, and soil structure. Soil depth, fertilization, enclosure, and root cutting each have specific mechanisms that play different roles in ecosystem restoration and soil quality improvement.

4.2. Mechanisms of the Effects of Different Restoration Methods on Soil Total Nutrients

Fertilization typically involves the supply of major nutrients such as nitrogen, phosphorus, and potassium. These external supplementation methods can compensate for the original nutrient deficiency in the soil, helping to increase the soil total nitrogen, total phosphorus, and total potassium contents.

The study showed that under enclosure measures, the soil total nitrogen content was higher than that under root cutting, while the soil total potassium content was lower than that under root cutting. Enclosures usually lead to a higher soil total nitrogen content, as vegetation is one of the primary sources of total nitrogen in the soil. Plants absorb nitrogen through photosynthesis, convert it into organic compounds, and store it within the plant [25]. By protecting vegetation, enclosures provide more opportunities for plants to absorb and accumulate nitrogen, thereby increasing the soil total nitrogen content. Additionally, enclosures can reduce soil exposure to the environment, reducing nitrogen loss. Nitrogen is typically present in a dissolved form in the soil and can be carried away by flowing water [26]. In contrast, root cutting may expose the soil and lead to erosion, resulting in nitrogen loss. Furthermore, enclosures help maintain biodiversity and biological activity in the soil, where microorganisms are often involved in nitrogen conversion and fixation, helping to maintain nitrogen levels in the soil [19].

Compared to enclosures, cutting roots usually increases the nutrient content of the top soil. This is because root cutting is usually associated with reduced plant growth, which results in more plant roots and residues in the surface soil, providing more organic matter to release potassium [27] and increasing the soil total potassium content. Potassium is typically present in a soluble form within plants, and plants absorb soluble potassium from the soil through their roots. Therefore, more roots in the soil lead to the absorption of more soluble potassium. Additionally, different restoration methods may also affect the physical and chemical properties of the soil, thereby altering the solubility and availability of potassium and subsequently affecting the soil total potassium content. Root cutting can also increase soil permeability and thus improve the circulation and metabolism of soil organic matter (OM), nitrogen (N) and phosphorus (P) by microorganisms [28,29], The lack of oxygen in soil will greatly limit the development of plant roots and microorganisms [30].

4.3. Mechanisms of the Effects of Different Restoration Methods on Soil Available Nutrients

Both enclosures and root cutting can increase the soil available nutrient content, but under enclosure measures, the soil available nutrient content is often slightly higher than that under root cutting. Enclosures can significantly reduce water and soil erosion. In contrast, under root cutting, the disruption of the original soil structure exacerbates leaching in the surface soil, which can result in the excessive loss of available phosphorus and alkali-nitrogen [26]. Enclosures, by providing protection to natural vegetation, effectively reduce the leaching process of these nutrients by rainwater, subsequently enhancing their content in the soil. Compared to root cutting, enclosures help maintain biodiversity and biological activity in the soil. Soil microorganisms are typically involved in nutrient transformation and cycling, contributing to the increase in the available phosphorus and alkali-nitrogen contents. Additionally, enclosures protect vegetation and reduce soil disturbance, which is conducive to maintaining microbial activity in the soil.

4.4. Mechanisms of the Relationship between Soil Nutrients and Vegetation Community

Typical correlation analysis revealed that the soil total phosphorus content played a predominant role in the relationship between soil nutrients and vegetation communities. Phosphorus is one of the essential nutrients needed for plant growth and development. It plays a crucial role in the synthesis of biological molecules such as nucleic acids, proteins, and ATP. Therefore, an increase in the soil phosphorus content provides more available phosphorus resources, allowing plants to more effectively absorb nutrients, thereby promoting their growth [31]. Additionally, an adequate total phosphorus content directly stimulates plant growth and development. Plant growth is closely related to the nutrient supply, and a higher phosphorus content provides plants with more growth resources. Plant roots and photosynthesis processes are highly sensitive to a sufficient phosphorus supply [32]. Therefore, an increase in the total phosphorus content contributes to greater plant biomass and height, as plants better utilize soil nutrients to build more biomass.

5. Conclusions

This study, through an analysis of the impact of various restoration methods on the soil nutrient content, has revealed their effects on the overall characteristics and specific aspects of soil nutrients. First, fertilization significantly increased the soil organic matter, total phosphorus, and available phosphorus contents, highlighting its positive influence on soil nutrients, particularly in enhancing organic matter, phosphorus, and potassium. However, no significant differences were observed in the total nitrogen and alkali-hydrolyzable nitrogen contents among the different treatments. Regarding the specific effects of different restoration methods on the soil nutrient content, it was found that fertilization significantly improved the soil organic matter content across various soil depths, particularly in the 0–10 cm and 10–20 cm soil layers. Fertilization also had a positive impact on the total nitrogen, total phosphorus, and total potassium contents, with the most notable improvement seen in total phosphorus. Additionally, available nutrients such as alkali-hydrolyzable nitrogen and available potassium also exhibited significant increases under the fertilization treatment. Furthermore, there was a positive correlation between soil nutrients and vegetation diversity, coverage, height, and other characteristics, among which the soil total phosphorus content had the most significant contribution to soil nutrient characteristics. This implies that the phosphorus supply in the soil has a vital influence on the growth and development of vegetation, particularly contributing to increased vegetation coverage and height. This study provides scientific guidance for the restoration and management of degraded grassland from the perspective of soil nutrients, and provides a theoretical basis for the selection and promotion of degraded technology in northern China in the future.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agronomy14010057/s1, Table S1: Plant community species composition under different grassland restoration measures in the study area.

Author Contributions: Conceptualization, P.Z., J.W., and Q.W.; methodology, J.W. and Q.W.; investigation, P.Z., D.S., L.Z., and T.Y.; data curation, P.Z. and T.Y.; writing—original draft preparation, P.Z. and T.Y.; writing—review and editing, T.Y., R.Y., and J.W.; and funding acquisition, J.W. and R.Y. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The data presented in this study are available on request from the corresponding authors. The data is not publicly available because it is required to remain confidential.

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

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